Middle Miocene Alluvial Fan—Fan Delta Sedimentation: 
the Kanaso Conglomerate and Sandstone Member 
of the Tôgane Formation to the North of 
Hamada, Southwest Japan

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(With 10 Figures)

Abstract

The Kanaso Conglomerate and Sandstone Member of the early Middle Miocene Tôgane Formation forms a coarse clastic wedge in shallow marine sandstones. The conglomeratic Kanaso deposits represent deposition in an alluvial fan–fan delta system. The alluvial fan prograded northward into the standing body of shallow water. Sediments delivered by the alluvial fan were deposited, mostly subaqueously, as the fan delta. A high rate of sediment supply in the alluvial fan–fan delta system kept pace, as a whole, with relative rise in sea level, which may have been of tectono-eustatic origin. The resultant sequence shows a remarkable lateral facies change in a N–S direction. Subaerial alluvial-fan conglomerates in the south pass northward, within a short distance, into the subaqueous (delta front) deposits and associated subaerial (fan-delta plain) and transitional (shoreline) deposits. The fan-delta plain conglomerates occur in three prominent tongues projecting into the fan-delta front deposits, implying episodic loss of balance between rate of sediment supply and relative rise in sea level.

Key Words: fan delta, alluvial fan, sedimentary facies, sea level rise, Tôgane Formation, Miocene, Setouchi Province, Hamada

Introduction

The Tôgane Formation is one of the early Middle Miocene formations in the western part of the Setouchi Geologic Province of Southwest 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, 1986). Basin subsidence was slow, and the resultant basin-fills are represented by a relatively thin succession, 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 Tôgane Formation, as a whole, shows a transgressive stratigraphy, like the equivalent formations in the western Setouchi Province. Continental deposits in the lower part of the formation grade upward into the shallow marine sandstones (Okubo, 1982; Nakajo et al., 1993a). Intercalated in the shallow marine sandstones is a conglomeratic wedge, the Kanaso Conglomerate and Sandstone Member, which

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shows a marked contrast in lithofacies characteristics to the marine sandstones. This conglomeratic deposit of the Kanasō Member shows a pronounced lateral facies change, consistent with deposition in an alluvial fan–fan delta system. This study focuses on facies relationships within the succession of the Kanasō alluvial fan–fan delta system, which may record a tectono-eustatic control on sedimentation.

**Geologic setting**

The Tōgane Formation crops out in a small area to the north of Hamada (Fig. 2). The formation unconformably rests on the Paleogene Kokufu Volcanic Rocks and is, in turn, unconformably covered by both the Pliocene–Pleistocene Tsunozu and Holocene Kokubu Groups. The Tōgane deposits appear to infill a N–S oriented depression in the basement rocks (NAKajo et al., 1993b). 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 is subdivided into four members, named, in ascending order: Tōganegawa Mudstone, Anegahama Sandstone, Kanasō Conglomerate and Sandstone, and Tatamigaura Sandstone Members (NAKajo et al., 1993b) (Fig. 3). Fossils reveal an overall transgressive stratigraphy in the formation.
The Tōganegawa Mudstone contains some freshwater molluscan fossils (Tsuru, 1983), whereas in the lower part of the Anegahama Sandstone, brackish-water molluscs have been reported (Okubo, 1982). Marine molluscs, sharks teeth and foraminifera are found higher up in the formation (Okubo, 1982; Tsuru, 1983). The Kanasō Conglomerate and Sandstone Member, which is the subject of this study, is 20 to 30 m thick, and shows a remarkable N-S lateral facies change. In the south, the member is characterized by a thick succession of conglomerates, which interfinger with coarse-grained, pebbly sandstone to the north (NakaJo et al., 1993b).

Fig. 2. Geologic sketch 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.
Sedimentary facies

Five sedimentary facies associations have been recognized in the Kanasō Conglomerate and Sandstone Member. The lateral and vertical relationships of these facies associations are shown in Figure 4.

Alluvial-fan facies association

The alluvial-fan facies association occurs in the southern part of the study area, and passes northward into the fan-delta plain and fan-delta front associations (Fig. 4). At Tōgane, in the southernmost part of the area, this association forms a 30 m thick sequence and occupies the entire thickness of the Kanasō Member, whereas the sequence is some 10 m thick at Kanasō in the central part of the area, forming the lower part of the member; it disappears to the north.

The predominant lithology of the alluvial-fan facies association is conglomerate with subordinate sandstone (Fig. 5). Conglomerate beds are up to 5 m thick. Pebble- and cobble-sized clasts are most common, but boulders up to 1 m in diameter are locally abundant. The conglomerates are mostly clast-supported. Matrix-supported
conglomerates also occur, but are rare.

Clast-supported conglomerates are poorly to moderately sorted, and contain matrices of medium to very coarse sand and granule grades. Two principal facies are recognized: massive to crudely stratified conglomerate and volumetrically subordinate, planar cross-stratified conglomerate. The massive to crudely stratified conglomerates generally show clear evidence of erosion at the base, commonly on a scale of several decimeters. Crude stratification is subhorizontal, and is defined by variations either in clast size or in degree of clast sorting. Clasts are sometimes imbricated, showing consistently northward-flowing paleocurrents. The planar cross-stratified conglomerate occurs in 2 to 5 m thick, solitary sets. The foresets consist of alternating fine and coarse particles, and commonly dip northward. The foresets become better defined in the down-current direction, whereas in the up-current direction, cross-sets sometimes show a lateral transition to massive or crudely subhorizontally stratified conglomerate. Intercalations of sandstone are up to 50 cm thick, and often lenticular. Many of the sandstones are plane-stratified and form cappings on the conglomerate beds. Planar cross-stratified sets occur occasionally as wedges between the conglomerates.

The texture and stratification of the clast-supported conglomerates strongly suggest a stream-flow origin. The massive to crudely subhorizontally stratified conglomerates are similar to framework-supported, gravelly, longitudinal bars in modern, braided-alluvial systems (Rust, 1978; Collinson, 1978), and probably represent superimposed longitudinal bar deposits. Longitudinal gravel bars are the primary bedform in equilibrium with high-stage flows (Rust, 1978). Subhorizontal stratification implies migration and accretion of low-relief bars during flood periods. The planar cross-stratified conglomerates could have formed by migration of independent transverse or medial bars (MiAll, 1977), by lateral modification of longitudinal bars during falling flood stage (Rust, 1978), or by vertical growth of bars with continued bar-top sediment transport, resulting in development of bar-front foresets (Hein and Walker, 1977). Thick cross-sets (up to 5 m) and lateral transition to the massive or crudely stratified conglomerates are highly suggestive of the third hypothesis for the origin of this facies. Large-scale conglomerate cross-sets are less common in literature description of braided-fluvial sequences. Several examples, however, have been reported (Rust, 1978; Steel and Thompson, 1983; Middleton and Trujillo, 1984; Kraus, 1984). Formation of thick cross-sets requires considerable water depth, greater than foreset thickness, and long duration of a flow. This implies that the planar cross-stratified conglomerate facies formed in significantly deep and prolonged flood flows (Rust, 1978; Kraus, 1984). The plane-stratified sandstones were presumably deposited on the surface of gravel bars during waning flood stages. Planar cross-stratified sandstones may represent accretion of sand wedges at the front or margin of gravel bars, or slip-face accretion of a low bar-form in a shallow channel dissecting the gravel bar surface (Rust, 1972; Smith, 1974; Boothroyd and
Fig. 4. Selected measured sections, showing lateral and vertical relationships of the sedimentary facies associations. Location of each section is shown in Fig. 2. AF, alluvial-fan facies association; DP, fan-delta plain facies association; DF, fan-delta front facies association; SL, shoreline facies association; TR, transgressive facies association.
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Tatamigaura Sandstone Member

Kanashō Conglomerate and Sandstone Member

Anegahama Sandstone Member

11 12 13 15 16
Rare matrix-supported conglomerates are poorly to very poorly sorted. The beds, 0.5 to 1 m thick, are unstratified and display no size-grading. Clasts are randomly set in a matrix of granules and all the finer fractions. These features are in accord with transport and deposition by a debris-flow mechanism (Bull, 1964; Nemeck and Steel, 1984).

The assemblage of stream-flow deposits and debris-flow conglomerates is consistent with deposition on an alluvial fan (Rust, 1978, 1979). The fan was dominated by stream-flow processes, as indicated by the predominance of clast-supported conglomerates of gravel-bar origin. Deep and prolonged flood flows were common to produce the large-scale cross-sets of conglomerate. This implies that run-off was abundant and less ephemeral, which is further suggestive of abundant precipitation in a humid climate. The scarcity of debris-flow deposits in this association may be either due to abundant run-off that prevents fine debris being stored in the source area or due to reworking of them by stream processes. Paleocurrent azimuths suggest that the fan built out to the north (Fig. 6). This is compatible with northward transition of this association into the fan-delta plain and fan-delta front associations (Fig. 4).

**Fan-delta plain facies association**

The fan-delta plain facies association occurs in three distinctive stratigraphic levels as prominent tongues of conglomerate, which extend northward from the alluvial
fan sequence into the fan-delta front deposits (Fig. 4). The lower tongue is 2 to 4 m thick (Fig. 7). It is the most widespread of the three and is traced to the northern end of the study area. The middle tongue, about 2 m thick, shows limited lateral extent, and wedges out at Kanasô. The upper tongue is up to 5 m thick; it progressively thins to the north and disappears at Akahana.

This association consists mainly of clast-supported conglomerate with occasional intercalations of sandstone and mudstone. Conglomerate beds are commonly 0.5 to 2 m thick, and comprise pebbles and cobbles with medium to coarse sand matrix. Some boulders are also present. The beds have a markedly erosional surface, with scours up to 1.5 m deep at the base. Most of the conglomerates are internally massive to crudely subhorizontally stratified. Well-developed clast-imbrication is frequently observed, showing consistently northward-flowing paleocurrents. Planar cross-stratified conglomerates also occur but are rare. The cross-sets are about 1 m thick and dip to the north. Intercalations of sandstone and mudstone are commonly less than
0.5 m in thickness. They are discontinuous due to marked erosion by the overlying conglomerate. Many of the sandstones form graded cappings on the conglomerate beds. Mudstones are massive to faintly laminated, and contain locally abundant plant debris.

The conglomerates of this association are basically similar in textural and stratification characteristics to those of the alluvial-fan facies association, and are also interpreted as alluvial fan deposits dominated by stream-flow processes. Some minor differences between them, however, lead to further evaluation of this association. The conglomerates of this association are commonly thinner bedded, and erosional scours at the base of the beds are more conspicuous. The conglomerate cross-sets are less common. All these features are strongly suggestive of rapid lateral shifting of more braided, shallower channels and lower relief bars. On alluvial fans, channels become more braided and shallower downstream (Boothroyd and Ashley, 1975; Rachocki, 1981). The conglomerates of this association thus represent deposition in a distal part of the alluvial fan. This interpretation is further supported by the lateral transition of this association with the alluvial-fan association and by the northward paleo-dispersal (Fig. 6). It has been commonly accepted that cross stratification increases in water-laid deposits down-fan as a consequence of decrease in grain size to water-depth ratio (Rust and Koster, 1984). The scarcity of cross-stratal sets in this association is probably due to the persistence of large clasts.

The deposits of this association form tongues of alluvial-fan conglomerate that project northward into subaqueous deposits of fan-delta front origin (Fig. 4). These tongues demonstrate episodic progradation of the alluvial fan into a standing water body. The conglomeratic deposits of this association, thus, undoubtedly originated as a fan-delta plain, which is a subaerial component of a fan delta directly built out into the standing body of water (Nemec and Steel, 1988; Nemec, 1993).

**Fan-delta front facies association**

The fan-delta front facies association occurs chiefly in the northern part of the study area, and is laterally transitional with the alluvial-fan and fan-delta plain associations toward the south (Fig. 4). Coastal cliffs from Kanasō to Akahana provide excellent exposures of this association (Fig. 7). The predominant lithology of the fan-delta front facies association is sandstone with subordinate conglomerate and mudstone. Sandstones are commonly pebbly and occur in units 1 to 8 m thick. Conglomerates commonly occur in beds up to 1 m thick. Pebbles and cobbles are most common, but boulders are locally present. Some beds contain outsized clasts over 1 m in diameter, which project into the overlying sandstone. Conglomerate decreases in abundance and in bed thickness toward the north, whereas mudstone is most common around the cape at Akahana at the northern end of the study area. The deposits of this association can be conveniently subdivided into
seven main facies, as described below.

(A) Bioturbated, cross-stratified sandstone is medium- to very coarse-grained. Pebbles are common, either scattered throughout the sandstone or concentrated in small pockets. Heavy bioturbation is characteristic. The recognizable trace fossils include *Ophiomorpha* and *Thallasinoides*. Primary sedimentary structures are almost completely destroyed. However, traces of laminae sometimes reveal medium-scale, trough cross-stratification in sets of 10 to 30 cm thick. Traces of planar cross-stratification also occur, but are rare. Sandstones yield locally abundant foraminifers (*Miogypsina*) and marine mollusks, including *Solidicorbula* and *Glycymeris*. These sandstones undoubtedly originated in a shallow subtidal environment, as indicated by yielding fossils and trace fossils. The traces of cross stratification indicate that the sandstones were primarily deposited from migrating dunes and rarely from sand waves, followed by disruption of beds due to intensive faunal activity. Paleocurrent azimuths determined from cross-strata are generally unidirectional, and indicate predominantly northward or north-northwestward-flowing currents.

(B) Laminated sandstone is very fine- to coarse-grained and is internally plane-stratified or hummocky cross-stratified. This type of sandstone occurs as occasional intercalations in the bioturbated, cross-stratified sandstone. Beds are 10 to 20 cm thick, with a sharp and broadly undulating erosional base. This facies
indicates wave-work processes. Hummocky cross stratification is indicative of deposition under strong storm-wave surge (Dott and Bourgeois, 1982; Walker et al., 1983). Subhorizontal stratification is also attributed to strong oscillatory wave surge producing sheet-flow conditions (Clifton, 1976; Myrow and Southard, 1991).

(C) Poorly sorted, matrix-supported conglomerate consists of clasts randomly distributed in a poorly sorted matrix of granules and sand to mud fractions. Beds are ungraded and unstratified. The beds are interpreted as cohesive debris-flow deposits (Lowe, 1982). Clasts dispersed in poorly sorted matrix indicate fully shearing, but also high viscosity mass flows.

(D) Massive, clast-supported conglomerate has a medium to coarse sand matrix with variably admixed granules. Beds are internally unstratified and display no size grading. Clast imbrication is locally abundant. This facies is interpreted as the result of high-density, cohesionless debris flows (Lowe, 1982). The lack of grading and stratification suggests that fluid turbulence was unimportant as a clast-supporting process. Rather, locally abundant clast-imbrication suggests that dispersive pressure due to clast collision played a somewhat greater role in maintaining clasts in a dispersed state. Imbricated clasts show dominantly northward-directed paleocurrents.

(E) Inversely graded conglomerate occurs in beds that are essentially unstratified. Inverse grading is developed over the entire thickness of the beds. Along with inverse grading, the beds commonly show an upward increase in matrix content. The conglomerates of this facies represent deposition from cohesionless debris flows, or density-modified grain flows (Lowe, 1976, 1982). Absence of internal stratification and development of inverse grading are strongly suggestive of limited turbulence and of the significance of clast collision in a highly concentrated dispersion. The upward increase in matrix content indicates subaqueous mass-flow origin (Nemec and Steel, 1984).

(F) Graded conglomerate displays markedly erosional lower surface. The conglomeratic lower part is normally graded, passing upward into crudely plane-stratified sandstone. Beds of this facies are interpreted as deposits of highly concentrated turbidity currents. The normally graded, lower portion represents direct suspension sedimentation from a turbulent clast dispersion. The crude, plane stratification in the upper sandy portion indicates tractional sedimentation in plane-bed flow regime. Crude, plane stratification may be in part due to flow unsteadiness, which not only accelerates deposition of a sand fraction but also prevents the growth of wavy bedforms. The well-developed internal organization, as represented by bipartition of the beds, is consistent with deposition of subaqueous mass flow (Nemec and Steel, 1984).

(G) One-clast thick, coarse conglomerate is made up of packed or isolated cobbles and boulders with some pebbles. Finer fractions are completely absent except for an infiltrated sand matrix. The beds are defined as sharply based, thin sheets of clasts. These conglomerates presumably originated as a lag from mass
flow. Most of the sediment bypassed was transported further on, and deposited in deeper water, leaving coarse lags behind. Sharply based beds, concentration of large clasts with little finer fractions and thin bed-thickness relative to clast size are all consistent with this interpretation.

(H) Mudstone is commonly silty to sandy and occurs in 5 to 90 cm thick units. Beds are mottled and massive due to intensive faunal activity. In places, however, thin layers of laminated or ripple cross-laminated sandstone are intercalated. These mudstones represent suspension settling of fine terrigenous materials with occasional influences of weak currents, and subsequent disturbance by biological activity.

The subaqueous deposits of this association are the distal equivalent of the alluvial-fan and fan-delta plain associations, as evidenced by their lateral relationships. Dispersal directions are concordant with paleocurrent directions of the alluvial-fan and fan-delta plain deposits (Fig. 6). This association thus represents subaqueous deposition of fan-derived coarse clastics, and is interpreted as a fan-delta front deposit.

The delta front is a zone of interplay between fluvial and marine (wave and tidal) processes. The predominance of bioturbated, cross-stratified sandstones indicates that the Kanaso fan-delta front was dominated by a fluvial process. Much detritus was delivered from braided channels on the alluvial fan or fan-delta plain into the fan-delta front and deposited as channel mouth-bars. The laminated sandstone facies represents partial reworking of channel mouth-bar deposits by storm-wave surge. However, the limited occurrence of this facies indicates that such a marine process played only a limited role in fan-delta front sedimentation. The mass-flow conglomerates are relatively thin and volumetrically minor. But an increase in their occurrence towards the south suggests that mass-flow processes were also important, especially in the proximal part of the fan-delta front.

Shoreline facies association

The shoreline facies association consists dominantly of fine- to coarse-grained sandstone, with intercalations of thin conglomerate. This association occurs in company with the lower and upper tongues of the fan-delta plain conglomerates (Fig. 4), although the lower occurrence is restricted. Sandstones of this association gradationally overlie the fan-delta front deposits and, in turn, underlie the fan-delta plain conglomerates with a sharp and erosive contact. Near the cape at Akahana, this association laterally wedges out to the north into the fan-delta front deposit. The sequence of the shoreline facies association, up to 3 m thick, is conveniently subdivisible into the lower, cross-stratified sandstone unit and the upper, planar-stratified sandstone unit.

The lower, cross-stratified sandstone unit, commonly 1 to 2 m thick, is characterized by complex interfingering of trough and planar cross-sets and conglomerate layers (Fig. 8A). The conglomerate layers, up to 20 cm thick, are usually poorly sorted, and have an erosional surface at the base. They are gently inclined
northward (Fig. 9). Individual conglomerates tend to thin up-dip southward 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 southward. Foresets consistently dip to the south at angles of 10° to 25° (Fig. 6). 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 bidirectional, 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. Laminations 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. 8B).

This facies association represents deposition in the transitional zone between the subaerial and subaqueous components of the fan delta, as evidenced by the lateral and vertical relationships with the fan-delta plain and fan-delta front facies associations. The variability in textural and stratification characteristics in the deposits of this association reflects complex hydraulic processes related to wave and wave-generated current activities in a shoreline environment. 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.

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 is explained by processes of swash action. Dominantly seaward dipping, low-angle cross-sets imply deposition chiefly in a foreshore. The oppositely dipping laminae may be 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 foreset azimuths and occasional burrows. An upper shoreface interpretation is further suggested by the local, landward transition with the planar-stratified sandstone of beach origin (Fig. 8B).

The conglomerate layers in the lower unit represent a record of intensive storm sedimentation on the upper shoreface. During storms, waves or wave-induced strong currents tend to erode the shore-zone materials and sweep them into a deeper area. The erosional surface at the base of gently seaward-dipping conglomerate layers shows that the upper shoreface profile was planed off during the storm period. Clasts were probably emplaced on the erosional surface as a coarse lag. Bidirectional 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. Through this process, a bar system develops and bars migrate landward. The onshore-dipping, planar cross-stratified sandstones represent deposition from such landward-migrating longshore bars. 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. 8A). This suggests that bar growth and landward migration was most significant in the declining stage of storms. 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.

**Transgressive facies association**

The transgressive facies association occurs just above each tongue of the fan-delta plain conglomerates, and marks the transition to fan-delta front deposits (Figs. 4 and 7). This association is up to 1 m thick, and consists of clast-supported conglomerate and overlying sandstone. The conglomerate is commonly 30 to 50 cm thick. Boulders and cobbles are concentrated (Fig. 10). The bed is laterally persistent for more than 500 m, and truncates the underlying fan-delta plain conglomerates. The sandstone, up to 50 cm thick, is medium- to coarse-grained. Beds are either intensely bioturbated, trough cross-stratified or planar stratified. The sandstone sometimes pinches out laterally, and the sequence of this association may be represented solely by the thin conglomerate bed.

The sequence of this association undoubtedly represents a transgressive episode because of its occurrence between the tongue of alluvial conglomerates below and subaqueous delta-front deposits above. The laterally persistent coarse conglomerate bed is interpreted as a transgressive lag. The basal truncated surface of the conglomerate represents a ravinement surface produced during the shoreline retreat. As the sea transgresses, coastal erosion is normally most intense in the foreshore and upper shoreface. Sediments eroded from the coast are moved offshore, with little sedimentary record in the nearshore during transgression. Clasts too large to be significantly moved are susceptible to being concentrated as a lag. The discontinuous sandstones resting on the lag conglomerate probably represent poorly preserved transgressive nearshore deposits.

**Discussion and conclusions**

The Kanasō Conglomerate and Sandstone Member of the Tôgane Formation represents deposition in an alluvial fan–fan delta system. The alluvial fan pro-
graded northward into a standing body of shallow water. Sediment delivered by the alluvial fan was deposited mostly subaqueously as the fan delta. The resultant sequence of the Kanaso alluvial fan–fan delta system shows a remarkable lateral facies change in a N–S direction. 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 (Fig. 4).

The buildup of the Kanaso alluvial fan–fan delta system occurred in a humid environment. The alluvial fan was, thus, dominated by fluvial processes, and the conglomerates deposited mostly as gravel bars, with rare debris-flow beds. Flood flows were probably deep and prolonged, being capable of producing thick conglomerate cross-sets. Braided channels that drained on the fan delivered the sediments to the fan-delta front. Most of the detritus was deposited as bed load. Subaqueous sediment gravity flow processes were, likewise, important in the fan-delta front, especially in its proximal part. Conglomerates derived by sediment gravity flows, although minor constituents, are more abundant in fan-delta front deposits than in their subaerial counterparts. This could be explained either by initiation of sediment gravity flows in the fan-delta front, by transformation of a fluvial traction current to a subaqueous sediment gravity flow in the fan-delta front, or by higher preservation potential of sediment gravity flow deposits in the fan-delta front. Overloading and slope instability due to rapid sediment accumulation on the fan-delta front tend to cause failure of water-saturated sediments and subsequent subaqueous gravity transport (Postma, 1984; Prior and Bornhold, 1988; Maejima, 1988; Nemec, 1990, among others). The Kanaso fan-delta front deposits, however, completely lack disturbed or slumped beds that are suggestive of subaqueous sediment failure, and this process is unlikely. A fluvial flood flow may transform to a turbidity current as it passes into the water and moves downslope over the steeper gradient of the fan-delta front (e.g., Kleinspehn et al., 1984). Such transformation of a flow may have occurred on the Kanaso fan-delta front, as suggested by the graded conglomerate-sandstone couplets that are interpreted as deposits of highly concentrated turbidity currents. However, the Kanaso fan-delta front deposits comprise several types of subaqueous sediment gravity flow conglomerates, including those of high-density debris-flow origin. Alternatively, it seems more likely that subaerial debris flows passed into the water and evolved into various types of subaqueous sediment gravity flow due to incorporation of water into the flow. The sediment gravity flow deposits on the fan-delta front were well preserved because of limited reworking by marine processes; subaerial debris-flow deposits were most likely reworked by stream-flow processes that dominated on the alluvial fan in a humid environment.

Records of transitional subaerial/subaqueous sedimentation are less well preserved. The alluvial fan and fan-delta plain sequence commonly passes laterally into fan-delta front deposits. This facies relationship indicates an actively depositing alluvial fan–fan delta system without significant contemporaneous redistribution of
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sediments by marine processes. Marginal destructive bars may have developed on an inactive or abandoned part of the fan. They, however, were mostly destroyed or eroded out by subsequent reactivation. Such a process is suggestive of a low to moderate wave-energy sea, and is consistent with a limited role of storm-wave reworking in fan-delta front sedimentation. The shoreline deposits accompanying the upper tongue of the fan-delta plain conglomerates 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 as the fan-delta plain extended basinward. Preservation of the shoreline deposits may reflect a diminished fluvial agency, which, although powerful enough to erode the substrate, was probably overpowered by moderate-energy wave processes.

The succession of the Kanasō Conglomerate and Sandstone Member basically consists of the alluvial-fan conglomerates in the south and the fan-delta front sandstones and conglomerates in the north, and forms, as a whole, neither a progradational nor retrogradational sequence. This is suggestive of a relative rise in sea level, keeping pace with the high rate of sediment supply in the alluvial fan–fan delta system. This relative rise in sea level could have been of tectonic, eustatic or combined origin. The conglomeratic Kanasō rocks show a marked contrast with the sandstone-dominated remainder of the Tōgane Formation. Build-up of the alluvial fan was related to uplift of the adjacent source terrain. Such tectonic activity was probably due to basin-margin faulting, which could have been accompanied by downthrow of the basin side. Eustatic control also seems to have been important. Global eustatic curves indicate a sea-level rise in the Early to Middle Miocene (Haq et al., 1987, 1988). At this time, marine formations were deposited simultaneously throughout the Japanese Islands (Tsuchi et al., 1981). Deposition of the Tōgane Formation took place under such conditions of eustatic sea-level rise.

The prominent tongues of the fan-delta plain conglomerates indicate that the relative sea-level rise episodically lost balance with the rate of sediment supply. These tongues show remarkable erosion at the base (Figs. 4 and 7). The lower tongue almost completely eroded out the shoreline and fan-delta front deposits, and commonly rests on the underlying sandstones of the Anegahama Member. The upper tongue also erosively rests on the beach and shoreface deposits, and has locally incised into the fan-delta front deposits. Such an erosional contact between the subaerial conglomerates above and the subaqueous deposits below is strongly indicative of control by relative sea-level change rather than 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.
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References


Huzita, K. (1962): Tectonic development of Median Zone (Setouchi) of Southwest Japan, since the Miocene. Jour. Geosci. Osaka City Univ., 6, 103-144.


Middle Miocene Alluvial Fan–Fan Delta Sedimentation


*: in Japanese with English abstract

**: in Japanese