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Sedimentation and Tectonics in the Cretaceous, Strike-Slip Izumi Basin, Izumi Mountains, Japan

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(With 13 Figures)

Abstract

The Upper Cretaceous, thick turbidite succession of the Izumi Group occurs in a narrow area (300 × 15 km) along the Median Tectonic Line of southwest Japan. The Izumi sequences have been interpreted as representing deposition in an east-west trending, elongated strike-slip basin, which extended eastward in stepwise fashion with the shifting of the locus of deposition due to left-slip movements of the Median Tectonic Line. Consequently, an eastward-younging succession with dominant sediment dispersal from the east accumulated in enormous thickness.

The succession in the Izumi Mountains provides an excellent example of deep-water clastic sedimentation with resepct to strike-slip basin formation. The present study reveals that the Izumi succession is basically made up of stacked depositional mega-units. The mega-units internally show pronounced lateral facies changes in the downcurrent direction, indicating various internal and external tectono-sedimentary controls. Two types of the mega-unit have been recognized in the study area: (1) the line-source type mega-unit, fed directly by coalescent steep-face fan deltas and (2) the point-source type mega-unit which resulted from a channel-fed, elongated, submarine-fan system.

The steep-face fan delta system comprises three main depositional segments, namely, a subaerial alluvial fan, a subaqueous delta slope and a prodelta. The system shows rapid and episodic input of coarse detritus through the high-relief, steep offshore slope into the main turbidite basin, forming a part of a larger, delta-fed line-source turbidite system.

The channel-fed, elongated, submarine-fan system shows transitions of depositional settings in the downcurrent direction, from a main channel with active over-spilling to distributary channels, and then to non-channelized sheet-flows. Consistent longitudinal sediment dispersal in the system strongly indicates the lateral confinement of the depositional body in the narrow strike-slip basin.

These depositional systems are regarded as products of every stage of the stepwisely extending basin. The resultant deposits, mega-units, were successively stacked with stepwise shift of the depocenter to the east, forming the eastward-younging, thick Izumi succession. Such a tectono-sedimentary process was consistent in the Izumi basin, reflecting the strike-slip movements along the Median Tectonic Line.

Key Words: Turbidites, fan delta, strike-slip basin, Izumi Group, Cretaceous.

1. Introduction

In late Cretaceous times, strike-slip movements along the Median Tectonic Line of

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southwest Japan produced an east-west trending elongated basin. The basin successively extended eastward with the shifting of the locus of deposition. The resultant basin-fill, the Izumi Group (Campanian-Maastrichtian) is represented by an eastward-younging, thick succession of turbidites and associated coarse clastic deposits (TANAKA, K., 1965). Petrographic studies of the Group suggest that source terrains were to the north of the basin (TANAKA, K., 1965; NISHIMURA, 1984). Paleocurrent measurements indicate that the materials derived from northern terrains were distributed in the basin by westward longitudinal flows (TANAKA, K., 1965; SUYARI, 1973; NISHIMURA, 1976, 1984). Such a relationship between the source terrain site and the main disperasl pattern is common to elongated basin settings controlled by active strike-slip movements (cf. CROWELL, 1974a; STEEL, 1976; STEEL and GLOPPEN, 1980). The Group crops out in an area that is about 300 km long and 15 km wide (Fig. 1); it has much greater dimensions than other, well-documented examples of strike-slip basin-fills (e.g., Ridge Basin, CROWELL, 1974b; Hornelen Basin, STEEL and GLOPPEN, 1980; Little Sulphur Creek Basin, NILSEN and McLAUGHLIN, 1985) which have dimensions of only several kilometers to several tens of kilometers length.

In narrowly confined, elongated basins like the Izumi basin, turbidite sedimentation is expected to differ from that in a submarine fan of an open system (NORMARK, 1970, 1978; MUTTI and RICCI LUCCHI, 1978; WALKER, 1978). Depositional systems in such narrow basins have not virtually well documented to date (cf. UNDERWOOD and BACHMAN, 1982; PICKERING *et al.*, 1989). Furthermore, active strike-slip movements are expected to play an important role in the lateral organization of basin-fill sedimentary bodies. It has been pointed out that active strike-slip tectonics commonly result in rapid facies changes in basin-fill deposits over short distances (MICHELL and READING, 1986; MIALL, 1990) with complicated lateral and vertical organization of sediments.

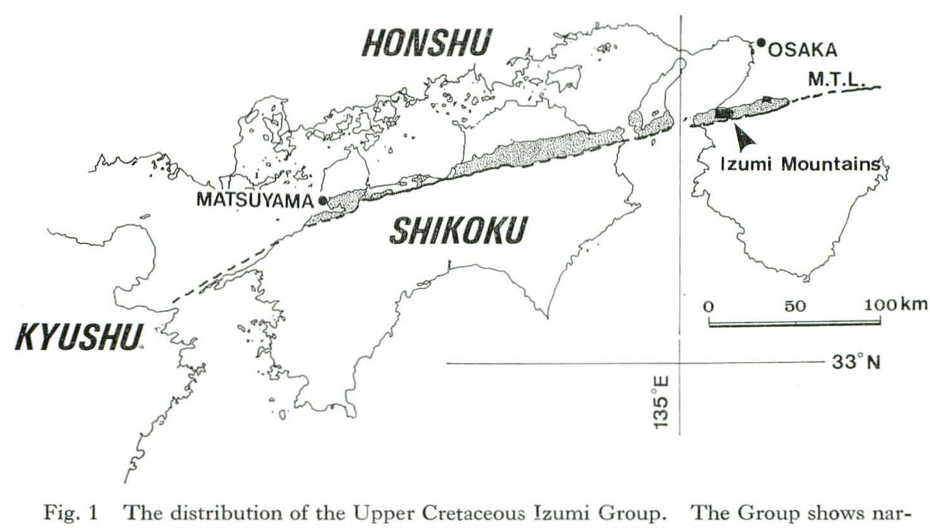

Fig. 1 The distribution of the Upper Cretaceous Izumi Group. The Group shows narrow distribution along the Median Tectonic Line (M.T.L.).

In this paper, I reconstruct the depositional systems of the Izumi Group as an example of turbidite sedimentation in a tectonically constrained, elongated basin, and evaluate the tectonic controls on the evolution of the basin.

2. Outline of Geology

2.1. General

The Izumi Group consists of a thick succession of sandstone, mudstone and conglomerate. It is distributed in an area about 300 km long and 15 km wide along the Median Tectonic Line, from Matsuyama of western Shikoku, through Awaji-shima Island, to the Izumi Mountains on the Kii Peninsula (Fig. 1). The Group unconformably overlies the Sennan rhyolitic rocks of the Ryoke Main Belt (ITIHARA *et al.* 1986) on the north, and is separated by the Median Tectonic Line on the south from the Sambagawa Metamorphic Rocks. The Izumi Group is Campanian-Maastrichtian in age, on the basis of paleontological evidence (SUYARI, 1973; MATSUMOTO and MOROZUMI, 1980; MOROZUMI, 1985; YAMASAKI, 1987), and shows eastward-younging age polarity, i.e., Campanian in Shikoku, Campanian to Maastrichtian in Awaji-shima Island, and Maastrichtian in the Izumi Mountains. The Group is gently folded, forming synclinal structures with axes plunging to the east.

ICHIKAWA *et al.* (1979) classified the Izumi Group in the Izumi Mountains into the northern marginal facies, the main facies and the southern facies, based mainly on their lithologic differences (Fig. 2). The deposits of the northern marginal facies consist of massive conglomerates, mudstones and subordinate sandstones. They are narrowly distributed along the northern margin of the Izumi distribution, and have been regarded as deposits in the northern margin of the basin (TANAKA, K., 1965; MATSUMOTO and MOROZU-

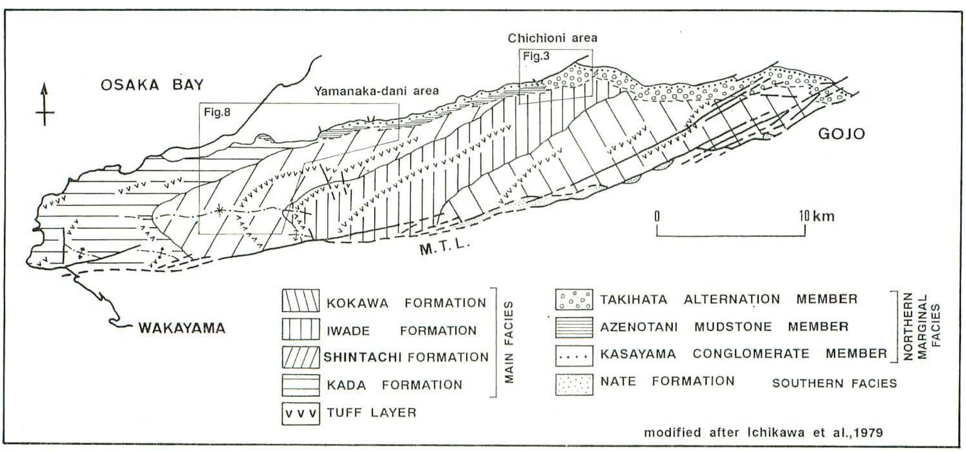

Fig. 2 Geologic sketch map of the Izumi Group of the Izumi Mountains (modified after ICHIKAWA *et al*,, 1979).

MI, 1980; TAIRA *et al.*, 1988).

The main facies comprises turbidites and associated coarse clastic deposits (TANAKA, K., 1965). These main facies deposits form the main basin-fill. Paleocurrent measurements have revealed that longitudinal sediment dispersal was dominant in the basin, and much of sediments were deposited from westward-flowing currents (e.g., TANAKA, K., 1965; SUYARI, 1973; TANAKA, J., 1989). It has been shown that the turbidites of the main facies pass laterally, northeastwards, into the northern margin facies deposits, indicating contemporaneous deposition (ICHIKAWA *et al.*, 1979).

The deposits of the southern facies show sporadic distribution along the southern margin of the Izumi Group, and consist of massive conglomerate, sandstone and mudstone (TANAKA, K. *et al.*, 1952; RESEARCH GROUP FOR MTL, 1981). They show quite different lithofacies from those of the main facies, and shallow-water origin has been postulated (TANAKA, K. *et al.*, 1952; HASHIZUME *et al.*, 1990).

2.2. Stratigraphy of the Izumi Group in the Izumi Mountains

The deposits of the northern marginal facies in the Izumi Mountains comprise the Kasayama Conglomerate Member, the Azenotani Mudstone Member and the Takihata Alternation Member (Fig. 2; ITIHARA *et al.*, 1986). Massive and unstratified conglomerates of the Kasayama Conglomerate Member show sporadic distribution along the northern margin of the Izumi Group, having unconformable and minor fault contacts with the underlying Sennan rhyolitic rocks. Massive mudstones of the Azenotani Mudstone Member conformably overlie the Kasayama Conglomerate Member in the middle and western part of the Izumi Mountains. In the eastern Izumi Mountains, massive mudstones of the Azenotani Mudstone Member are replaced by interbedded conglomerates, sandstones and mudstones of the Takihata Alternation Member, having an interfingering relationship with the former.

The deposits of the main facies consist of interbedded sandstones, mudstones and conglomerates of turbidite and associated coarse clastic deposits. They are subdivided, in ascending order, into the Kada, Shintachi, Iwade and Kokawa Formations (Fig. 2; ICHIKAWA *et al.*, 1979).

3. Depositional System in the Chichioni Area

3.1. Sedimentary facies

Facies analysis reveals three facies associations in the deposits of the northern marginal facies of this area (Figs. 3, 4, 5). The succession composed of these facies associations is conformably overlain by deep-water turbidites of the main facies deposits.

Alluvial-fan (subaerial fan-delta) association

The deposits of the alluvial-fan association show limited occurrence along the northern margin of the Izumi Group and rest unconformably on the basement of the Sennan rhyo-

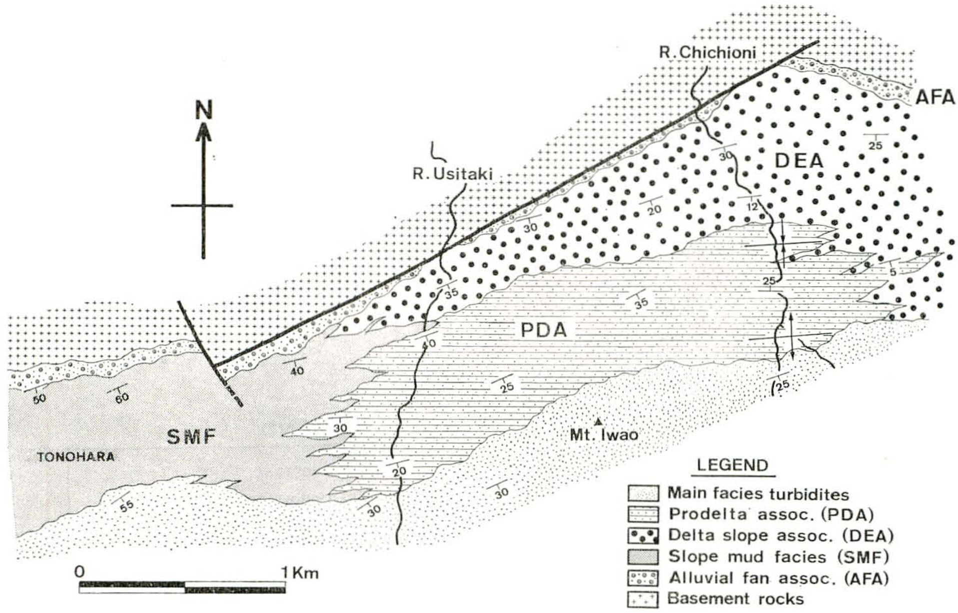

Fig. 3 Facies association map of the Chichioni area.

litic rocks (Fig. 3). This association consists of crudely bedded, poorly sorted pebble- to cobble-conglomerates (Fig. 5). Most of the conglomerates are matrix-supported. Subangular to subrounded clasts are randomly scattered in the matrix of sand-mud mixture, displaying strong polymodal grain-size distribution.

The conglomerates of this association represent deposition on a debris-flow dominated alluvial fan on the northern margin of the Izumi basin. The non-erosive base, matrix-supported framework and poor sorting with polymodal grain-size distribution are all in accordance with debris-flow origin (JOHNSON, 1970; MIDDLETON and HAMPTON, 1976; LOWE, 1982). The crude bedding in the conglomerate succession suggests that the surging debris flow was the predominant process (NEMEC and STEEL, 1984). The poor internal organization or lack of it in the conglomerates is suggestive of subaerial emplacement of debris flows (RUST, 1978, 1979; NEMEC and STEEL, 1984; MAEJIMA, 1988). The lack of the channel erosion and of traction-current deposits in this association indicates the limited importance of stream-flow processes on the alluvial fan.

Delta-slope association

The deposits of the delta-slope assocaition conformably overlie and laterally grade into the alluvial fan conglomerates (Fig. 3). This association is represented by a 200–300 m thick succession of polymictic conglomerates of various types. TANAKA, J., (1992) recognized three conglomerate facies: (1) non-graded, clast-supported conglomerate of cohesionless, gravelly, debris-flow origin; (2) graded, conglomerate-sandstone couplet of

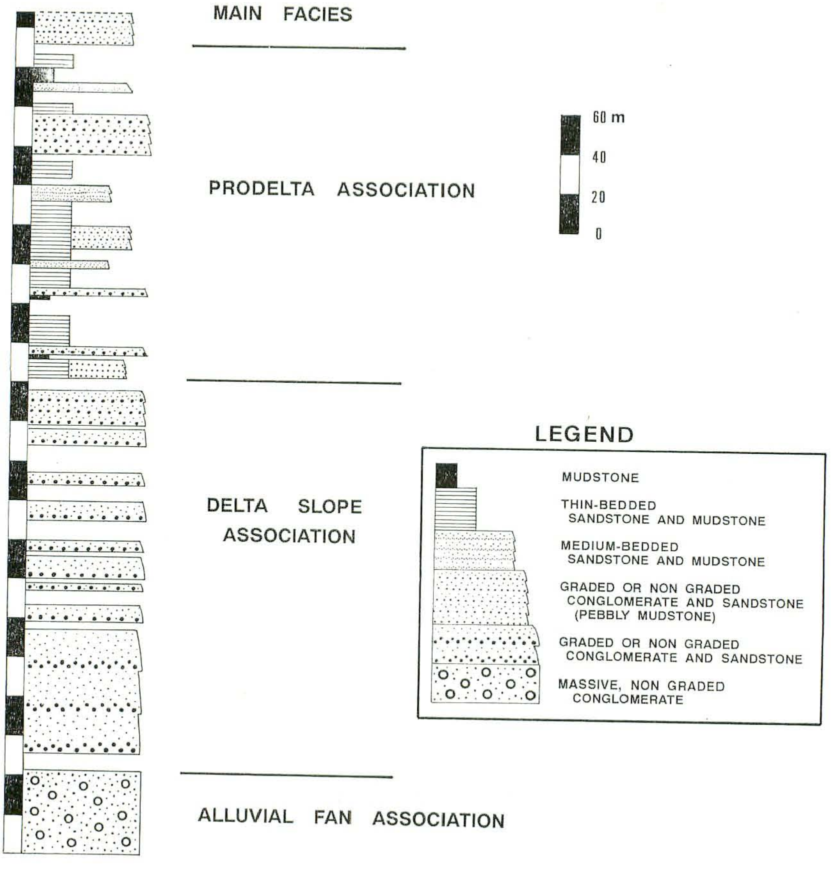

Fig. 4 Stratigraphic section of the Izumi Group on the Chichioni-river route.

high-density turbidity-current origin; and 3) matrix-supported conglomerate of intensively turbulent debris-flow origin. These conlgomerates are randomly stacked and form the succession of the delta-slope association. Individual conglomerate beds commonly show amalgamation and low angle basal scours up to 0.5 m deep. However, most of the beds are essentially tabular in the outcrop scale. Deeply incised channels have not been observed. The succession basically lacks fine representatives such as mudstones and thin-bedded, fine-grained sandstones.

The predominance of conglomeratic, mass-flow deposits and the well-developed internal organization of beds suggest that this association is likely to represent deposition on a subaqueous, steep surface of the delta slope. Although the geometry of the individual conglomerates is not clearly identified due to limited dimensions of the outcrops, the delta-slope conglomerates seem to have been deposited in such a way as to form a lobe-like body rather than a deeply channelized one. The scarcity of the deeply incised channel-scours and of intraformational clasts of rip-up origin is appropriate to this interpretation.

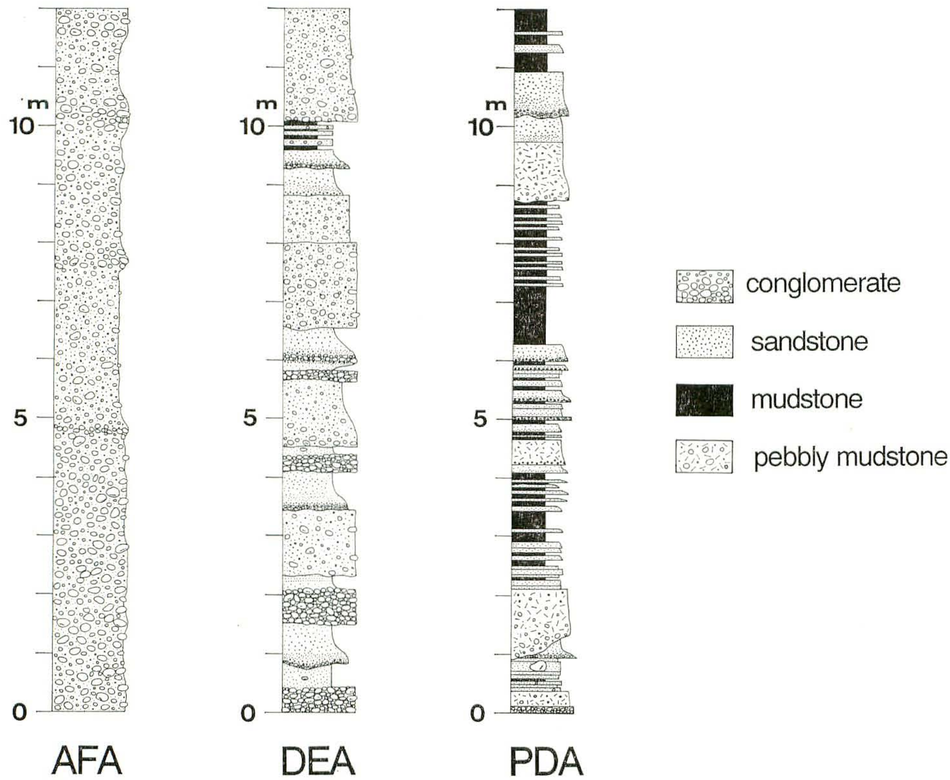

Fig. 5 Examples of log of the facies associations in the Chichioni area.
(AFA): Alluvial-fan association, (DEA): Delta-slope association, (PDA): Prodelta association.

The subaerial debris flows presumably passed directly down into the subaqueous delta slope. During the passage of the debris flows into the basinal water, a large amount of fine fractions was probably transported basinward as buoyantly supported surface plumes, whereas coarse materials flowed down the delta slope as a bottom flow, resulting in the conglomeratic lobe deposits poor in mud content.

Prodelta association

The deposits of the prodelta association are basically represented by the succession of thin-bedded sandstones with homogeneous mudstone interbeds (Fig. 5). Sandstones are mostly less than 10 cm thick, and are medium to very coarse grained. Some beds contain granules in their basal parts and show weak to well-developed grading. Abundant rip-up mud clasts are scattered in the uppermost parts of some beds. Despite being thinly bedded, these sandstones are interpreted as the deposits from high-density turbidity currents, on account of their coarse grain size and the common presence of rip-up mud clasts. The intercalated, homogeneous mudstones are generally less than 10 cm thick,

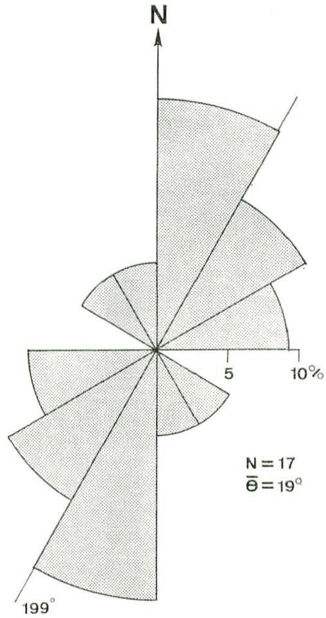

Fig. 6 Directions of the axis of channel structure in the prodelta association. N: number of observations.

but may occasionally be as much as 2 m thick. Internally, the beds are intensely bioturbated and homogenized. Enclosed within the thinly-interbedded succession are thick-bedded, channel-fill pebbly sandstones and pebbly mudstones in units 2–20 m thick. These channels commonly have N-S to NE-SW axes (Fig. 6).

This association represents deposition in a mass-flow-dominated prodelta environment fringing the delta slope. The common occurrence of the homogeneous mudstones throughout the succession indicates continuous suspension settling of fine materials, most of which were segregated from coarse detritus when subaerial debris flows passed into the basinal water. Following the emplacement of debris flows on the delta slope, residual turbulent flows were decelerated and deposited as sheet-like, thin sandstones on the prodelta. Some of the residual flows were still powerful enough to erode the muddy substrates, forming channel-fill pebbly sandstones.

Slope mud facies

The slope mud facies occurs in the western part of this area (Fig. 3). This facies is represented by intensely bioturbated, massive mudstones. The succession of the slope mudstone facies, which is 500 m thick, conformably rests on the deposits of the alluvial-fan association and laterally interfingers with the deposits of the delta slope and prodelta associations (Fig. 3).

The mudstones of this facies are attributed to normal background sedimentation of hemipelagic fine materials on the slope between the basin-margin alluvial fan and the deep-water turbidite basin. Relatively slow accumulation of mud enhanced bioturbation of sediments resulted in almost completely homogenized beds.

3.2. Depositional model

Based on the preceding interpretations of each facies associations and their lateral and stratigraphic relations, the deposits of the alluvial fan, the delta slope and the prodelta associations undoubtedly represent a steep-face fan-delta system. The fan delta had built on the southward-dipping slope on the northern margin of the Izumi basin and prograded directly into the deep-water turbidite basin(Fig. 7).

The sedimentation on the subaerial part of the system, the alluvial fan, was characteristically dominated by subaerial debris-flow processes. The restricted occurrence of the alluvial-fan conglomerates is suggestive of a limited development of a subaerial delta-plain component due to the deep coastal water without a receiving of the shallow shelf (see ETHRIDGE and WESCOTT, 1984; MASSARI, 1984; SURLYK, 1984; NEMEC, 1990).

The subaqueous segment of the fan delta, the delta slope, was essentially a depositional site for gravels and coarse sands. The fan-derived mass flow sustained a significant loss of fine fractions due to the buoyant lift of the basin water. As a result, mud fractions were completely segregated from coarse fractions and extended into the basin as buoyantly supported surface plumes. The residual coarse fractions were deposited on the delta slope from various types of sediment gravity flows, including cohesionless gravelly debris flows, high-density turbidity currents and turbulent debris flows, forming non-channelized, conglomeratic lobes.

The basinward extension of the delta slope is represented by the prodelta. The pro-

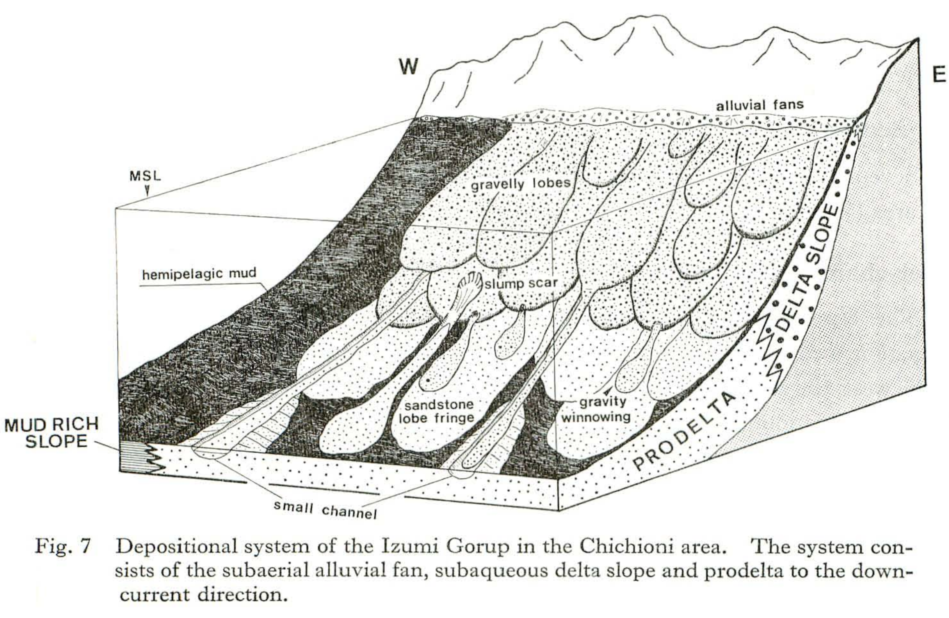

Fig. 7 Depositional system of the Izumi Gorup in the Chichioni area. The system consists of the subaerial alluvial fan, subaqueous delta slope and prodelta to the down-current direction.

delta was basically the site for hemipelagic sedimentation of mud. Suspension-fall muds supplied by the buoyantly supported surface plumes successively accumulated in this region. Concurrently with mud deposition, residual flows, which had deposited most gravelly loads on the delta slope, intermittently transported sands into the prodelta region and formed thin sandstones fringing the conglomeratic lobes on the delta slope. Large-scale residual flows were able to scour the muddy substrates to form small channels as revealed by thick-bedded, channel-fill pebbly sandstones. The incorporation of water into the flow or the loss of coarse fractions, or both, may have enhanced the increase in flow turbulence and consequent channel scouring. Some of the channels may have been formed through an up-slope retrogression of slump scars. Occasional pebbly mudstones in the channel-fills are suggestive of this process.

The deposits of this fan-delta system are laterally equivalent to the massive mudstone of the slope deposits to the west. The juxtaposition of the high-energy, gravel-dominated sedimentary environment and the low-energy environment consistently receiving hemipelagic falls suggests that the western-end of the domain of the conglomerate sedimentation may have been confined by a large gully wall or canyon wall (Fig. 7).

On the other hand, the conglomeratic delta-slope deposits extend further to the east (at least 20 km) along the northern margin of the Izumi distirbution (Fig. 2, RESEARCH GROUP FOR MTL, 1981). Accordingly, conglomerates in the Chichioni area are regarded as a part or the western end of a larger, coalescent, fan-delta complex. In the eastern half of the study area and further east, the conglomeratic delta slope deposits are contiguous to the main-basin-fill turbidites, lacking in prodelta deposits between them. Therefore, the main-basin-fill turbidites are thought to have been directly fed by the coalescent fan deltas, representing a line-source turbidite system rather than a point source one.

4. Depositional System in the Yamanaka-dani Area

4.1. Sedimentary facies

Seven facies associations have been recognized in the Izumi Group of the Yamanaka-dani area (Figs. 8, 9).

Upper-channel association

The upper-channel association occurs in the northern part of this area (Fig. 8). This association wedges out to the east into the massive mudstone of the slope mud facies. To the west, the sequence gradually thickens and interfingers with the deposits of the lower-channel association.

The upper-channel association consists of granule- to cobble-grade conglomerates, pebbly sandstones, pebbly mudstones and coarse-grained sandstones of up to 2 m thick beds with rare intercalations of mudstones (Fig. 9). The beds frequently show erosional features, as revealed by scour and fill, rip-up mud clasts and amalgamation. These deposits represent deposition from high-density and high-energy sediment gravity flows

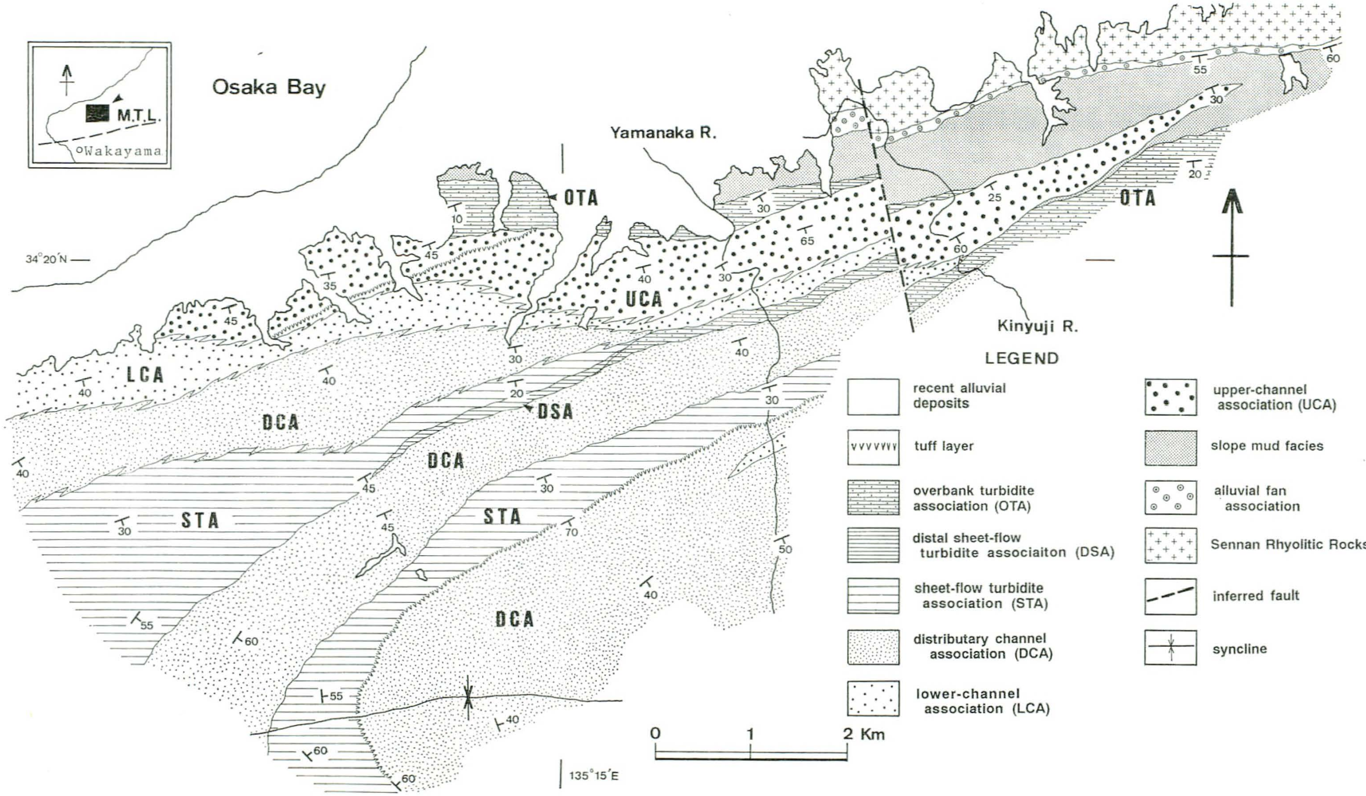

Fig. 8 Facies association map of the Yamanaka-dani area.

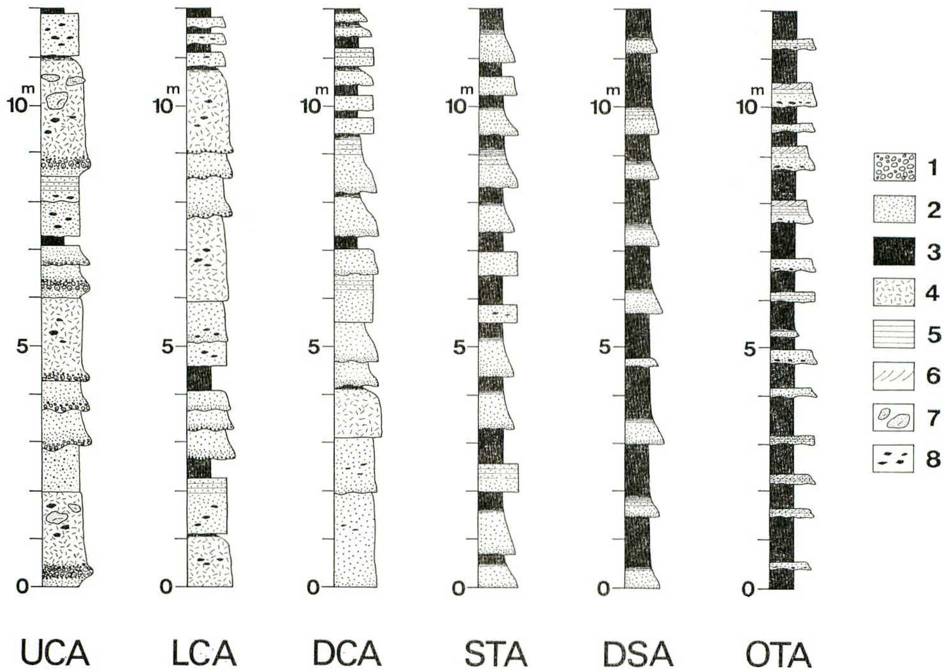

Fig. 9 Examples of log of the facies associations in the Yamanaka-dani area. (UCA): upper-channel association, (LCA): lower-channel asscoiation, (DCA): distributary-channel association. Section indicates typical fining-upward sequence recognized in this association, (STA): sheet-flow turbidite association, (DSA): Distal sheet-flow turbidite association, (OTA): Overbank turbidite association.
1: conglomerate, 2: sandstone, 3: mudstone, 4: slurry sandstone, 5: parallel lamination, 6: cross lamination, 7: sandstone intraclast, 8: mudstone intraclast.

such as high-density turbidity currents, sandy and muddy debirs flows, and modified grain flows (cf. TANAKA, J., 1989). This association shows a fining-upward seqnence throughout the succession. Internally, however, individual facies are complexly interbedded with one another, so that, any minor cycles are not recognized.

The characteristics of the upper-channel association are similar to those of the paleosubmarine channel-fill deposits studied by MUTTI (1977), MUTTI and RICCI LUCCHI (1978), HEIN and WALKER(1982) and others. The overall fining-upward sequence of this association reflects a gradual broadening of the channel with the lapse of time, which probably resulted from an active up-building (ANDREWS and HURLEY, 1978; HOOKE and SCHLARGER, 1980; SHEPARD, 1981) of the channel. The lack of internal minor cycles suggests deposition in an active single-channel system without multi-branching, network channels in it. An east-west trending axial channel is inferred from paleocurrent measurements (Fig. 10).

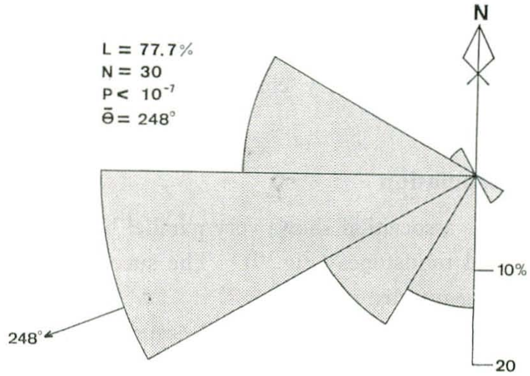

Fig. 10 Paleocurrent measurements (sole marks). Measurements were mainly made in the upper- and lower-channel associations.
L: vector magnitude, N: number of obsrevations, P: significance of rayleigh test.

Lower-channel association

The lower-channel association occurs in two distinctive stratigaphic levels in the study area. Out of the two, the lower occurrence of this association interfingers with the upper-channel association (Fig. 8). This association shows strong facies affinity with the upper-channel association. The important difference between the upper-channel and lower-channel associations is that the latter comprises finer clasts than the former (Fig. 9). The maximum clast size in this association is commonly of pebble- to granule-grades.

The lower-channel association is interpreted as channel-fill deposits, as in the case of the upper-channel association. It undoubtedly represents deposition in the distal part of the channel, as evidenced by the lateral transitional relationship with the upper-channel association and the westward paleo-dispersal.

Distributary-channel association

Many fining-upward sequences on the order of 10 m thick are recognized in this association (Fig. 9). A typical fining-upward sequence abruptly starts at a few beds of massive, very thick (1.5–2 m), coarse- to very coarse-grained sandstones. These sandstones are overlain by a succession of structureless or crudely, subhorizontally stratified thick sandstones (50–60 cm) with interbeds of thin mudstone (commonly 15 cm thick), which in turn grades upward into interbedded, thin (up to 40 cm thick) sandstones and mudstones. Occasionally intercalated in the sequence are pebbly mudstones (up to 80 cm thick) of muddy debris-flow origin. These fining-upward seqeunces are interpreted to have been formed by filling and abandonment of minor channels.

This association is recognized in three distincitve levels in the study area (Fig. 8). Of them, the lowest occurrence of this association interfingers with the lower-channel association. From the westward paleo-dispersal direction, the deposits of this association are inferred to have been derived through the channel which was responsible for organization of the conglomeratic channel associations. The main channel probably distributed into many minor channels (distributary channels), resulting in many fining-upward sequences.

Sheet-flow turbidite association

The succession of this association shows very parallel bedding, with consistent interbedding of sandstones and mudstones (Fig. 9). The succession is monotonous without any thinning- or thickening-upward motif.

Sandstones are generally medium grained, and occur as beds 10–50 cm thick. Most of the sandstone beds are graded, passing upwards into the overlying mudstones. The sandstones are internally structureless, although the uppermost parts of many beds reveal parallel lamination. The basal surface of the sandstone is sharp and flat, seldom showing scours.

The sheet-flow turbidite association is recognized in two distinctive levels in the study area. Of the two, the lower occurrence of this assoication interfingers with the distributary-channel association (Fig. 8). From the westward paleo-dispersal, it is supposed that the sheet-flow turbidite association was deposited in a more distal environment than the interfingering distriburary channel association. The general absence of basal erosional surfaces and the monotonous succession lacking in any cyclic motif represent deposition from non-channelized, sheet flow of turbidity currents.

Distal sheet-flow turbidite association

The distal sheet-flow turbidite association occurs in the central part of the study area (Fig. 8). This association is represented by the succession of monotonous, parallel interbedding of sandstones and mudstones, both up to 30 cm thick, without channeling and any cyclic motif (Fig. 9). Sandstones are fine grained and gradually grade upward into overlying mudstone. Sandstones show the Bouma Tab sequence.

The monotonous succession of this association is similar to that of the sheet-flow turbidite association, and represents deposition from sheet-like turbidity currents as in the case of the latter. However, this association consists of thinner and finer-grained sandstones than those of the sheet-flow turbidite association, implying deposition in a more distal environment.

Overbank turbidite association

The overbank turbidite association is recognized in two distinctive levels in this area (Fig. 8). The lower occurrence of this association is overlain by the upper-channel association, with a local interfingering relationship; it has a transitional contact with the underlying massive mudstone of the slope mud facies.

This association is represented by the succession of thinly interbedded sandstones and mudstones (Fig. 9), which are basically similar to those of the distal sheet-flow turbidite association. However, the deposits of this association consist of coarser sandstones (i.e., very coarse to fine grained), than those of the distal sheet-flow turbidite association. Sandstone beds are up to 60 cm thick (mostly less than 10 cm). Both of the upper and lower surfaces of the sandstone beds are sharp, and the lower ones, especially, are commonly irregular. Some beds show lenticular bedding. Internally, sandstones show the Ta-c, Ta, Tab and Tbc sequences of BOUMA (1962). The beds commonly contain abundant rip-up mud clasts.

The occurrence of this association along the channel-fill deposits of the upper channel association suggests deposition near the channel margin. In addition, the characteristics of this association, such as irregular bedding and corase grain size of sandstones in spite of its thin bed thickness, are similar to those described in previous works as natural levee or interchannel deposits (CARTER and LINDQVIST, 1975; MUTTI, 1977; MUTTI and RICCI LUCCHI, 1978; NELSON *et al.*, 1978; CARTER, 1979; WINN and DOTT, 1979; PICKERING, 1982; WALKER, 1985). This association is considered to represent deposition of sediments spilled over the main channel.

Alluvial-fan association

The deposits of this association are narrowly distributed along the northern margin of the Izumi distribution, and directly rest on the bedrock of the Sennan rhyolitic rocks (Fig. 8). The entire thickness of this association is highly variable and ranges from 10 to 150 m. This association dominantly comprises crudely bedded, ungraded matrix-supported conglomerates. The beds consist of pebble- to cobble-grade clasts (and occasional boulders) with medium to corase sand matrix. The conglomerates represent deposition from debris flows. The matrix-supported texture, poor sorting and polymodal grain size distribution are appropriate to a debris-flow origin.

Clast-supported conglomerates subordinately occur as beds of a few cm to 2 m thick. The beds show normal grading with well-sorted texture containing granule- to pebble-grade clasts. The basal surfaces show low angle scours up to 0.1 m deep. The conglomerates of this facies may have resulted from a heavily sediment-laden stream flow (LAWSON, 1982; NEMEC and STEEL, 1984). The normal grading and clast-supported framework imply successive sorting of the flowing materials by fluid turbulence.

The close stratigraphic association of the debris flow deposits and stream-flow deposits strongly suggests that the conglomerates of this association are likely to represent deposition on a alluvial fan on the northern margin of the Izumi basin.

Slope mud facies

The deposits of the slope mud facies occur in the northern margin of the Izumi distribution, having conformable relationships both with the underlying alluvial fan deposits and with the overlying turbidites (Fig. 8). The succession of this facies ranges in thickness from 300 to 500 m, and comprises highly bioturbated, massive mudstones yielding locally abundant molluscan fossils (ICHIKAWA and MAEDA, 1958; MATSUMOTO and MORO-

ZUMI, 1980).

The mudstones of this facies represent normal background sedimentation on the slope between the alluvial to coastal environments and the deep-water turbidite basin.

4.2. Depositional model

Based on the preceding facies interpretations, the depositional site of the Izumi Group in the Yamanaka-dani area can be divided into two distinctive suites: (1) northern margin of the basin and (2) main basin. The deposits of the northern margin of the basin were dominated by the alluvial fan conglomerates and slope mud. The narrow and restricted occurrence of these deposits stronlgy suggests a steep slope on the northern margin of the Izumi basin. In the main basin site, it is clear that the upper-channel, lower-channel, distributary channels, sheet-flows, distal sheet-flows and overbank turbidite associations form a depositional mega-unit (TANAKA, J., 1989). Three depositional mega-units are stacked in the Yamanaka-dani area (Fig. 8). The lowest one is a complete mega-unit; others are incomplete in the study area. The depositional model of the complete mega-unit is summarized in Fig. 11.

Transitions of the facies associations in a mega-unit reveal that the mega-unit is a product of a channel-fed, elongated, submarine-fan system in which the depositional setting passes, in the downcurrent direction, from a main channel with active over-spill-

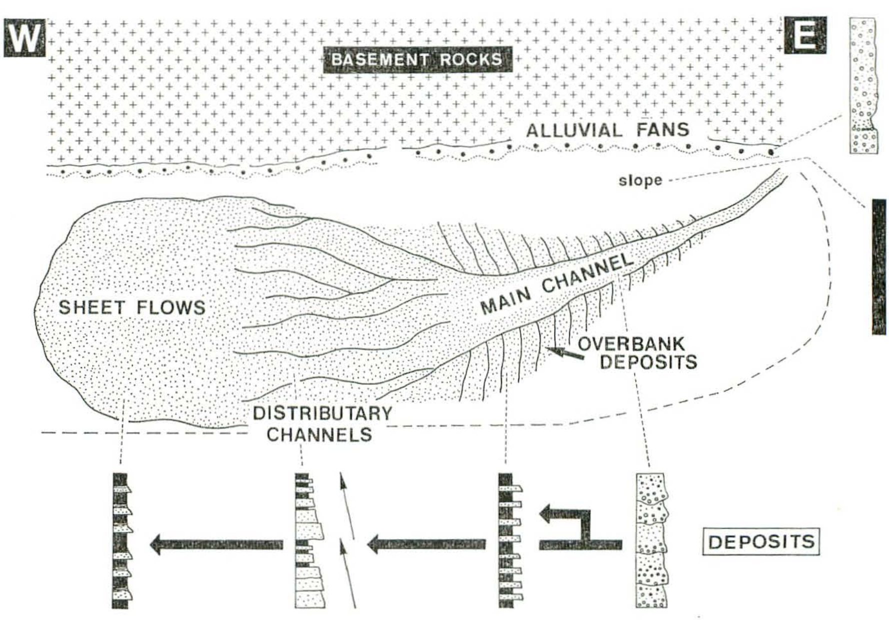

Fig. 11 Depositional system and resultant deposits of the Yamanaka-dani area. The depositional system of the northern basin margin consists of alluvial fans and slope. The main-basin-fill system (dotted) consists of a main channel with overspilled deposits, distributary channels, and sheet-flow in the downcurrent direction (westward).

ing to distributary channels, and then to non-channelized sheet flows (Fig. 11).

Sediment gravity flows passed into the central part of the basin via the main channel. The upper- and lower-channel associations were formed within this main channel. The lower-channel association is a distal representative of the upper-channnel association. The lack of the internal minor cycles in the main channel deposits, and the close association of thick, over-spilled deposits, suggest a relatively stationary position of the channel and active deposition in the single channel without multi-branching, network channels in it. Well-developed over-spilled deposits (the overbank turbidite association) are indicative of active spill-over of sediments from the channel. Down slope, the main channel branched into small channels. Filling and abandonment of these channels resulted in many vertically stacked, fining-upward sequences in the distributary channel association. General absence of over-spilled deposits in this association suggests frequent channel cutting and migration. Further down slope, these distributary channels gradually became shallower and finally disappeared. Consequently, the sediment gravity flows were released from the channel relief, resulting in broadened, sheet-like turbidity currents. The monotonous succession of the sheet-flow turbidite and distal sheet-flow turbidite associations were accumulated in this manner.

This depositional system appears to be basically similar to that of the submarine fan model (NORMARK, 1970; WALKER, 1978). The system, however, does not show a radial fan shape owing to confinement within the narrow basin, as evidenced by the marked longitudinal sediment-dispersal pattern. Furthermore, sequences indicative of depositional lobes are not recognized in this system. It is probable that the distributary channels gradually disappeared, resulting in a gradual transition from confined flow in the distributary channel to unconfined, non-channelized sheet-flow. There is a possibility that plural distributary channels existed contemporaneously for sheet-flows spreading out over the entire width of the narrowly confined basin.

This system gradually reduced its agent, probably due to the gradual lowering of the efficiency of the channel, leading to a fining- and thinning-upward mega-unit. Comparing it with other examples of sandy submarine-fan systems, this system would be classified into the smallest group in its dimensions. The lateral transitions of depositional settings are rapid and take place over a distance of less than 15 km. This is probably due to the active over-spilling of the channelized flow, which resulted in the rapid reduction of the flow competence. Thus, residual flows could not form a widely distributed sedimentary body (TANAKA, J., in prep.).

5. Sedimentary Tectonics

5.1. Basin development

The Izumi basin has been regarded as a result of active strike-slip movements along the Median Tectonic Line (TAIRA *et al.*, 1983; MIYATA, 1990). The basin-fill is basically made by stacked depositional mega-units, as mentioned above. The mega-unit is regarded as the basic sedimentation unit for the Izumi basin fill. The stacking of the mega-units is a sedimentary response to the stepwise basin extension caused by strike-slip movements (cf. TANAKA, J., 1989).

The mega-units of the Yamanaka-dani area are successively stacked to the east, indicating the eastward basin shifting with stepwise migration of the depocenter. Strike-slip movements along the Median Tectonic Line may have formed a depression while the curvature in the northern block, which was due to strike-slip movements of the Median Tectonic Line, probably formed a topographically relieved uplifting zone in the north-eastern region, adjacent to the basin. Such uplifted regions provided abundant terrigenous detritus into the basin which formed the succession of the mega-unit. Continuing strike-slip movements along the Median Tectonic Line caused the eastward extension of the basin, resulting in the successive formation of new depressions on the eastern flank of the previous depocenter. A new mega-unit was then formed in this depression to the east of the abandoned mega-units, one after another; at the same time, it partly overlay the former mega-unit. Such a stacking process resulted in the eastward-younging stacks of the mega-units (Figs. 12, 13).

5.2. Tectonic control on sedimentation

Individual mega-units are the products of their own depositional systems which had formed at every stage of the stepwisely extending basin. Therefore, these depositional systems reflect tectono-sedimentary conditions of the receiving basin and are thus used as good tectonic interpreters. The present study reveals two types of depositional systems: the coalescent, steep-face fan-delta system and the channel-fed, elongated submarine fan system. The steep-face fan-delta system of the Chichioni area represents a proximal part of a line-source turbidite system in which land-derived coarse detritus was fed

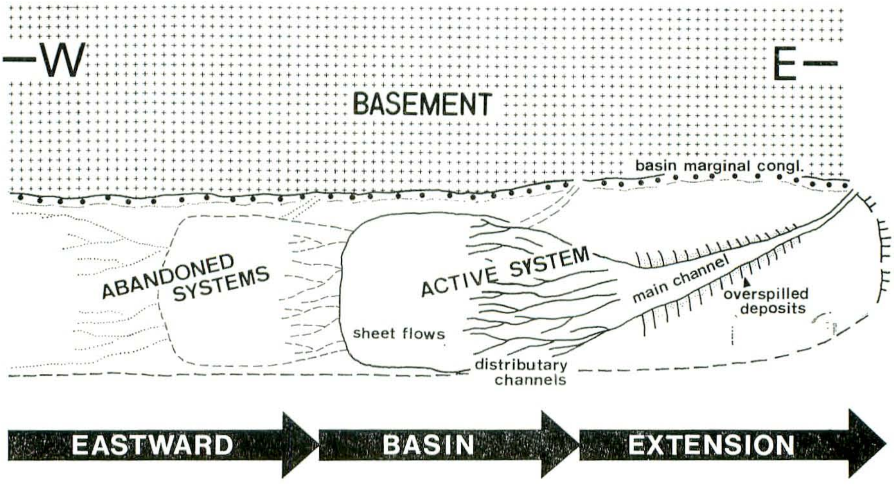

Fig. 12 Active system stepwisely shifted to the east owing to the eastward extensions of the basin.

to the deep-water basin directly by a fan delta on the slope of the basin margin. The development of such a system requires high-rate accumulation of coarse materials on the coastal area and deep basinal water depth (e.g., CARTER and NORRIS, 1977; SURLYK, 1978, 1984; HELLER and DICKINSON, 1985; HIGGS, 1990, NEMEC, 1990). The high rate of accumulation of clastic is indicative of the rapid uplift of the source area, probably due to the tectonic curvature on the northern block of the strike-slip basin. On the other hand, despite the high-rate detritus input, which could have resulted in rapid aggradation, deltaic deposits of this area do not form a shallowing-upward sequence but are overlain by the deep-water turbidite sequence. This indicates both the rapid basin subsidence and the eastward migration of the active feeding system.

The point-source, channel-fed, elongated submarine fan system of the Yamanakadani area coexists with the well-developed, mud-dominated slope deposits, and demonstrates less vigorous uplift of the northern block of the basin than in the Chichioni area. The system characteristically shows several evidences of sedimentation in the tectonically constrained, active strike-slip basin. The elongated geometry of these systems, as revealed by marked longitudinal sediment distributions, indicates lateral confinement of the depositional body in the narrow basin. The lack of records of distinctive lobe sedimentation in the system indicates the lateral confinement of the non-channelized flow by the narrow basin geometry. Furthermore, the occurrence of the distal sheet-flow turbidites is quite restricted. The scarcity of the most distal representative, in spite of successive lateral shifts of the locus of deposition, is indicative of the uplift and eastward tilting of the previous depressional area with eastward shift of the depocenter. Owing to this gentle slope on the west of the depocenter, the sheet-flows were probably prevented to continue to flow further to the west, and accelerated to deposit all the fractions

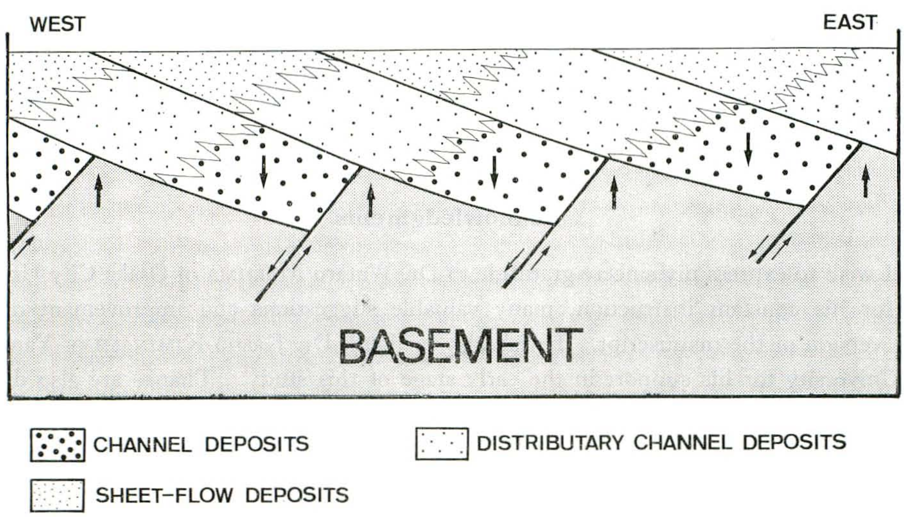

Fig. 13 Interpretative cross section of the stacking pattern of the Izumi Group.

without generating distal turbidites. Consequently, large quantities of sediments were fed into this confined basin and were deposited mainly as proximal facies associations.

6. Conclusions

The Izumi succession is basically made up of stacked depositional mega-units. Each of the mega-units is regarded as a product of every stage of the stepwisely extended basin. The present study reveals two types of the mega-unit: (1) the line-source type mega-unit fed directly by coalescent steep-face fan deltas and (2) the point-source type mega-unit resulting from a channel-fed, elongated submarine fan system.

The depoists of the steep-face fan delta system show transitions of depositional settings from the subaerial alluvial fan, through the subaqueous delta slope, to the pro-delta. The system was built on the southward-dipping slope of the northern margin of the Izumi basin and prograded directly into the deep-water. The development of the steep-face fan delta is strongly suggestive both of rapid basin subsidence and of the high-rate accumulation of the detritus into the basin.

The channel-fed, elongated submarine fan system shows transitions of depositional settings from the main channel with active overbank sedimentation, through distributary channels, to sheet-flows. The consistently longitudinal sediment distribution in this system indicates a lateral confinement of the depositional body in the narrowly confined, strike-slip basin. In addition, the uplift and eastward tilting of the previous depressional area had caused restricted downward (westward) extension of this system.

These mega-units are characteristically stacked as a result of the stepwise shift of the depocenter to the east with respect to the eastward extension of the basin. Consequently, each mega-unit partly overlies the former mega-unit successively, thus forming the eastward younging, extraordinarily thick, Izumi succession. The sedimentary and tectonic evolution of the Izumi Group can be clearly explained by the formation of mega-units and their successive stacking process. Such a tectono-sedimentary process was consistent in the Izumi basin, reflecting strike-slip movements along the Median Tectonic Line.

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