GROWTH PATTERN OF THE EARLY PLEISTOCENE HIGASHIHIGASA
SUBMARINE CHANNEL, BISO PENINSULA, CENTRAL JAPAN

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Abstract The Higashihigasa Formation in the middle Plio-Pleistocene Kazusa Group in the Boso Peninsula, central Japan, consists mainly of gravel and sand, and is the infill of a large trough called Higashihigasa Channel. This channel was formed by the erosion of sediments with more than 600 m of stratigraphical thickness.

The sediments filling the channel repeatedly change their facies vertically and five cycles with 80 to 140 m in thickness can be seen. Each cycle is subdivided into the basal part composed of closely-compact mud clasts, the lower part mainly of gravel and sand including many mud clasts, the upper part of sand occasionally revealing Bouma division (Tab or Tabc) and the uppermost part of alternating sand and mud, thus showing an overall fining-upward. Most of the sediments in the channel are bounded by steep walls, but alternating beds of the uppermost part of each cycle can be traced to the outside of the channel. As sediments of the younger cycle are distributed in the eastern area of the channel, the channel is thought to advance eastward, deviating its thalweg slightly southward.

The channel bifurcates into east and west at its influx. While the west channel can be traced for a distance of only 1km, the east channel, the main course, runs straight for about 7 km along the axial part of the syncline. The syncline is inferred to have grown during the deposition of the Higashihigasa Formation based on the paleosubmarine topography suggested by the sliding direction of large slumped masses in the surrounding sediments on both sides of the channel.

We conclude that the channel was produced by a sudden supply of coarse sediments into the axial area of the growing syncline, and was filled up at the end of each cycle, but had grown due to alternating processes of erosion of the previous channel fill and deposition in the new channel. Supply of coarse sediments into the channel might be ascribed to movements of the source area accompanying the large-scale migration of the depocenter.

Introduction

In sedimentary basins in tectonically active regions, not only uplifting and subsiding take place during the deposition, but also faulting (PREISS, 1987), folding (NORMARK & PIPER, 1972) and even movements resulting in a partial unconformity take place (ANADON ET AL., 1986). It is shown to be reasonable that such movements caused or controlled sedimentation and even growth patterns of submarine fan-channel systems. Some modern submarine canyons with tectonic controls are reported (NORMARK & PIPER, 1972; HOOKE & SCHLANGER, 1980; SHEPARD, 1981). For example in the La Jolla (California) submarine fan system, the position and courses of channels are controlled by borderland faults and sub-bottom structural features (GRAHAM & BACHMEN, 1983).

Studies of the geological structures around ancient submarine fan-channel systems have not always been carried out on land. MACDONALD (1986) lists ancient fans with external control of the sedimentation pattern, though most of them are controlled by faults, especially boundary faults. There are some other reports on the fan-channel systems controlled by faults (DICKAS &
PAYNE, 1967; PICA, 1979; WESCOTT & ETHRIDGE, 1983; RUIZ-ORTIZ, 1983; KLEVERLAAN, 1989), but, a few are estimated to have been controlled by other movements of the basin. For example, SHANMUGAN & MOOLA (1985) inferred that the distribution of channels and lobs in the Eocene Hecho Group in Spain is controlled by the actively growing anticline during the deposition of the group.

Also, it is rare that the morphology of an ancient channel and sediments filling it can be observed in detail for several kilometers along its axis.

The Kanto Plain in central Japan is one of the active areas. The thick marine sediments of the Miocene to Pleistocene Ages which were deposited in a forearc basin along the Japan Trench are widely distributed in and around the Kanto Plain (NIREI, 1982). One of these, the Kazusa Group is composed of Plio-Pleistocene marine sediments with a total thickness of about 5000 m.

SATO & KOIKE (1957) have suggested that the Higashihigasa Formation already in the Kazusa Group was deposited in a large furrow which had been formed by erosion at the bathyal depths, and designated it the “Higashihigasa Fossil Submarine Canyon”. The furrow can be traced for a distance of about 7 km in an axial direction. As the loose sand and gravel filling it are well exposed on a large scale in artificial outcrop belts, detail facies organization and geometry can be observed closely.

This paper is concerned with the morphology of the Higashihigasa Channel (which is referred to as “the furrow” in this paper), facies of the channel fill and sedimentary structures of the surrounding sediments, and aims to provide an insight into the relationship between channel development and the tectonic evolution of the sedimentary basin.

**Geological setting**

The Miocene to Pleistocene beds in and around the Kanto Plain are divided, in ascending order, into the Hayama, Miura, Kazusa, Shimoso groups and other formations of the younger Pleistocene Age. The Kazusa Group is also distributed under the Kanto Plain, in the Boso Peninsula and below the sea floor off the Boso Peninsula, occupying an area of 200 km x 150 km (Fig. 1).

In the Boso Peninsula, south of the Kanto...
Plain, the Kazusa Group rests unconformably upon the Miura Group and the unconformity between the two groups is called the "Kurotaki Unconformity". Though the relationship between the two groups is a parallel unconformity in the western and central areas of the peninsula, the Kazusa Group onlaps onto the Miura Group in the eastern area (Mitsunashi et al., 1961).

The Kazusa Group changes its thickness laterally from about 1500 m on the west coast of the peninsula to more than 2500 m on the east coast, and its facies is also variable so that stratigraphical divisions are different between the western and the central to eastern areas (Fig. 2). However, the group includes many volcanlastic beds which are useful as marker-beds. As volcanlastic beds indicate chronologically similar surfaces, the marker-beds described and traced by Mitsunashi et al. (1961) are used as criteria for precise stratigraphical correlation in this study. The Kazusa Group monoclinally inclines northward at an angle of a few to 20 degrees near the Koito River which is situated along the eastern margin of this area, but in its western part a gentle syncline and an anticline which have northeast-southwest trending axes of about 6 km long are developed (Fig. 3). They are called the Yamawaki Syncline and the Tanokura Anticline, respectively.

The Group in and around this area is divided into 10 formations as shown in Fig. 2. The Higashihigas Formation, consisting mainly of gravel to medium-grained sand, is distributed along the axial part of the Yamawaki Syncline and fills a large furrow which deeply incises underlying sediments of sandy mud and mud. However, the formation rests conformably upon the underlying sediments to the west of the Koito River where the syncline terminates, and grades into the Umegase Formation to the east of the river. The furrow evidently erodes the Marker-bed Kd38 in the Takeoka Formation in the western part of the this area, and is covered conformably by alternating beds of sand and silt.
Fig. 3. Geological map of the Higashigusa Formation. Numerals beside + marks show depth of the channel floor from the ground surface.
Fig. 4. Schematic north-south cross section through cycle IV of the Higashihigasa Formation. Bent solid line indicates a probable position of Fig. 6.

Fig. 5. Closely compacted mud clasts in the basal part of cycle III. A hammer at the right side is about 90 cm long.

just below the Marker-bed U3 in the upper Umegase Formation. The stratigraphical thickness between the Marker-beds Kd38 and U3 near the Minato River ranges up to 380 m, but it attains to about 550 m near the Koito River which bounds the eastern margin of this area.

The furrow is about 7 km long and 500 m to 2 km wide but its depth is known only at three points: two wells to the east of Yokoyama reach the channel bottom at a depth of 53 m and one to the south of Morokuzure at a depth of 37 m (Fig. 3).

Sedimentary facies and cycles in channel fill

Sediments filling the Higashihigasa Channel change their facies repeatedly and five cycles of 80 m to 140 m in thickness can be observed. They are herein named cycles I to V in ascending order. Lateral and vertical facies changes in cycle IV are observed in detail, as represented by a schematic cross section in Fig. 4.

Each cycle is subdivided into the basal, lower, upper and uppermost parts, and the sediments tend to become finer upward. The basal part of
Fig. 6. Well rounded gravel in the lower part of cycle IV, which is imbricated and shows inverse grading. Flow was from right to left. A coin at lower right corner is about 2.5 cm in diameter.

Each cycle except for cycle II, usually a few to ten meters thick, is composed of closely compacted mud clasts, intermingled with gravel (Fig. 5). Mud clasts which are usually a few tens of centimeters in diameter are considered to have been derived from muddy sediments on both sides of the channel or from the uppermost part of the previous cycle. On the other hand, the basal part of cycle II is composed of gravel beds intercalated with a thick bed of pebbly mud.

The thicknesses of the lower parts are variable; for example, lower parts of cycles III and IV have a maximum thickness of about 40 m but that of cycle V is about 10 m thick. The lower parts are composed mainly of coarse sediments ranging in size from cobble to medium-grained sand, containing mud clasts closely compacted into many zones less than a few meters thick. Gravel is generally inverse-to-normally or normally graded, and some are imbricated (Fig. 6).

The sediments of the upper parts, ranging in thickness from 20 m to 40 m, reveal fining- and thinning-upward sequences, and typically include Bouma Tab or Tabc divisions (Fig. 7A). Gravel of granule size is scattered partly in sand, which is intercalated with some mud seams less than 1 cm thick and a few lenses of mud clasts (Fig. 8). Slumped masses of 1 m to more than 5 m thick are developed in the upper parts of cycles II, III and IV.
near the channel walls (Fig. 9). Characteristically, intergranular mud is not contained in sand of the lower and upper parts (SATO & KOIKE, 1957).

The uppermost parts, a few meters to about 10 m thick, are composed of sand alternating with silt or pebbly mud. Sand beds which are a few meters thick near the boundary between the upper and uppermost parts become gradually thinner into the upper parts to be 10 cm thick or less. On the other hand, silt beds are usually less than 30 cm thickness near the axial part of the channel, but become thicker in the upper parts attaining at more than 1 m near the margin of the channel (Fig. 7B). Sand usually shows normal grading from very coarse- to medium-grained and reveals Bouma Tabc division.

Although most of the sediments in the channel are bounded by steep walls (Fig. 13), alternating beds of sand and silt in the uppermost part of all cycles except for cycle I can be traced laterally into the outside of the channel (Fig. 7B). Sands that overflowed from the channel are pinching out into the surrounding sediments of the channel, but terminate within 1 km from the channel.

The uppermost alternating beds of each cycle, except for cycle V, are usually preserved near the side walls, but in an axial part of the channel they were eroded by coarser sediments of the basal part of the younger cycle.

Slumped masses of a few meters thick are observed in the alternating sand and silt of cycle IV at the margin of the channel. Its inner structure indicates that the sediments slide toward the inner side of the channel.

Sedimentary facies of the basal and lower parts of each cycle is characterized by many gravels and closely compacted sand clasts. Such facies corresponds to the upper fan channel fill of the submarine fan model proposed by WALKER (1978). Sediments of the upper and uppermost parts, which are occasionally represented by pebbly or massive sand deposits, correspond to the mid-fan channel fill. However, overflowed sand of the uppermost parts near the margin of the channel may be turbidites deposited on the levee and small-scale slumpings occurred on the levee slope.

The channel fill sediments include many well rounded gravel of Pre-Miocene sandstone, chert, and shale (SATO & KOIKE, 1957). As no exposure of similar rocks is known in the southern Kanto district, the above-mentioned rocks appear to have been derived from the Kanto Mountains where the Palaeozoic and Mesozoic rocks, similar to the gravels, are widely exposed.
Sand and gravel in the lower part of each cycle yield many kinds of neritic to bathyal molluscan fossils (Fig. 10). Bathyal shells are preserved relatively well but neritic ones are occasionally broken fragments (Sato & Koike, 1957). Moreover, Takai (1938) reported land mammal fossils, such as Parelephas proximus and Deperetia kazusensis, from the Higashihigasa Formation.

Coarse sediments in a cycle occasionally incise the underlying finer sediments to produce a large or small trough less than a few meters in depth (Fig. 11). Paleocurrent directions in the channel are examined by measuring directions of the side walls of erosional troughs or imbricated gravel, or by integrating both directions (Fig. 12). These sedimentary structures indicate that sediments in cycles II to V were derived from different directions as observed at Yokoyama, where transported generally northeastward. However, the northward or northwestward currents are predominant in the sediments of cycle I at Yokoyama.

**Morphological features**

The sediments of cycle I fan out at Yokoyama. But the sediments on the north of Yokoyama rest on the wide terrace of the channel wall and both of eastward and northwestward furrows from Yokoyama are observed. The north- or northwestwards currents are predominant in the sediments of cycle I at Yokoyama and a slumped mass indicates northwards sliding. The floor of the furrow extending northwestwards inclines northwest at an angle of five degrees near the Minato River. These field evidences indicate that the Higashihigasa Channel bifurcates east and west near Yokoyama and the sediments of cycle I are transported from the south to Yokoyama.

In the east channel, the main course runs nearly straight for a distance of about 7 km from Yokoyama, varying in width from 500 m to 2 km, and a furrow filled with sediments of a cycle is about 70 m to 100 m deep (Fig. 3). The west chan-
nel, a branch, can be traced north-eastwards for a distance of only 1 km. Both channels are filled with sediments of cycle I and a wide terrace jutting southwards appears at the junction of the two channels.

Where gravel-rich sediments of a lower part of a cycle flanked the muddy sediments (Fig. 13), the channel is the narrowest and the channel walls dip at an angle of more than 60 degrees, gradually becoming gentler in the upper parts.

The side walls of cycles I, II and IV have terraces, which are bounded on the bottom floor by a steep scarp and have relatively smooth surfaces descending towards the channel axis at an inclination of a few degrees. Sediments on the terraces are rich in mud clasts (Fig. 14).

As sediments of the younger cycle are distributed in the more eastern parts of the channel, the channel may have advanced eastwards. Concurrently, the thalweg of the furrow filled with sediments of the younger cycle deviates slightly more southwards, going away from the Tanokura Anticline.

**Sedimentary structures of the surrounding sediments**

On the southern side of the channel there are four smaller channels filled by gravel and sand very similar to those of the Higashihigasa Formation. The largest one, called the Nishihigasa Channel (Fig. 2), is about 80 m wide and 50 m deep and joins the Higashihigasa Channel near the Koito River, where it is conformably overlain by the sediments of cycle III of the Higashihigasa Channel and separated into the upper and lower units by interbedded mud of the lower Umegase Formation. The Nishihigasa Channel may be correlated with cycle III because its stratigraphical position is equivalent to cycle III based on the marker-bed. But the other smaller channels are older than the Higashihigasa Channel, characteristically including slumped beds which occupy the greater part of the channel fill.

Besides small slumped beds in the Higashihigasa Channel, many slumped beds are developed in the surrounding sediments of the channel,
especially between the Marker-beds Kd23 and O27 near Takamizo on the south of the channel (Fig. 15), where the sediments between the Marker-beds Kd23 and O27 increase its thickness; the largest one is about 40 m thick. Their internal structures indicate that they moved towards the north (Fig. 12). On the north side of the channel, there are also many slumped beds of less than 10 m in thickness which are intercalated in the surrounding sediments. Their internal structures show that they slid towards the south, except for the one in the lowest stratigraphical horizon, above the Marker-bed Kd38, which is inferred to have moved northwards.

**Sedimentary environment**

The channel fill, called the Higashihigasa Formation, is precisely correlated with the uppermost part of the Otadai Formation and the lower part of the Umegase Formation distributed in the east of this area (Mitsunashi et al., 1961). On the basis of the benthonic foraminiferal assemblages in both formations, their sedimentary environments are inferred to be the upper to middle slope (Aoki, 1968; Itihara et al., 1973). As Hirayama & Nakajima (1977) concluded that turbidites in the upper part of the Otadai Formation have been funneled into the middle to outer fan of the topographic divisions of Mutti (1974) through the channel, the Higashihigasa Channel, therefore, is inferred to be situated on the upper to middle fan of a slope basin.

This conclusion is also supported by the channel fill which is generally equivalent to those sedimentary facies on the upper fan
of submarine fan models by Walker (1978) or Shanmugam & Moiola (1985), as discussed above.

**Sedimentation and tectonic evolution**

An upper limit of each stratigraphical range of cycles II to V can be determined owing to the existence of the lateral extension of the uppermost overflowed sand of each cycle, which occurs between the Marker-beds O7 and U3 (Fig. 15). The stratigraphical horizon of cycle I can not be determined directly in the field. As a large quantity of sand is contained in two horizons of the surrounding sediments between the Marker-beds O7 and U8 in the south of the channel, the overflowed sands of cycles I to II may be correlated with these sand-rich horizons.

Although Kuenen (1967) mentions that submarine slumping occur following the temporary, local slope in sedimentary basins, many large-scale slumped masses, which slid in the same direction, probably reveal that the paleosubmarine floor descended in the same direction for a certain period of time. The isopach map of the middle Kazusa Group (Fig. 2) shows that the paleosubmarine floor around this area inclined as a whole northeastwards during the deposition. However, the axial part of the Yamawaki Syncline was probably a lower land on the paleosubmarine floor because most of the slumped beds on both flanks of the syncline are estimated to have slid towards its axial part just before the deposition of the Marker-bed O27. Also, the axial part of the Tanokura Anticline might have been a ridge on the paleosubmarine floor; if so, then both the syncline and the anticline had begun to grow before the deposition of the Marker-bed O27. It is suggested by the unfolded Marker-bed U3 that folding may have disappeared before its deposition.

Sato & Koike (1957) inferred that the whole form of the Higashihigasa Channel was produced by erosion during the deposition of sediments between Marker-beds O7 and U8, and then the channel was filled up after the deposition of Marker-bed U8. But deposition of the cyclic sediments, as mentioned above, cannot be explained by such a depositional process. It can be explained only by the following process.

During the deposition of sediments between Marker-beds O7 and U8, sediment flows which contained a great mass of gravel and sand began to come from the south into the lower land along the axial part of the growing Yamawaki Syncline. The Tanokura Anticline played a role of a topographic obstruction that separated the sediment flows into northwest and east, and each flow eroded muddy sediments on the slope to form two channels near Yokoyama (Fig. 16). When sediment-loaded flows became weaker, they stopped erosion and began filling up the channel.

After the deposition of muddy sediments about 50 m thick on both sides of the aggregated channel, gravel-rich sediments were supplied again from a new influx which diverged slightly eastwards from the influx of the cycle I stage. Flows transporting new coarse sediments are shown to have run only northeastwards along
Fig. 16. Paleogeographic reconstruction showing relations between the Higashihigasa Channel and the Tanokura Anticline. Arrows indicate paleocurrent direction. Levee morphology might be produced only during sedimentation of the upper or uppermost parts of a cycle.

the axial area of the Yamawaki Syncline which had grown to extend further northeastwards. New sediment-loaded flows resurgened to incise the buried channel filled up by the sediments of cycle I and muddy sediments surrounding it, reconstructing a new channel which extended further northeastward and migrated its thalweg slightly southwards. When the sediment-loaded flows became weaker again, the channel was gradually filled up by sediments of cycle II resulting in its temporary disappearance.

The channel is estimated to have grown through such an alternating process of both erosion of the previous channel fill and filling of the new channel, and the channel gradually advanced northeastwards. Concurrently, the channel thalweg shifted southwards away from the growing anticline axis. During the cycle V stage, the channel discharged sediments near the Koito River, where the Tanokura Anticline and the Yamawaki Syncline disappear. The anticline and the syncline discontinued their growth just before the deposition of the Marker-bed U3, so that the channel filled by sediments of cycle V had not resuscitated again.

The above process suggests that the Higashihigasa fan-channel system progradated northeastwards as time went by. As the facies of the sediments in one cycle shown in Fig. 4 change vertically from the upper fan channel fill to the mid-fan channel fill of the submarine fan model proposed by Walker (1978), the sediments filling the upper fan channel would have had the same facies as that of the mid-fan during the fan-channel progradation when the supply of sediments decreased.

As coarser sediments in one cycle erode occasionally underlying sediments to produce smaller channels and cause lateral change of its facies (Fig. 3), the main channel shows a meandering or braided thalweg and terraces on its floor, similar to the model by Johnson & Walker (1979). It appears from the above that mud seams in the upper part of cycle IV in the fill of the Higashihigasa Channel (Fig. 4) are overbank terrace sediments transported from some distance away.

It is commonly thought that most long-driven sediments were trapped on the continental shelf when the sea level was high and submarine fans grew in response to the activation of sediment supply into basin floors (Brown Jr. & Fisher,
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1977; SHANMUGAM et al., 1985). If the intermittent supply of sediments into the Higashihigasa Channel was controlled only by fluctuating sea levels, a question arises as to why the sediments did not come to be supplied again into the channel during the period of low sea levels after the deposition of the Marker-bed U3.

It is inferred that the depocenter of the sedimentary basin of the Kazusa Group migrated on a large scale just before the deposition of the Marker-bed O7 in the Otadai Formation, in association with the uplifting of the source area of terrigenous sediments (MITSUNASHI & YAMAUCHI, 1988). The movements caused depression by faulting at the western margin of the sedimentary basin of the Kazusa Group and would be expected to suddenly supply a great mass of coarse sediments into the channel. But the supply came to an end when the movements abated.

Conclusion

The depocenter of the basin had been migrated northwestwards during deposition of the Umegase Formation, the middle Kazusa Group. The uplifting of the source area was inferred to be raised at the migration of the depocenter, consequently causing the sudden supply of a lot of coarse sediments into the basin.

Coarse sediments which were transported from the Kanto Mountains to the shelf south of this area flowed into the lower land along the axial part of the growing syncline on the slope and eroded muddy sediments to form a large furrow. When the sediment-loaded flows became weaker, they began filling up the channel. As coarse sediments are supplied intermittently during deposition of the Marker-beds O7 to U3, both processes of erosion of the previous channel fill and filling of the channel were alternated, consequently the channel had grown.

The channel gradually prograded northeastwards with the growth of the syncline and the thalweg was shifted away from the growing anticline. When the syncline and the anticline discontinued their growth, the channel had not resuscitated again.

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References


* in Japanese with English abstract

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(要旨)


長崎半島の上総層群中部基底の東日笠層は、向斜構造の軸部に沿って発達する長さが約7km, 幅500m～2kmのチャネルを充填する砂層からなる。チャネル充填層は層相から5サイクルに区分され、各サイクルの堆積層のほとんどはチャネル壁にアパサトするが、最上層の互層は、局所の地層と指接関係にあり、変成と埋積を繰り返してチャネルが成長している。古いサイクルの堆積層ほどより東方に分布し、チャネルの中心線が南から東へ移動している。チャネルの周囲の周辺のスラブ構造のすべり方向から、斜め面はこの時間に成長していたと推定される。また、この時期には上総層群の堆積盆地は堆積の中心を大きく移動させており、後背地の隆起と堆積盆地内の差別の沈降運動が激しくなり、そのため急激に供給された多量の砂礫が、成長しつつある向斜の軸部に間欠的に流れ込んで、東日笠チャネルが形成され、向斜の成長がやむともにチャネルも消滅した。