Stratal patterns of bouldery conglomeratic successions in the eastern part of Jinan Basin (Cretaceous), SW Korea

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Introduction

Sedimentation in small-scale strike-slip basins is largely controlled by the sense and magnitude of fault movements (Steel, 1976). At the basin margin, stratigraphy and depositional architecture of coarse-grained deposits are closely related to the bounding fault movements possessing components of both strike-slip and normal-slip (Hempton, 1983). Both strike-slip and dip-slip movements of the fault cause the accommodation and its lateral migration for successive deposition (Steel & Gloppen, 1980; Frostick & Steel, 1993). Vertical movement of the bounding fault determines the accommodation space which can largely affect the internal architecture and facies of the coarse-grained deposits (Dune & Hampton, 1984). Earlier studies have, however, focused on the effect of strike-slip movement on external geometry and vertical textural trends of the coarse-grained deposits (e.g., Steel, 1988). On the contrary, depositional architecture and facies of conglomerate bodies (3.2 km thick) in the eastern part of the Jinan Basin suggest that the accommodation and depositional slope were controlled by variations in dip-slip movements along the strike-slip margin.

Geologic Setting

The Jinan Basin comprises a nonmarine succession (ca. 13 km thick) of conglomerate, gravelly sandstone, sandstone, and black shale which were intruded by andesitic-rhyolitic volcanics and overlain by andesitic-rhyolitic tuffs. In the eastern part of the basin, the sedimentary successions (ca. 4 km thick) are divisible into three lithologic units: conglomerate, sandstone/gravelly sandstone, and black shale/sandstone. The sedimentary successions mostly dip either northeast or southeast and conglomerates occur along the basin margin (Fig. 1).

The conglomerate units are largely of cobble to boulder-grade with minor gravelly sandstone and sandstone beds (< ca. 10%) which are transitional to sandstone/gravelly sandstone basinward, showing an abrupt lateral facies change. The black shale/sandstone is characterized by an alternation of thinly bedded black shale and sandstone.

Depositional Settings

The conglomerate and sandstone/gravelly sandstone can be organized into longitudinal-fill and lateral-fill sequences based on paleocurrent directions and clast compositions (Fig. 1). Sedimentary facies and facies associations in the longitudinal-fill and the lateral-fill sequences are summarized in Tables 1, 2, 3, and 4.

Longitudinal-Fill Sequence

This sequence (ca. 3 km thick) is characterized by large-scale, sheetlike geometry of amalgamated bouldery conglomerates (Facies Gd-1, Gd-2, and Gi) with rare sandstone and mudstone layers (Facies association A) (Tables 1, 3). The amalgamated bouldery conglomerates are transitional basinward to thin- to medium-thick sandstone and dark mudstone beds (Facies Sm, Sn, Ss, Sl, SMl, and Ml) containing openwork gravel lens (Facies Gol) and isolated bouldery clasts (Facies association B) (Tables 1, 3). Facies associations and depositional architecture of the longitudinal-fill sequence suggest a large-scale, steep-sloped delta environment. These large-scale, coarse-grained deltas generally developed in steep-sloped basin margin, reflecting relatively high rate of vertical subsidence. The paleocurrent directions and the facies association transition from FA A to FA B indicate that the longitudinal-fill sequence prograded toward the west with a radial pattern (Fig. 1). This sequence shows repetitive and overlapping patterns toward the east, which is opposite to the paleocurrent directions (Fig. 1). The eastward repetitive and overlapping patterns are indicative of eastward migration of the depocenter and the source area, accompanied with sinistral strike-slip fault movements.

Lateral-Fill Sequence

The lateral-fill sequence can be differentiated into the lower and upper parts on the basis of facies associations and bed geometry (Fig. 1). The lower part of the lateral-fill sequence (ca. 1.4 km thick) consists largely of channelized,

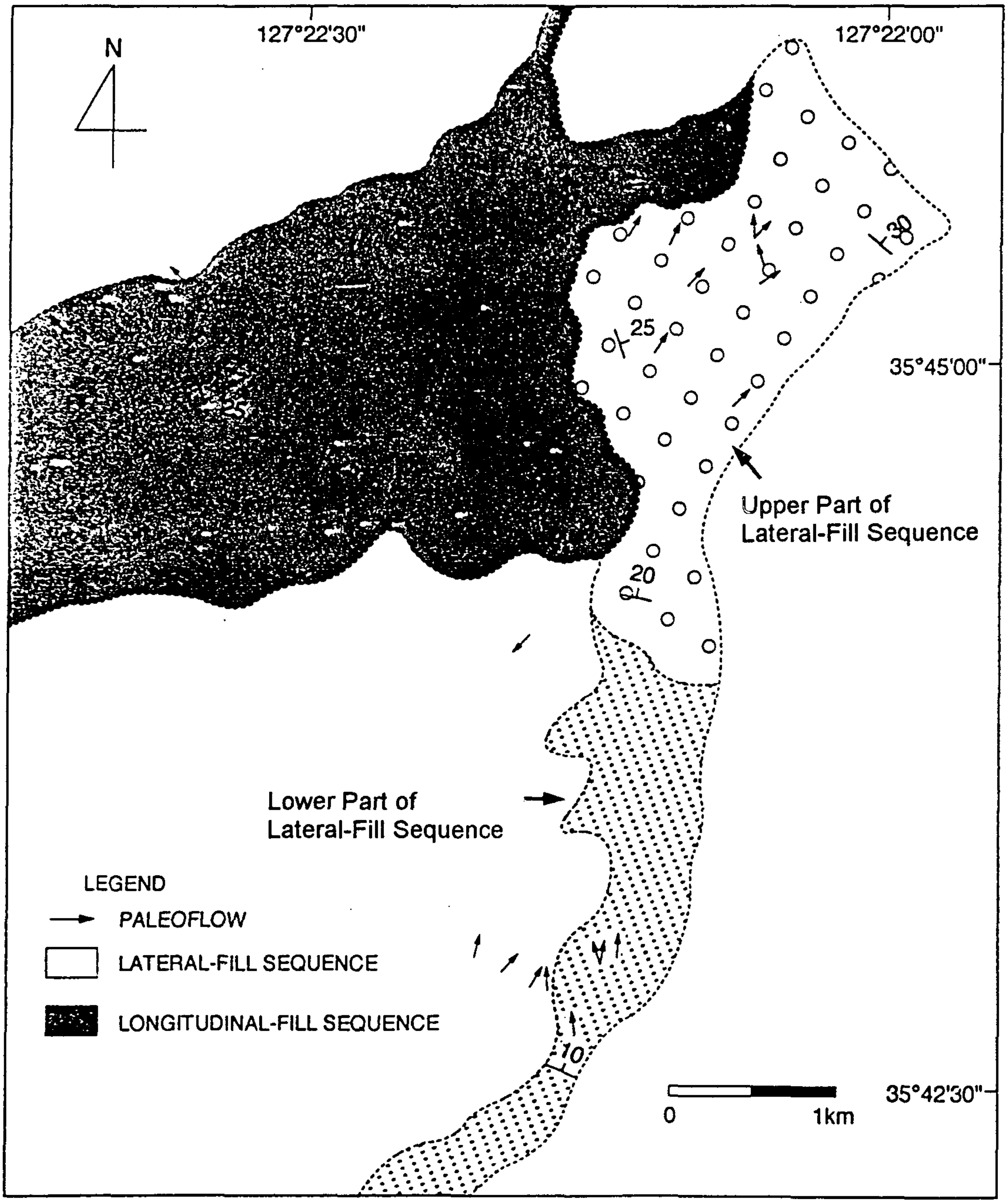


Fig. 1 Distribution map of longitudinal-fill and lateral-fill sequences in the eastern part of the Jinan Basin.

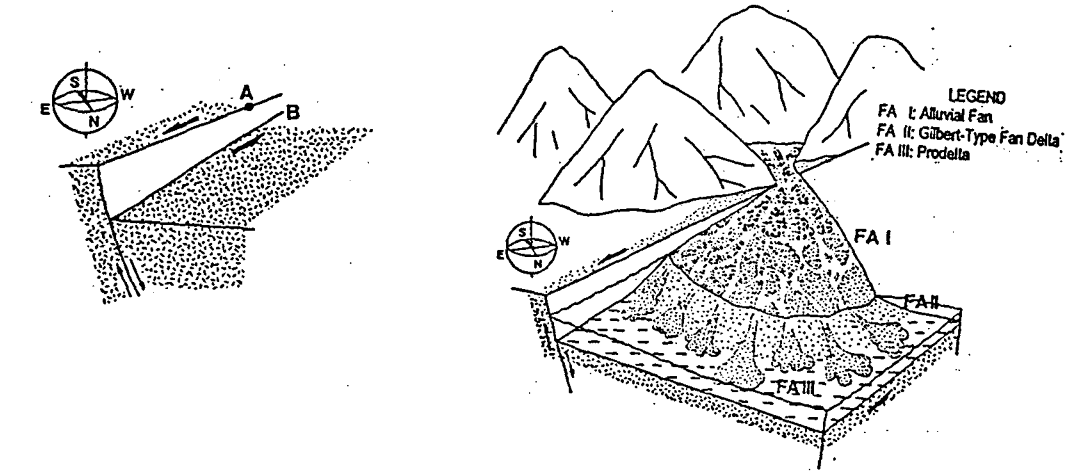
amalgamated bouldery conglomerates (Facies Gm, Gcd, and Gn) interlayered with minor reddish sandstone beds (Facies association I) (Tables 2, 4). The amalgamated conglomerates are transitional northeastward to small-scale Gilbert-type delta sequences (Facies Gcd, Gcs, Sm, and Sn: Facies association II) with thinly bedded sandstone and dark mudstone layers (Facies Sl, SMl, and Ml: Facies association III) (Tables 2, 4). The facies associations and the bed geometry of the lower part of lateral-fill sequence represent a shallow, gentle-sloped lacustrine margin, which suggests relatively low rate of vertical fault movement (Fig. 2).

The upper part of the lateral-fill sequence (ca. 1.8 km thick) is represented by large-scale, sheetlike geometry of amalgamated bouldery conglomerates (Facies Gd-1, Gd-2, and Gi) with rare sandstone and mudstone layers (Facies association A) (Tables 1, 3). The amalgamated bouldery conglomerates are transitional northeastward to pebble to cobble-grade, disorganized (Facies Gd-1) and normally graded (Gn), and crudely stratified (Facies Gcs) conglomerates with abundant interbeds of sandstone and mudstone layers (Facies association B) (Tables 1, 3). The upper part of the lateral-fill sequence is characterized by a large-scale, steep-sloped conical delta environment, lacking subaerial distributary delta plains (Fig. 2). The deep and steep-gradient environment and the lack of subaerial distributary systems are suggestive of relatively high rate of dip-slip fault movements (Fig. 2).

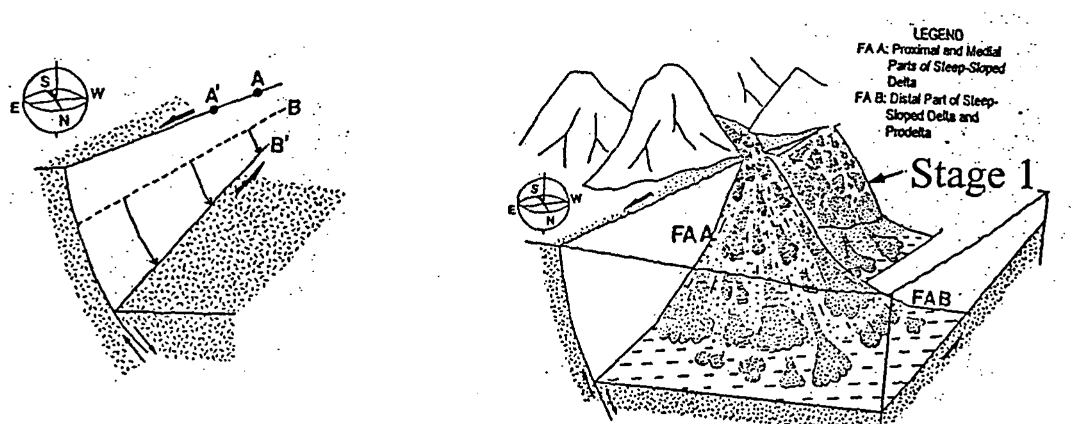
The lateral-fill sequence is characterized by northeastward overlapping and skewed stratal patterns, indicating a northeastward migration of the depocenter. The northeastward overlapping and skewed patterns reflect sinistral strike-slip movements (Fig. 2). The distribution of facies associations and the paleocurrent directions indicate that the lateral-fill sequence prograded toward the northeast, oblique to the basin margin. The consistent northeastward progradation is suggestive of northeastward basin-floor tilting caused by differential subsidence along the fault-bounded margin (Fig. 2). The sequential changes in stratal patterns and facies from the lower part to the upper part of the lateral-fill sequence suggest a northeastward basin-floor tilting which implies a higher subsidence rate (Fig. 2).

Conclusions

In the eastern part of the Jinan Basin, bouldery conglomeratic bodies can be classified into longitudinal-fill and lateral-fill sequences based on the



Lower Part of Lateral-Fill Sequence



Upper Part of Lateral-Fill Sequence

Fig. 2 Depositional settings for the lateral-fill sequence

Table 1 Description and Interpretation of sedimentary facies in the longitudinal-fill and the upper part of the lateral-fill sequence

Facies	Description	Interpretation
Disorganized conglomerate: clasts randomly oriented (Facies Gd-1)	Variable in thickness ranging from 30 to 150 cm; very poorly sorted, pebble to boulder-grade clasts; medium sand to small pebble matrix; basal inverse grading; common bouldery protruding clasts; sharp, non-erosional base; randomly oriented clast fabric; irregular, undulatory upper boundary; blunt lateral or frontal margin; wedge-shaped	Cohesionless debris flows (Enos; 1977; Shultz, 1984; Nemec & Steel, 1984)
Disorganized conglomerate: clasts oriented parallel to bedding plane (Facies Gd-2)	Very poorly to poorly sorted, pebble to cobble-grade clasts with rare boulder-grade clasts; coarse sand to granule matrix; parallel oriented clast fabric; diffuse lower and upper boundaries; laterally amalgamated; less than 30 to 40 cm thick	Cohesionless debris flows (Fisher, 1971; Nemec & Steel, 1984)
Inversely graded conglomerate (Facies Gi)	Poorly to very poorly sorted, clast-supported, pebble to boulder-grade clasts; medium sand to small pebble matrix; common boulder uptruding clasts; upward increase in clast size and matrix content; cobble to boulder-grade unit: randomly oriented or imbricated clast fabric, pebble-grade unit: parallel oriented to bedding plane; variable in thickness ranging from 20 to 70 cm; irregular, undulatory upper boundary; planar-convex geometry	Cohesionless debris flows (Middleton & Hampton, 1976; Nemec & Steel, 1984; Shultz, 1984)
Normally graded conglomerate (Facies Gn)	Poorly sorted, pebble to cobble-grade clasts; medium sand to granule matrix; normally graded; clasts either imbricated or parallel oriented to bedding plane; shallow erosional base ranging in relief from 5 to 20 cm; variable in thickness from 15 to 70 cm	Gravelly high-concentration turbidity currents or pseudoplastic debris flows (Lowe, 1982; Shultz, 1984; Surlyk, 1984)
Crudely stratified conglomerate (Facies Gcs)	Alternation of diffuse, gravel- and sand-rich layers; gravel-rich layer: clast-supported, pebble to cobble-grade clasts with medium sand to granule matrix, 5 to 15 cm thick, either randomly oriented or parallel oriented clast fabric to bedding plane; sand-rich layer: laterally discontinuous, less than 10 cm thick; variable in thickness ranging from 30 cm to 70 cm	Cohesionless debris flows, density-modified grain flows or gravelly high-concentration turbidity currents (Middleton & Hampton, 1976; Lowe,. 1979, 1982; Nemec, 1990)
Openwork gravel lens (Facies Gol)	Moderately to well-sorted, openwork cobble to boulder-grade clasts; single grain- to a few clasts-thick layer; (broad) lenticular geometry; clasts either randomly oriented or imbricated; terminated abruptly and several clasts-thick layer laterally passes into single grain-thick layer	Debris falls; several clasts-thick layer: grain-assemblage debris falls; single-grain-thick layer: single-grain debris falls (Nemec, 1990; Kim et al., 1995; Sohn et al., in press)

Facies	Description	Interpretation
Massive (gravelly) sandstone (Facies Sm)	Poorly to moderately sorted, massive medium to granular sandstone and pebbly sandstone; diffuse, discontinuous granule to pebble trains ; variable in thickness from 5 to 50 cm	Rapid suspension settling from high-and low-concentration turbidity currents with weak tractive transport (Middleton & Hampton, 1976; Lowe, 1982; Surlyk, 1984)
Stratified (gravelly) sandstone (Facies Ss)	Alternation of few-centimeters-thick granular sandstone and medium to coarse sandstone layers; individual layers: diffuse boundary; variable in thickness ranging from 15 to 50 cm; undulatory drapes over the uptruding clasts	S_1 division of high-concentration turbidity currents (Lowe, 1982); Undulatory drapes: rapid sediment fallout rate (Lowe, 1988)
Normally graded (gravelly) sandstone (Facies Sn)	Poorly to moderately sorted, medium to granular sandstone and pebbly sandstone; distributional normal grading; shallow erosional base; some diffuse, laterally discontinuous granule to pebble trains; variable in thickness ranging from 5 to 40 cm	S_3 division of high-concentration turbidity currents or T_a division of classical turbidite (Bouma, 1962; Lowe, 1982)
Inversely graded (gravelly) sandstone (Facies Si)	Poorly to moderately sorted, medium to granular sandstone and pebbly sandstone; inversely graded; less than 10 cm thick; single or repetitive units	S_2 division of high-concentration turbidity currents (Lowe, 1982, 1988)
Laminated sandstone (Facies Sl)	Moderately to well sorted, fine to coarse, horizontally laminated sandstone; individual laminae: a few millimeters to centimeters thick; 5 to 30 cm in thickness; undulatory drapes over the protruding clasts	Low-and high-concentration turbidity currents (Bouma, 1962; Chun & Chough, 1995); Undulatory drapes: rapid sediment fallout rate (Lowe, 1988)
Laminated sandstone-mudstone couplets (SMl)	Thin sandstone layers alternating with dark gray to black mudstone layers; 5 to 10 cm in thickness; each lamina: a few millimeters thick; fining- and thinning-upward trend	T_{bd} division of classical turbidite (Bouma, 1962; Chun & Chough, 1995)
Laminated mudstone (Ml)	Mostly thinner than 5 cm; each lamina: a few millimeters thick; fining- and thinning-upward trend	T_e division of classical turbidite (Bouma, 1962; Chun & Chough, 1995)
Homogeneous mudstone (Mh)	Homogeneous texture; grayish olive green (5GY 3/2) in color; less than 1 cm thick	Suspension sedimentation in subaqeous conditions (Chun & Chough, 1995)

Table .2 Description and interpretation of sedimentary facies in the lower part of the lateral-fill sequence.

Facies	Description	Interpretation
Matrix-supported, disorganized conglomerate (Facies Gm)	Matrix-supported, cobble to boulder-grade clasts (up to 2 m); silt to granule matrix; randomly oriented clast fabric; common protruding clasts; sharp, non-erosional base; reddish massive sandstone caps; tabular geometry; greater than 80 cm in thickness	Visco-plastic debris flows (Nemec & Steel, 1984; Shultz, 1984; Costa, 1988)
Clast-supported, disorganized conglomerate (Facies Gcd)	Clast-supported, pebble to boulder-grade clasts; poorly sorted, medium sand to small pebble matrix; low matrix content (<5%); either randomly oriented or imbricated clast fabric; some basal inverse grading; sharp, erosional base; reddish massive sandstone caps; variable in thickness ranging from 40 to 120 cm	Hyperconcentrated or high-magnitude flood flows (Allen, 1981; Smith, 1986; Wells & Harvey, 1987)
Normally graded conglomerate (Facies Gn)	Clast-supported, pebble to cobble-grade clasts; medium sand to granule matrix; low matrix content (<5%); normally graded; imbricated clast fabric; sharp, erosional base: scour relief ranging from 10 to 70 cm; variable in thickness ranging from 20 to 100 cm	Hyperconcentrated or high-magnitude flood flows (Allen, 1981; Smith, 1986; Wells & Harvey, 1987)
Crudely stratified conglomerate (Facies Gcs)	Alternation of gravel- and sand-rich layers; steeply inclined (15°-20°); gravel-rich layer: clast-supported, pebble to cobble-grade clasts, medium sand to granule matrix, individual layers: 10 to 20 cm in thickness, clasts oriented parallel to bedding plane, sometimes inversely graded; sand-rich layer: laterally discontinuous, less than 10 cm in thickness	Density-modified grain flows or debris avalanches (Middleton & Hampton, 1976; Lowe, 1979; Postma, 1986; Nemec, 1990)
Normally graded to stratified conglomerate (Facies Gns)	Poorly to moderately sorted; granule to pebble-grade clasts and fine to very coarse sand matrix; distributional normal grading and stratification; some basal inverse grading; sometimes imbricated, large clasts floating at the interface between the lower, pebble-rich and the upper, pebble-poor parts; variable in thickness ranging from 15 to 70 cm	Traction carpet of high-concentration turbidity currents (Postma et al., 1988; Chun & Chough, 1992)
Massive (gravelly) sandstone (Facies Sm)	Poorly sorted, massive medium to granular sandstone and pebbly sandstone; discontinuous pebble to granule trains; tabular geometry; well-defined beds; 20 to 45 cm in thickness	Rapid suspension settling from high-/low-concentration turbidity currents or subaerial sand-laden flows (Lowe, 1982; Arnott & Hand, 1989; Maizels, 1993)
Normally graded (gravelly) sandstone (Facies Sn)	Poorly to moderately sorted, medium to granular sandstone and pebbly sandstone; distributional normal grading; some diffuse, discontinuous pebble to granule trains; tabular geometry; variable in thickness ranging from 5 to 50 cm	Turbulent suspension of high-/low-concentration turbidity currents or subaerial sand-laden flows (Lowe, 1982; Smith, 1991; Maizels, 1993; Chun & Chough, 1995)
Laminated sandstone (Facies Sl)	Horizontally laminated; fine to coarse sandstone; individual laminae: a few millimeters to centimeters thick; less than 20 cm thick	T_b division of low-concentration turbidity currents (Bouma, 1962; Chun & Chough, 1995)
Laminated sandstone-mudstone couplet (Facies SMl)	Alternation of very thin sandstone layers and dark gray to black mudstone layers; individual laminae: a few millimeters thick; 5 to 10 cm in thickness	T_{bd} division of low-concentration turbidity currents (Bouma, 1962; Chun & Chough, 1995)
Laminated mudstone (Facies Ml)	Dark gray to black, laminated mudstone; individual laminae: a few millimeters thick; less than 10 cm in thickness	T_e division of low-concentration turbidity currents (Bouma, 1962; Chun & Chough, 1995)

Table 3. Characters of facies associations and depositional environments in the longitudinal-fill and the upper part of the lateral-fill sequences

Facies Association (FA)	Dominant Facies	Minor Facies	Type of Deposits	Depositional Environment
FA A	Gd-1, Gd-2, Gi, Gcs, Gn, Gol	Sm, Sn, Ss	Deposits of cohesionless debris flows/modified grain flows/high-concentration turbidity currents/debris falls	Proximal and medial parts of steep-sloped (ca. 20°) delta environments
FA B	Gd-1, Gol, Sm, Sn, Si, Ss, Sl, SMl, Ml	Gcs, Gn	Deposits of high and low-concentration turbidity currents/debris falls/cohesionless debris flows	Distal part of steep-sloped delta and prodelta environments

Table 4. Characters of facies associations and depositional environments in the lower part of the lateral-fill sequence

Facies Association (FA)	Dominant Facies	Minor Facies	Type of Deposits	Depositional Environment
FA I	Gm, Gcd, Gn	Sm, Sn	Deposits of debris flows/unconfined, hyperconcentrated flood flows	Alluvial fan
FA II	Gns, Gcs, Sm, Sn, Sl, SMl, Ml	Gn, Gcd	Deposits of high-concentration turbidity currents/modified grain flows/debris avalanches	Small-scale, Gilbert-type fan delta
FA III	Sm, Sn, Sl, SMl, Ml		Deposits of low- and high-concentration turbidity currents	Prodelta

paleocurrent directions and facies associations. The longitudinal-fill and lateral-fill sequences are characterized by successively overlapping and skewed stratal patterns toward the north and northeast, indicating sinistral strike-slip fault movements. The oblique progradation of the lateral-fill sequence to the basin margin represents a northeastward basin-floor tilting caused by differential subsidence. The sequential changes from the lower small-scale, Gilbert-type fan-delta succession to the upper large-scale, conical delta succession in the lateral-fill sequence suggest a northeastward progradation of basin-floor tilting which implies a higher subsidence rate with time. These features imply that the bouldery conglomeratic successions in the eastern part of the Jinan Basin were formed under the conditions of a northeastward increase in vertical subsidence accompanied with sinistral strike-slip movements.

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