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Channel-fill Deposits of Gravel-bed Stream, Southeastern Eumsung Basin (Cretaceous), Korea

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Abstract: Alluvial-plain deposits in the southeastern part of the Eumsung Basin (Cretaceous) are characterized by coarse-grained channel fills encased in purple siltstone beds. It represents distinct channel geometry, infill organization, and variations in facies distribution. The directions of paleocurrent, sedimentary facies changes, and channel-fill geometry can be used to reconstruct a channel network in the alluvial system developed along the southeastern margin of the basin. The channel-fill facies represent downstream changes: 1) down-sizing and well-sorting in clast and martix of channel fills and 2) internal organization of scour fill or gravel lag and overlying cross-stratified, planar-stratified beds. These findings suggest multiple stages of channel-filling processes according to flooding and subsequent stream flows. In the small-scale pull-apart Eumsung Basin (~7×33 km^2 in area), vertical-stacked alluvial architecture of the coarse-grained channel fills encased in purple siltstone is expected to result from episodic channel shifting under a rapidly subsiding setting.

Keywords: channel fills, gravel-bed stream, pull-apart basin, Cretaceous, Eumsung Basin

Introduction

Reconstruction of a formative system in an alluvial succession starts with an analysis of channel-fill deposits and their stacking patterns (e.g., Allen, 1983; Ramos et al., 1986; Marzo et al., 1988; Holbrook et al., 2006). Coarse-grained channel sediments are apt to be preserved in stratigraphic records, but their incorporation into sedimentary sequences within a basin depends largely on a complex interaction between the mode of channel shifting, subsequent erosion and filling by following streams, and the rate of aggradation and/or subsidence (Brierley, 1996). Internal organization within channel fills thus reflects sequential formation of bedforms/scour surfaces and local rate of aggradation where the channels form. On the other hand, the resultant external organization of the channel-fill units can be interpreted in terms of the variables of aggradation rate, avulsion frequency, and channel migration (Bristow and Best, 1993).

In alluvial deposits, an integral reconstruction of alluvial channels demands three-dimensional outcrops for spatial distribution of facies and paleocurrent direction (Bridge, 1985; Miall, 1985). Alluvial-plain deposits in the southeastern part of the Eumsung Basin (Cretaceous) (Figs. 1, 2) are characterized by conglomeratic and pebbly sandstone channel fills in purple siltstone beds (Ryang and Chough, 1997). It represents distinct channel geometry and variations in facies distribution (Figs. 2, 3). In addition, three-dimensional sections along the southeastern basin margin provide rare opportunities for the study of channel-filling processes in alluvial gravel-bed streams. This study may help understand factors that control downstream-changing alluvial channels in a small-scale strike-slip basin.

Geological Setting

In the southwestern Korean Peninsula, Cretaceous nonmarine basins were formed along a series of strike-slip faults trending NE-SW (inset in Fig. 1; Chough et al., 2000). The Kongju and Kwangju fault systems are characteristic of normal and en echelon patterns with high-angle transtensional faults. The Kongju faults were activated by sinistral strike-slip

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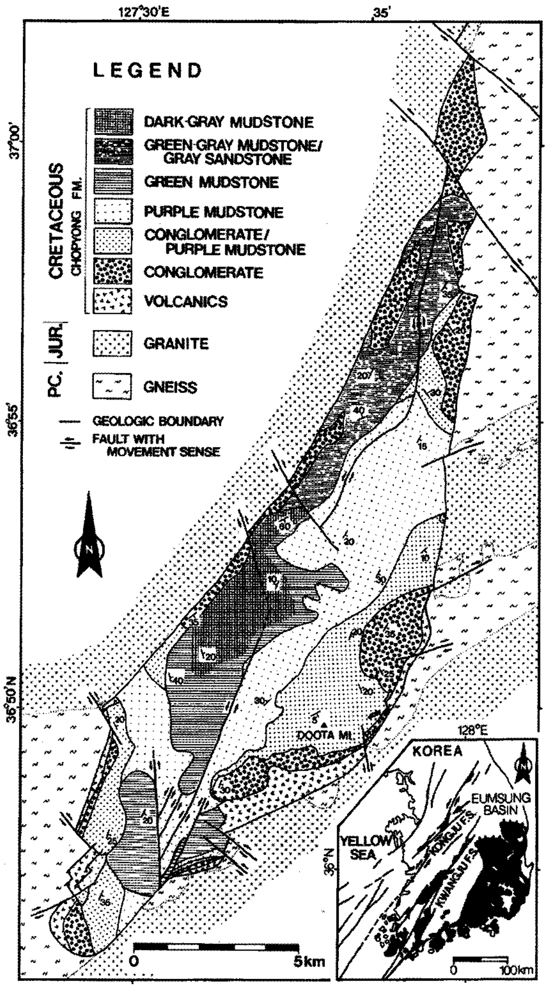

Fig. 1. Geologic map of the Eumsung Basin (1 : 50,000). Inset represents distribution of Cretaceous basins and fault pattern in the Korean Peninsula (modified after KIER, 1984; Chun and Chough, 1992; Baag and Baag, 1994; Kim and Kee, 1994; Choi, 1996). Solid arrow indicates the Eumsung Basin.

movements in the Late Jurassic to the Cretaceous, forming small-scale rhomboidal basins (Chun and Chough, 1992; Cluzel, 1992). These elongated basins were filled with alluvial to lacustrine sediments during the Early to Late Cretaceous, controlled by left-lateral strike-slip faults (Lee and Paik, 1990; Kim, 1996; Kim et al., 2003).

The rhomb-shaped Eumsung Basin (~7 × 33 km^2 in area), located within the Kongju fault system (Fig. 1), is bounded by two left-stepping sinistral master faults which are in contact with foliated cataclasite, microbreccia, and mylonite in the basin margin (Precambrian gneiss and Jurassic granite) (Fig. 1; Chun et al., 1994; Choi, 1996). An analysis of mylonitic foliation and minor fault orientations suggests that the major faults have attitudes of N13°E/82°W in the eastern part and N38°E/75°E in the western part (Cheong, 1987), indicating strike-slip or high-angle normal faults bordering the basin margin. The Eumsung Basin contains the Cretaceous Chopyong Formation (>8 km thick), consisting of seven lithologic units: volcanics (including andesite, basalt, and tuffaceous sediments), conglomerate, conglomerate/purple mudstone, purple mudstone, green mudstone, green-gray mudstone/gray sandstone, and dark-gray mudstone (Ryang, 1998; Fig. 1). The coarse-grained deposits contain clasts of granite, granitic gneiss, and banded gneiss derived from the basement, and volcaniclasts from the calc-alkaline volcanic rocks along the basin margin (Figs. 1, 2; Lee et al., 1992).

Ripple marks and calcareous nodules are present in the dark-gray mudstone, and desiccation cracks and calcareous nodules are present in the purple siltstone. According to Song et al. (1990) and Chun et al. (1994), the various fossil assemblages of plants (Conifers and Ginkgoales), invertebrates (estherids), and microfossils (charophyta) are suggestive of a temperate climate and a fresh-water lacustrine environment. In the southern part of the basin, charophyta fossils in the green mudstone were dated as Hauterivian-Aptian age (Choi et al., 1995).

In the southeastern part of the Eumsung Basin, the coarse-grained deposits are present along the basin margin, which are divisible into two sequences: the lower Dootasan and the upper Berjae sequences (Ryang and Chough, 1997). The former is characterized by a basinward change from debris-flow-dominated alluvial-fan deposits to channel fills in the alluvial plain, whereas the latter is dominated by stream-dominated alluvial-fan to alluvial-fan-fringe and alluvial-plain deposits (Ryang, 1998). Floodplain in alluvial plain was developed in the vicinity of the basin margins where crevasse splay and avulsion processes

Table 1. Description of sedimentary facies and inferred depositional processes

Facies Type	Description	Interpretation
Conglomerate encased in siltstone (CE)	Present in hollows of purple or green (pebbly) siltstone; generally thick (up to several meters); ribbon-shaped or sheetlike geometry; sharp, erosional base and relatively diffuse upper boundary; amalgamated with pebbly sandstone; disorganized, clast-supported in the lower part of hollows; crudely stratified or low-angle cross-stratified, matrix-rich in the upper part of hollows; very coarse to coarse sandstone matrix; occasionally inversely-to-normally graded; partly open-work fabric; pebble- to cobble-size clasts; parallel-oriented elongate clasts [a(t)]; partly imbricated [a(t), b(i)]	Water flood and subsequent stream flow; coarse-grained deposits-channel lag or entrapment in scoured hollows; fine grains-rapid settling from overflow
Stratified pebbly sandstone encased in siltstone (PSE2)	Present in hollows of purple siltstone; sheetlike geometry; variable in thickness (up to 2 m); indistinctly stratified or cross-stratified pebbly sandstone; poorly to well sorted very coarse to medium sand matrix; conglomerate or pebbly sandstone layers commonly forms discontinuous stringers or patches	Unconfined high-concentration flow and subsequent stream flow
Pebbly siltstone (PZ)	Variable in thickness (decimeters to several meters); poorly sorted; disorganized and partly stratified; randomly dispersed clasts; includes sandstone stringers, isolated pebbly sandstone lenticles; gravel patches and trains	Muddy debris flow; rapid fall-out deposition from high-concentration flow
Purple sandy siltstone (Zp)	Purple (5R 3/4); ubiquitous facies; generally thick (a few meters); poorly sorted; common inclusion of granules and sand grains; some calcareous nodules and sand-filled desiccation cracks	Rapid fall-out deposition of fine grains from tractive overflow on floodplain; oxidizing condition during and after deposition
Green sandy siltstone (Zg)	Green (10G 4/2); thin to very thick (decimeters to a few meters); common inclusion of dispersed granules and sand grains	Rapid settling of suspended grains below water level in pond or lake; reduction condition during and after deposition

were operative (Rhee et al., 1993). The main characteristics of each facies are briefly described and interpreted in Table 1 (Ryang, 1998).

Depositional Facies and Environments

This study is concerned with the Dootasan Sequence in the southeastern part of the basin. According to the paleocurrent data of three-dimensional exposures, clast size, and composition, the Dootasan Sequence was largely derived from the southeastern margin where calc-alkaline volcanics are present along the basin margin (Fig. 2). The consistent paleocurrent directions also suggest that distributary channel systems persisted toward the north and northeast [014°~067° in Fig. 2], representing a basinward change from the proximal channel-fill facies to the distal. Based on facies occurrence and comprising clast size, the basin-fill sequence is divisible into 3 lithofacies: 1) conglomerate channel fills (proximal alluvial plain); 2) pebbly sandstone channel fills (distal alluvial plain); and 3) fine-grained sediments (floodplain and lake).

Lithofacies 1: Conglomerate channel fills (proximal alluvial plain)

Description: This facies is represented by relatively coarse-grained (mainly pebble size) channel-fill deposits (Facies CE), encased in purple siltstone of Lithofacies 3 (Facies PZ, Zp). Most channel bodies represent complete-fill sequences of gravel or gravelly sand, well preserved in purple siltstone beds. There is no case of partial or mud-filled hollows (e.g., Jones, 1992; Kraus and Davies-Vollum, 2004). The complete channel fills can be explained as two types, distinguishable on the basis of the boundary condition of channel body encased in fine-grained sediments.

(i) Type 1 is characterized by partly distinct but mostly diffuse or irregular channel boundaries in purple pebbly siltstones (Facies PZ). Most clasts are angular or subangular, pebble-to-cobble grade, and of

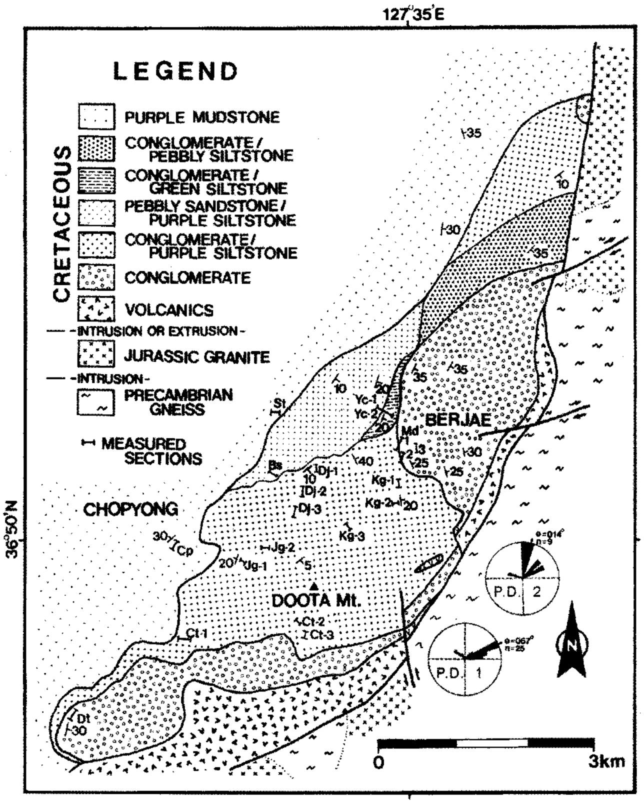

Fig. 2. Lithofacies and location map of the southeastern part of the basin (1:25,000). Measured locations are indicated. Rose diagram shows dominant paleoflow directions (P.D.) measured from channel exposures (P.D. 1: sections of Dj and Bs; P.D. 2: sections of Yc and Md; θ = dominant vector mean, n = number of readings).

volcanic origin (>70%). Channel-fill units generally occur in poorly sorted coarse-grained deposits near the basin margin (subsections Ct-2, 3, Kg-3; for location, see Fig. 2). In section of Kg-3, the asymmetric hollow in the lower part is stuffed with clast-supported and disorganized conglomerates with relatively distinct base. Whereas, upwardly widening upper part of the hollow is bounded by laterally diffuse and irregular boundaries and is overlain by crudely low-angle (<20°) cross-stratified conglomerate units (Fig. 4). These sequentially filled units are separated by thin (<10 cm) siltstone layers or openwork pebble trains. Openwork pebble lenticles and disorganized conglomerate beds with diffuse boundaries are present in purple gravelly siltstone.

(ii) Type 2 is characteristic of thick (3-8 m) and wide (50-150 m), sheetlike or ribbon-shaped channel-fill deposits with distinct bounding surfaces, encased in purple sandy siltstone (Facies Zp). The encased channels are bounded by erosional bases and relatively diffuse tops. Conglomeratic fills are generally accumulated by alternating decimeter units of clast-supported, disorganized conglomerates and matrix-rich, cross- or parallel-stratified conglomerates. In parallel sections, most complete channel fills are initiated by disorganized conglomerate unit with a sharp base in the lower part, overlain by parallel-stratified unit, followed by cross-stratified unit, and finished by parallel laminated fine sands (Fig. 5). Occasionally, inclined-filled conglomerate unit is overlain by crudely stratified units (Fig. 5). Fining-upward units are often present in conglomerate fills (Fig. 5). Decimeter-deep load casts with erosional base are also present on the channel bottom. In transverse sections, channels generally show inclined hollow-fill pattern and amalgamated alternating units of clast-supported,

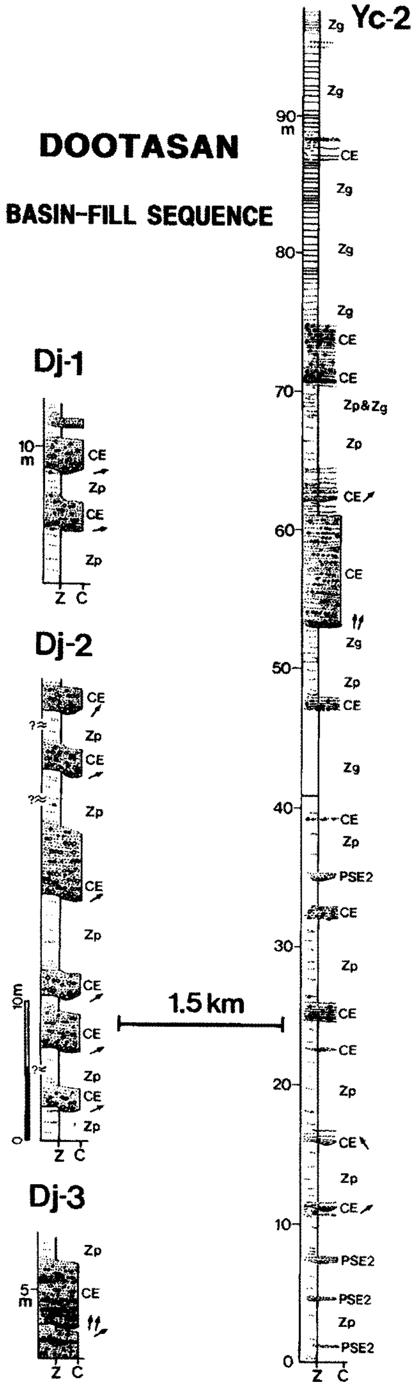

Fig. 3. Measured stratigraphic section (Z, siltstone; C, conglomerate) (Ryang and Chough, 1997). Section locations are shown in Fig. 2 and thickness is in meters. Paleoflow directions are synthesized in rose diagrams of Fig. 2 and north is towards the top of the figure. Note lateral facies transition from section Dj to section Yc. Lateral distance from Dj to Yc is ~1.5 km.

disorganized conglomerates and crudely stratified gravelly sandstones. Paleoflow directions obtained from the channel wall and axis are persistent but skewed along the basin margin (P.D. 1 in Fig. 2).

Interpretation: The conglomerate fills were probably formed by multiple stage deposition such as scour fill or gravel lag by flooding and subsequent infilling by stream flows. The presence of lateral grain-size variation, coarse-grained openwork fabric, and the upward-fining of the hollow fills can be explained by deposition from waning floods and subsequent reworking/winnowing by stream flows.

Conglomerate channel fills in pebbly siltstone (Type 1) are indicative of tributary channels, based on irregular channel boundaries, poorly organized fills, poorly sorted matrix, and relatively abundant composition of angular volcanic clasts. The scour-fills with sharp bases, poor sorting, and limited extent of the beds are suggestive of short-distance transport and erosion/deposition from ephemeral flows rather than perennial flows (Bridge, 1984).

Channel fills in purple siltstone (Type 2) are suggestive of trunk channels. The presence of cut-and-fill structure with erosional base, poorly- to moderately-sorted sand matrix and the dominant stratification indicate that these deposits were formed by flooding during peak discharge and channelized stream flows. The lower part of the channel fills is commonly characterized by disorganized conglomerate bodies which are usually overlain by (cross-) stratified conglomerates. These channel fills were probably formed by multiple stage deposition such as scour fill or gravel lag by flooding and subsequent infilling by stream flows. Ribbon or sheet conglomerate bodies with irregular bases are indicative of scouring by turbulent flows and subsequent filling (Allen, 1962).

Lithofacies 2: Pebbly sandstone channel fills (distal alluvial plain)

Description: These channel fills are representative of relatively thin (mostly less than 2 m thick), stratified pebbly sandstone deposits, largely forming

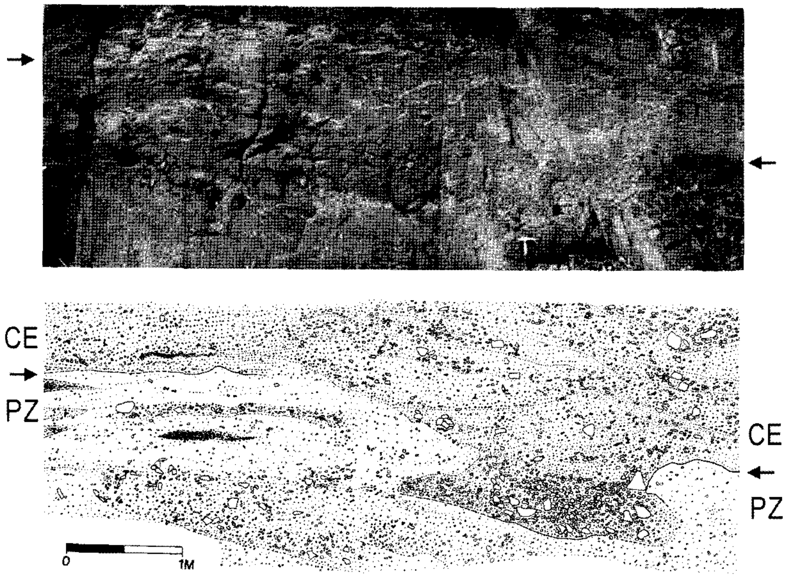

Fig. 4. Photograph and sketch of conglomerate channel fills and dispersed gravel lenticles in subsection Kg-3 (for location, see Fig. 2). Note the irregular base of overlying channel fills and inclined channel-filling pattern of conglomerates and pebbly sandstones. Paleocurrent directions inferred from channel walls are 350°~355°. Most clasts are basalt/andesite (76%) with minor amounts of granite/gneiss (19%), based on clast counting data.

sheets encased in purple siltstone (Facies PSE2; Fig. 6). It comprises multiple storey bodies, bounded by a planar or concave-up base and flat top. Hollow with wings is symmetrically filled with stratified pebbly sandstone, upward widen to sheet geometry. There are some discontinuous sheets or lenticular beds (a few decimeters thick) and laterally either terminates abruptly or wedges out. These persistent, multi-storey units are repeated with an interval of 5 -10 m in a succession, forming cycles together with thin units (Facies PSE2 and PZ; Fig. 6).

Interpretation: The sheetlike geometry is indicative of less confined ephemeral flows. Some symmetrically scoured hollows suggest that the channels acted as distributive or crevasse-splay channel systems. The discontinuous coarse-grained beds may be emplaced by overflows without significant scour, probably due to the lack of channel confinement (Rhee et al., 1993). The single-storey units show a fining-upward trend, which suggests deposition from ephemeral flows during episodic events (e.g., storm or flood) (Allen, 1981). Based on the external form, scale, and interchannel organization, the hollow deposit is interpreted as crevasse-splay fill. The sharp-based, sheetlike beds are interpreted as crevasse splays formed from episodic, unconfined waning flood events. The small-scale individual crevasse splays with irregular base were formed by sudden influxes of sediment-laden floodwater, and the upward-fining of a single unit is characteristic of waning flow during deposition (Guion, 1984). The isolated small-scale pebbly sandstone lenticles are interpreted as overbank deposits by flash flooding (Costa, 1974; Ritter, 1975; Stene, 1980). Away from the trunk channel, the distributive flow became semi-confined or unconfined, forming sheetlike coarse-grained beds. These basinward facies changes represent genetic- or process-related deposition from basin-margin trunk stream to basinward distributary stream (e.g., Marzo et al., 1988).

Lithofacies 3: fine-grained deposits (floodplain and lake)

Description: This facies is represented by purple siltstone (Facies Zp) and green-gray mudstone (Facies

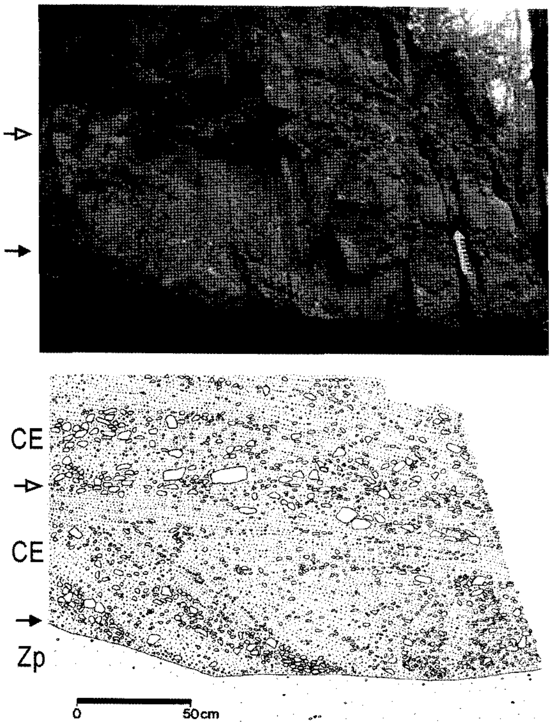

Fig. 5. Conglomerate-dominated channel fills encased in purple siltstone beds crop out at three-dimensional sections of Dj-2 (for location, see Fig. 2). This shows a parallel section (065°) of conglomerate channel fills. Note sharp bases (solid arrows) and cross-bedded channel fills of conglomerate on purple siltstone bed. Note inclined channel-fill deposits on scoured purple sandy siltstone beds and upward change to relatively low depositional angle on relatively parallel scour surface (open arrow). Photograph of two fining-upward channel-fill units (solid and open arrows) within one channel-fill deposit. Scale is 20 cm long.

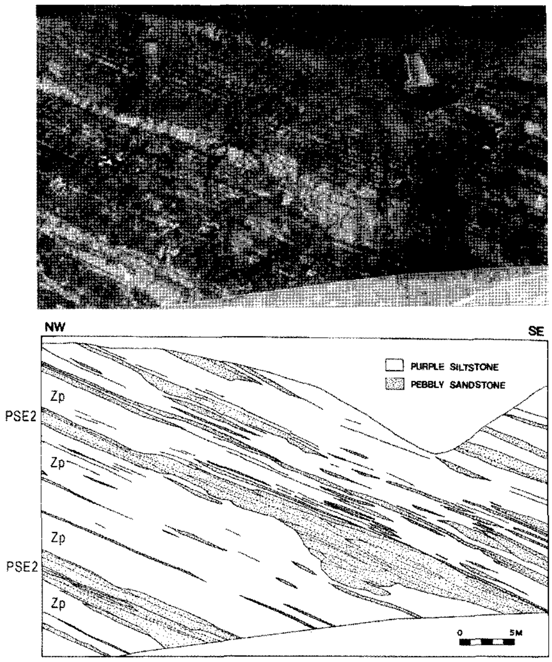

Fig. 6. Photograph and sketch of the uppermost part of the Dootasan Sequence (Subsection Yc-1; for location, see Figure 2). Alternating facies of pebbly sandstone (Facies PSE2) and purple siltstone (Facies Zp) is transitional upward to facies of conglomerate (Facies CE1, 2) and green siltstone (Facies Zg). Pebbly sandstone body is encased in purple siltstone beds and hollows are filled with multi-story units. A person in photograph is for scale.

Zg). There are no mature paleosols. The fine-grained deposits mainly comprise poorly-sorted purple sandy siltstone, it commonly contains dispersed gravels and gravel patches. The poorly sorted purple sandy siltstone includes some calcareous nodules and desiccation cracks.

Interpretation: Purple siltstone are indicative of subaerial exposure. Green-gray mudstone were formed in subaqueous lacustrine environments when small-scale lake was formed or base level rose toward the basin margin. In the basin margin, this association (a few meters thick) of purple siltstone and green siltstone (section Yc-2; Figs. 2, 3), forming proximal to distal alluvial deposits. Toward the basin center, the development of green or dark gray mudstone facies is indicative of deposition from alluvial plain transitional to lacustrine environments (Fig. 1).

Channel Pattern and Alluvial System

In the Cretaceous Eumsung Basin, the southeastern part is characterized by abundant conglomeratic channel fills in proximal part and pebbly sandstone channel fills in distal part of alluvial systems. The directions of paleocurrent, sedimentary facies changes, and channel-fill geometry can reconstruct a channel network in the alluvial system developed along the southeastern margin of the basin (Fig. 7). The

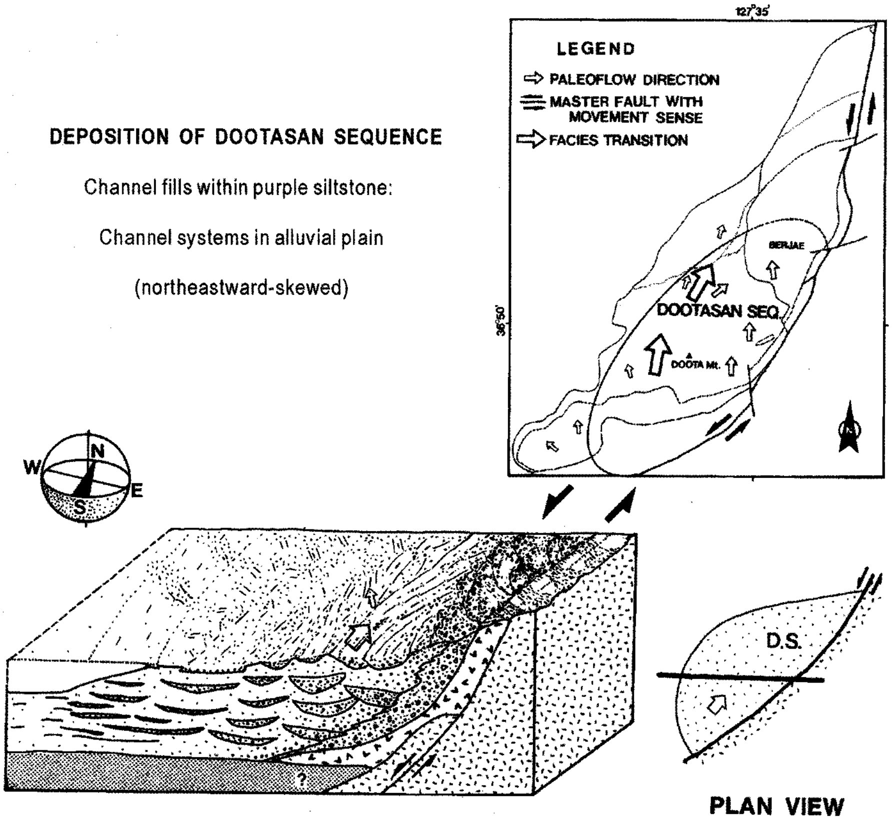

Fig. 7. Depositional model for downstream channel changes of alluvial systems in the Dootasan Sequence, southeastern Eumsung Basin (Cretaceous). Half solid arrows indicate transtensional faulting with left-slip motion. Open arrows show the dominant directions of sediment transport on the basis of facies transition and paleocurrent data.

downstream changes show a trend of down-sizing and well-sorting in clast and martix of channel fills. Internal organization represents scour fill or gravel lag at the bottom of channel fills, overlying cross-stratified beds, and planar-stratified beds in the upper part. These suggest multiple stages of channel-filling processes according to flooding and subsequent stream flows. The fining-upward sequences of conglomerate fills encased in purple siltstone are interpretative of channel shifting and abandonment (Allen, 1981).

In the study area, the sequences are characteristic of vertical-stacked channel fills encased in purple siltstone, whereas lateral-accreted hollow fills are not found frequently. Bentham et al. (1993) emphasized that architectural organizations of braided channel fills contained in thick overbank deposits are formed by rapid aggradation rate and frequent avulsion within an unconfined basin. Avulsion in a rapidly aggrading setting can be a dominant long-term influence on channel evolution and basin-fill architecture (Richards et al., 1993). Recent theoretical studies on channel-stacking patterns in alluvial suite suggest that downstream changes in alluvial architecture are dominantly affected by basin subsidence (Mackey and Bridge, 1995) or tilting due to faulting (Heller and Paola, 1996).

The basin filling in a strike-slip setting is variable through time and space, depending on the complex interplay of structural, depositional, climatic, and paleogeographic controls (Woodcock and Schubert, 1994; Nilsen and Sylvester, 1995). In small-scale strike-slip basins of a transtensional regime, depositional styles of alluvial/lacustrine systems are generally in response to fault activity and displacement (Mann et al., 1983; Dunne and Hempton, 1984). The fault movement with strike-slip motion results in longitudinal and lateral basin asymmetry, episodic rapid subsidence, abrupt lateral facies changes, and local unconformities (Christie-Blick and Biddle, 1985). The depocenter migration was due to the sinistral strike-slip fault movement and provided variations in mountain valley front and catchment area of the source rock along the basin margin (Ryang and Chough, 1997; Fig. 7). In the southeastern part of the Cretaceous Eumsung Basin, the coarse-grained channel fills encased in purple siltstone most likely resulted from episodic channel shifting under a rapidly subsiding setting.

Conclusions

1. In the Dootasan Sequence of the Cretaceous Eumsung Basin, the channel-fill facies represent a basinward and downstream change from conglomeratic to pebbly sandstone infill facies on the basis of paleocurrent data.

2. The sequential internal organization of scour fill or gravel lag at the bottom of channel fills, overlying cross-stratified beds, and planar-stratified beds in the upper part reflects multiple stages of channel cut-and-fill processes according to flooding and subsequent stream flows.

3. Vertical-stacked alluvial architecture of the coarse-grained channel fills encased in purple siltstone most likely resulted from episodic channel shifting under a rapidly subsiding setting.

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