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STRATIGRAPHIC ARCHITECTURE OF FLUVIAL SEQUENCES IN THE NORTHWESTERN PART OF KYONGSANG BASIN

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ABSTRACT

The northwestern part of Kyongsang Basin largely comprises interbedded sandstone and mudstone with local conglomeratic deposits in the basin margin, representing marginal alluvial fans and fluvial depositional environments. The non-marine successions are divided into successive stratigraphic units, each of which is unique in facies assemblages and architecture of sandstone bodies. Two stratigraphic units, i.e., Sinpyong-Anpyong and Jotap units are examined in terms of stratigraphic architecture and its causative processes. Detailed architectural analysis reveals that the channel systems of Sinpyong-Anyong unit were of braided patterns, whereas those of Jotap unit were dominated by small-scale bedforms. The difference in fluvial styles can be attributed to the changes in amount and caliber of sediment load and water discharge, which might have been ultimately governed by basin tectonics, climate, and base level. Along with the marked change in fluvial style, the two successive units show repeated expansions of distal, water-logged floodplains and lacustrine facies in the basal and uppermost parts of Sinpyong-Anpyong unit, where the proportion of channel sandstone bodies is relatively low. These stratigraphic intervals are succeeded by the sequences with proximal, well-drained floodplain facies and relatively coarser-grained channel sandstone bodies of higher proportion, reflecting the progradation of proximal systems (the middle part of Sinpyong-Anpyong unit and Jotap unit). The overall stratigraphic architecture can be ascribed to the fluctuations in accommodation space and sediment supply induced by repeated basin subsidence.

INTRODUCTION

Stratigraphic architecture of alluvial strata has been given much attention with growing interest in the application of sequence stratigraphic concept to non-marine settings (e.g., Shanley *et al.*, 1992, Shanley and McCabe, 1994; Wright and Marriott, 1993; Aitken and Flint, 1995; Legarreta and Uliana, 1998; Robinson and McCabe, 1998; Martinsen *et al.*, 1999). Such sequence stratigraphic approaches have provided a new framework for resolving fluvial sequences and their causative processes. Successful applications, however, appear to be limited to coastal environments or distal fluvial systems where sea level has a direct influence on depositional systems. In proximal systems far from the influence of sea level, the development of sequences may be different from that predicted by sea-level control alone, as hinterland effects (tectonism and climate) are expected to have a significant role on non-marine sedimentation (Schumm, 1993; Blum, 1994; Shanley and McCabe, 1994; Ethridge *et al.*, 1998). Furthermore, closed non-marine settings have no relation with the contemporary sea level. In such depositional settings, stratigraphic architecture is relatively poorly known, particularly in the standpoint of accommodation space and sediment supply and their variations in relation to controlling factors.

In the northwestern part of Kyongsang Basin, alluvial successions are divided into successive stratigraphic units, each of which is unique in architecture of sandstone bodies (Fig. 1). The stratigraphic positions of marked changes in alluvial architecture are consistent with abrupt lithologic changes such as extensive deposition of conglomerate and dark mudstone beds. These overall features are suggestive of a primary control by basin tectonics (Rhee *et al.*, 1998). The development of alluvial sequences, however, has not been systematically explained in terms of accommodation space and sediment supply. In this study, two stratigraphic units (Sinpyong-Anpyong and Jotap units) are defined and their stratigraphic architecture is examined in terms of proportion and connectedness of channel deposits and the regional distribution of fine-grained facies. These data are analyzed for the extrinsic controls on non-marine sedimentation, highlighting the role of basin subsidence in regulating accommodation space and sediment supply.

ALLUVIAL SUCCESSIONS IN THE NORTHWESTERN PART OF KYONGSANG BASIN

The alluvial successions in the northwestern part of the Kyongsang Basin comprise conglomerate, gravelly sandstone, sandstone, and mudstone. Conglomeratic deposits occur locally along the northern basin margin and pass southward into interbedded sandstone and mudstone (Fig. 1). The successions can be divided into four discontinuity-bounded stratigraphic units, which are comparable to allostratigraphic units (Rhee *et al.*, 1998). Individual stratigraphic unit consists of basin-margin cong-

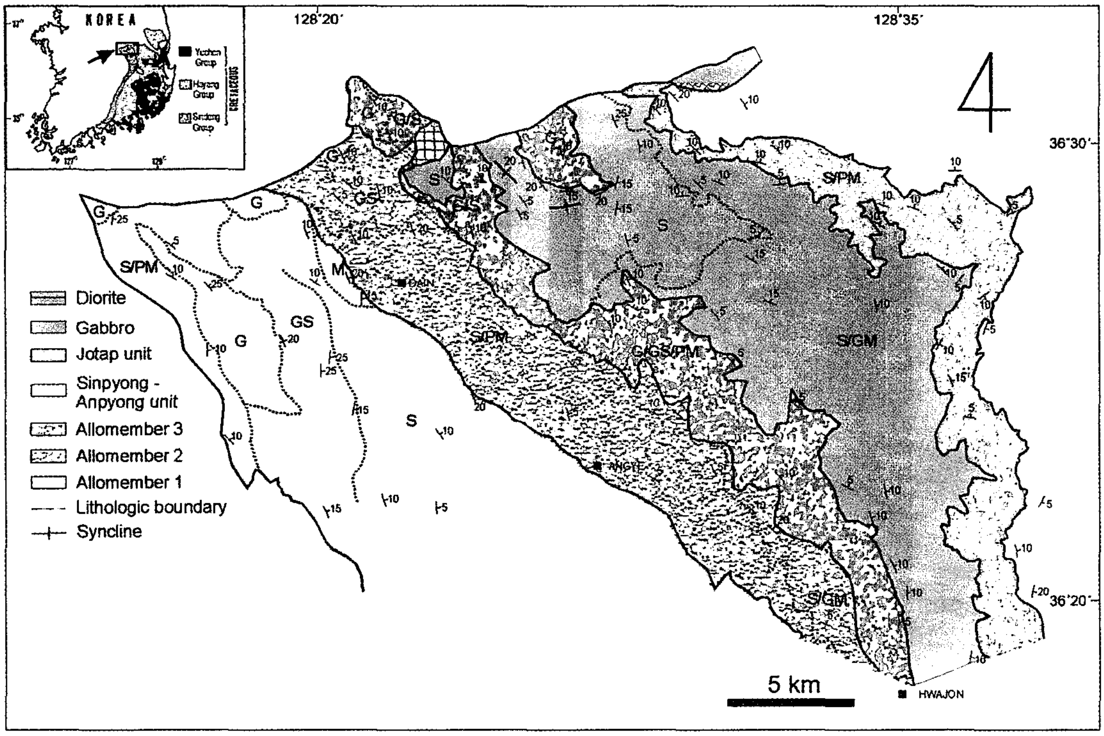

Fig. 1. Lithologic map of the northwestern part of Kyongsang Basin. Allomembers (1, 2, and 3) were defined by Rhee et al. (1998). G=conglomerate, G/S= conglomerate/sandstone, GS=gravelly sandstone, S=sandstone, S/PM= sandstone/ purple mudstone, S/GM=sandstone/gray mudstone, M=mudstone.

lomeratic deposits and interbedded sandstone and mudstone to the south, reflecting genetically linked depositional systems of alluvial fans in the northern basin margin and fluvial channels and floodplains in the southeast. The fluvial deposits show considerable variations in architecture of sandstone bodies across the stratigraphic discontinuities, reflecting significant changes in river styles (Rhee *et al.*, 1998). These variations in fluvial styles can be ascribed to changes in basin subsidence.

In this study, two stratigraphic units, i.e., Sinpyong-Anpyong and Jotap units were additionally defined, following the criteria adopted by Rhee *et al.* (1998) (Fig. 1). The two units correspond to Chinju Formation and the lower part of Ilchik Formation, respectively. The Sinpyong-Anpyong unit is demarcated by gray mudstone beds in its basal part from the underlying unit. The northwestern part of Sinpyong-Anpyong unit largely comprises sandstone and associated gray and purple mudstones with increasing amounts of conglomerate and gravelly sandstone toward the northern basin margin. In the southeastern part, the unit consists of sandstone and gray mudstone. The Jotap unit comprises sandstone and purple mudstone. It is differentiated from the underlying unit (Sinpyong-Anpyong unit) by purple mudstone. The Jotap unit includes gravelly sandstone in the northwestern part.

SINPYONG-ANPYONG UNIT

The deposits of Sinpyong-Anpyong unit are classified into three major components based on lithology: thick sandstone body, thin sandstone body, and mudstone-dominated body. Thick sandstone bodies (> 2 m in thickness) mainly consist of coarse to very coarse sandstone with subordinate conglomerate. Individual body rests on an erosional surface and shows sheet geometry, extending laterally for more than hundreds of meters. The sandstone bodies comprise assemblages of architectural elements with a considerable variation in element assemblages from body to body. The constituent elements are organized into a number of groups that are bounded by laterally persistent, erosional surfaces. A group or vertically stacked groups of elements (1-5 groups) form a sandstone body. Each element group largely comprises laterally superposed, architectual elements with finer-grained and flat bedded, uppermost part. The thick sandstone bodies are interpreted as deposits of major channels or channel belts, because constituent architectural elements are indicative of various within-channel morphologic units. Each group of elements most likely represents individual channel belt. Within individual channel-belt deposit, assemblages of elements reflect superposition of bars and channels. The fining-upward trend indicates decrease in flow velocity as the channels and bars are gradually abandoned. The channels were probably of braided patterns, which is supported by large numbers of laterally superposed elements (channels and bars) within a channel-belt deposit, relatively short distance of lateral accretion, the presence of mid-channel bar deposits, and coarse grain size (Friend *et al.* 1979; Allen, 1983; Bridge, 1993, Willis, 1993). Measurements of paleocurrents are indicative of southward- or southeastward-draining channel systems.

Thin sandstone bodies consist of fine to coarse sandstone (dominantly medium-grained) which are massive, horizontally stratified/laminated, and cross-laminated. Individual bodies are generally less than 2 m thick and sheet-like, extending for tens of meters. Constituent beds are flat and commonly organized into fining-upward bedsets. In some cases, burrows and calcareous nodules are present. This sandstone bodies are interpreted as deposits of crevasse splays on the basis of the sheet geometry and stratal patterns. Burrows and calcareous nodules were likely formed during the periods of non-deposition. Mudstone-dominated body mainly consists of massive and laminated mudstones with thin beds of very fine to fine sandstone. Individual bodies are decimeters to a few tens of meters thick and extend laterally for hundreds of meters to kilometers. The mudstone is dominantly gray in color, but commonly purple in the northern (proximal) part. Calcareous nodules are commonly present in these bodies. In some cases, laminated limestone beds and stromatolite are associated with gray mudstone beds. Burrows are also commonly present. The laminated gray mudstone is indicative of low-energy and reducing conditions, deposited in water-logged floodplains and ponded water (shallow lakes). The presence of stromatolites, abundant calcareous nodules, and symmetrical ripples is also suggestive of shallow lacustrine environments (Platt, 1989; Platt and Wright, 1991). The purple siltstone is interpreted as the deposits of well-drained floodplains of an oxidizing condition. The differential distribution of gray and purple mudstones suggests that the floodplains in the distal part were poorly drained with shallow lakes, whereas those in the proximal part were commonly of well-drained condition.

JOTAP UNIT

The deposits of Jotap unit can be divided into three components based on lithology: thick sandstone body, interbedded sandstone/siltstone body, and siltstone-dominated body. Thick sandstone bodies mainly consist of coarse to very coarse sandstone and subordinate gravelly sandstone and conglomerate. Individual body is 2 to 10 m thick and extends laterally for tens to hundreds of meters, mostly showing a sheet geometry. The sheet bodies rest on a generally flat but erosional base with large-scale hollows (> 1.7 m deep). In laterally extensive sections, some sheet bodies show steep margins and pass laterally into thin sandstones. Some bodies are ribbon-shaped with a relatively high thickness/width ratio (> 1/15). The sandstone bodies comprise assemblages of architectural elements, which are organized into element groups. Most sandstone bodies consist of 1-2 groups of elements. The element groups largely consist of trough cross-stratified and horizontally stratified sets. Measurements of axes of trough cross-strata indicate an overall paleocurrent direction to the east and southeast. The thick sandstone bodies are interpreted as the deposits of major channels or channel belts for the reason that the constituent architectural elements are indicative of within-channel processes. Within a sandstone body, each element group probably represents individual channel or channel belt. The channels might have been covered dominantly by 3-dimensional dunes and upper-flow-regime plane beds.
Interbedded sandstone/siltstone bodies mainly comprise thin sandstones interbedded with purple siltstone. The sandstone units are fine- to very coarse-grained and comprise massive, trough cross-laminated, and horizontally laminated beds. Individual sandstone unit is decimeters to 2 m thick and either sheet-like or lenticular.

Some sheet sandstone units are laterally transitional to thick sandstone bodies, forming wings of thick bodies. The purple siltstone units are crudely bedded. Individual beds are dominantly massive with partly crude lamination. Burrows are commonly present. Calcareous nodules are present in some units. The interbedded sandstone/siltstone body is interpreted as deposits of floodplains adjacent to major channels, i.e., proximal floodplains, where sand-size sediment is frequently supplied by crevasse and overbank flows (McCarthy *et al.*, 1997; Khan *et al.*, 1997). The thin, sheet sandstone units probably represent crevasse splays and sand sheets on floodplains and levees of major channels. The lenticular sandstone units are suggestive of crevasse channels or small channels on floodplains. The siltstone units might have been deposited by low-velocity overbank flows. Siltstone-dominated body mostly consists of purple, massive siltstone and very fine to fine sandstone. Individual body is a few to several meters thick and extends laterally for hundreds of meters. Calcareous nodules are present in some bodies. Burrows are commonly present. Some bodies include a few, thin sandstone units. This body is interpreted as deposits of floodplains far away from the major channels, i.e., distal floodplains (McCarthy *et al.*, 1997; Khan *et al.*, 1997). The purple color of the siltstone and very fine sandstone is suggestive of well-drained, oxidizing conditions of the floodplains (Turner, 1974).

STRATIGRAPHIC ARCHITECTURE

Along with the marked changes in fluvial styles from Sinpyong-Anpyong to Jotap units, floodplain and shallow lacustrine facies also show stratigraphic variations in regional distribution in harmony with the variations in proportion and connectedness of sandstone bodies (Fig. 2). The basal part of the Sinpyong-Anpyong unit is characterized by gray mudstone of shallow lakes. The transition from the underlying unit (Allomember 3 of Rhee *et al.*, 1998) to the Sinpyong-Anpyong unit is marked by a gradual change from well-drained floodplain facies to shallow lake/water-logged floodplain facies. In this stratigraphic interval, the proportion of sandstone body is relatively low. The shallow lakes and water-logged floodplain facies in the basal part of Sinpyong-Anpyong unit pass upward into well-drained floodplain facies in the proximal part (middle part of Sinpyong-Anpyong unit; Fig. 2). Sandstone bodies are relatively coarser-grained and increase considerably in proportion, with a slight increase in connectedness. In the uppermost part of the unit, shallow lake facies extend to the northern basin margin, accompanied with a decrease in proportion of sandstone bodies. The transition from Sinpyong-Anpyong unit to Jotap unit is characterized by a change from water-logged floodplain/shallow lacustrine facies to well-drained floodplain facies (Fig. 2). Sandstone bodies show an increase in proportion.

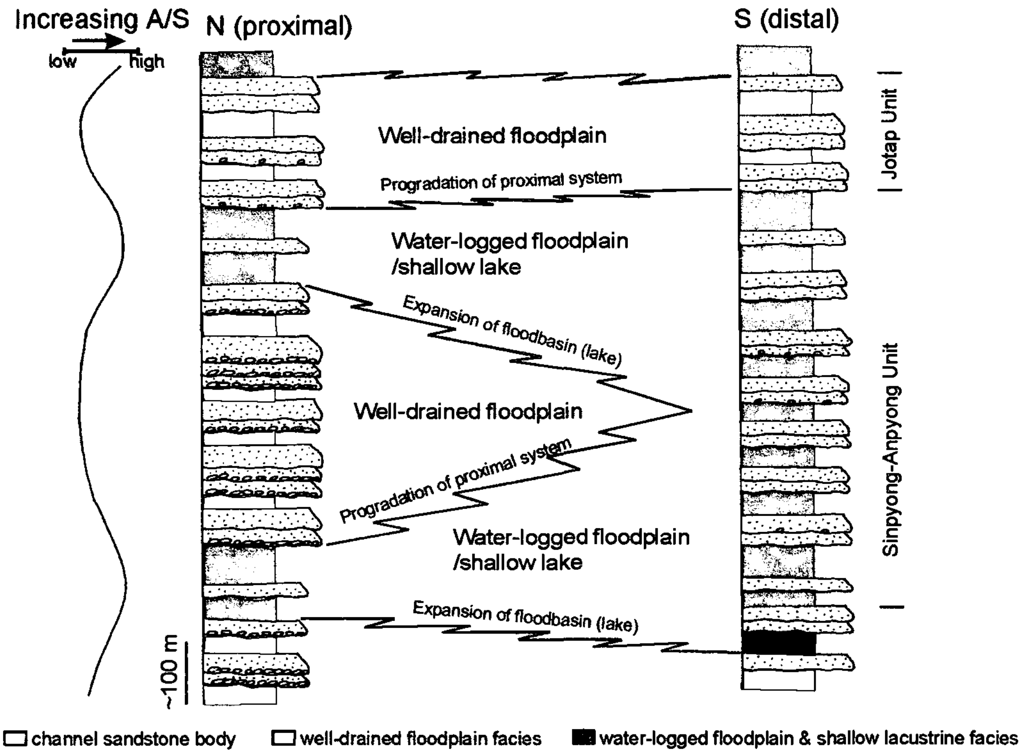

Fig. 2. Stratigraphic architecture of Sinpyong-Anpyong and Jotap units. Water-logged floodplain deposits (distal) show repeated expansion, accompanied with low proportion of channel sandstone (the basal and uppermost parts of Sinpyong-Anpyong unit). It is succeeded by progradation of well-drained floodplain (proximal) deposits interbedded with channel sandstone bodies of relatively coarser grain size and high proportion and connectedness (the middle part of Sinpyong-Anpyong unit and Jotap unit). These changes can be explained in terms of fluctuations in the ratio of accommodation space to sediment supply (A/S ratio).

CONTROLS ON ALLUVIAL SEDIMENTATION

As interpreted previously, purple siltstone represents well-drained floodplains, whereas gray mudstone represents water-logged floodplains with local shallow lakes. The two fine-grained facies reflect the difference in height of depositional surface above the contemporary water table. Well-drained facies might have been formed in floodplains with relatively high elevation above water table, probably in proximal alluvial systems. Water-logged (poorly-drained) facies would have been formed in distal, low-land areas where water table was close to the depositional surface or above the surface forming shallow lakes. The stratigraphic variations in spatial distribution of fine-grained facies are suggestive of repeated expansions and contractions of water-logged floodbasin (shallow lacustrine) environments. In the stratigraphic intervals of lake expansion, the proportion and connectedness of channel sandstone bodies are relatively low, whereas comparably high in the intervals of lake contraction accompanied with the progradation of proximal systems. These stratigraphic variations are suggestive of extrinsic controls on non-marine sedimentation on a regional scale, i.e., changes in accommodation space and sediment supply induced by basin tectonics, climate, and base level (Shanley and McCabe, 1994; Wright and Marriot, 1993; Aitken and Flint, 1995; Legarreta and Uliana, 1998; Martinsen *et al.*, 1999).

The stratigraphic architecture of Sinpyong-Anpyong and Jotap units was most likely formed by tectonically-controlled non-marine sedimentation. The expansion of lacustrine facies might have been due to rapid basin subsidence, during which accommodation space was rapidly created and sediment delivery into the basin was relatively low (e.g., Blair and Bilodeau, 1988; Crews and Ethridge, 1993). The resultant increase in A/S ratio led to the expansion of basinal facies and relatively low proportion of channel sandstone (the basal and uppermost parts of Sinpyong-Anpyong unit). During the following periods of subdued subsidence, the rate of accommodation creation became lower, whereas sediment supply increased significantly as the source area was progressively denuded. The ensuing decrease in A/S ratio resulted in progradation of proximal systems and relatively high proportion of channel sandstone bodies (the middle part of Sinpyong-Anpyong unit and Jotap unit). Conclusively, repeated basin subsidence led to cyclic fluctuations in A/S ratio, regulating overall stratigraphic architecture and facies distribution.

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