

LOWER OLIGOCENE FLUVIO-ESTUARINE FACIES IN KUOHSING, CENTRAL TAIWAN

NENG-TI YU¹, LEH-CHYIN WU² AND LOUIS S. TENG¹

1. Institute of Geosciences, National Taiwan University
2. Department of Geology, Chinese Culture University

ABSTRACT

Prominent facies changes among lower Oligocene sandy/coaly strata in Taiwan lead to ambiguous recognition of fluvial deposits and problematic reconstruction of paleoenvironments. With respect to this, those strata with fluvial facies reported in Kuohsing are reexamined.

These particular strata and overlying muddy/fossiliferous strata are found deposited in "fluvial plain, estuarine shoreline and shelf" environments. The fluvial plain is occupied by middle/lower reaches of a low-sinuosity sandy bedload river system. The estuarine shoreline, an estuary-barrier system replacing the fluvial plain, is dominated by wave influences. The shelf, an open-marine offshore inundating the estuarine shoreline, is influenced by storm waves. Six facies associations are identified, namely the fluvial channel gravelly sandstones, natural levee interbeds, floodplain laminated interbeds, estuary interbeds, barrier sandstones, and offshore interbedded mudstones.

The fluvial-estuarine-shelf succession studied displays a transgressive sequence marked by two marine-flooding surfaces, which represent the onsets of slow and then rapid sealevel rises. It reveals a more complete geohistory of continental margin inundation in Taiwan during late Paleogene than the other comparable successions, most of which only record later drastic changes from coastal to shelf environments. It also provides crucial clues to reconstruct the late Oligocene paleoshoreline with detailed sedimentary processes, which clearly shows an eastward protrusion of prograding fluvial-deltaic system around Kuohsing.

Key words: Lower Oligocene, fluvial plain, barrier-estuary, shelf, Kuohsing

This compound interpretation, however, is challenged by increasingly detailed facies investigations in recent years, because the terrestrial deposits are rarely recognized and the occurrences of *C. baronensis* are found associated with the coastal deposits (e.g. Wu, 1986; Huang and Huang, 1987; Teng *et al.*, 1988; Teng *et al.*, 1991; Huang and Lee, 1992; Liu, 1992; Ke, 1992; Tai *et al.*, 1994). It is also confusing that the fluvial deposits, only identified in two localities, appear problematic owing to insufficient stratigraphic and facies constraints. For example, the sandy/coaly strata in Kuohsing, being exclusively attributed to fluvial deposition (Wu, 1986), require much refined facies delineations, because the brackish-water mollusks like *Ostrea* sp. and *Cerithidae* sp. related to coastal deposition occur in the upper part (Tan, 1944, 1971; Kanno and Chung, 1975). The others in the Meichi Sandstone appear even more ambiguous in facies description and geological age controls (Huang and Lee, 1992).

Consequently, the strata in Kuohsing become the most crucial to examine the existence of late Oligocene fluvial deposition, and the fluvial-coastal facies variations in these comparable strata in Taiwan (Figure 1-B). To deal with these issues, this study first reinvestigates the outcrops along the Peikangchi River valley in Kuohsing to discriminate the facies characteristics of fluvial and coastal deposition. The overlying muddy/fossiliferous neritic strata are also documented to much completely display the vertical facies variations. The facies succession of the strata studied is further compared with the previous results of the other comparable strata to demonstrate the lateral facies variations. The preliminary outcomes show that the sandy/coaly strata in Kuohsing are deposited in a fluvio-estuarine environment with the overlying neritic strata deposited in a shelf. This overall transgressive sequence separated by two marine-flooding surfaces reveals interesting findings regarding the rising sealevel. The comparison with the other successions provides new findings in the lateral facies changes and paleoshoreline configuration.

GEOLOGICAL BACKGROUNDS

The upper Paleogene strata expose in the axial area of a N-S anticline, i.e. the Hsiaoan Anticline, in the Peikangchi River valley near Kuohsing (Figure 1-B; Chiu, 1972, 1975; Lo *et al.*, 1999). The western flank with continuous outcrops is the main target of this study.

The rock strata are divided into the Paileng and Shuichangliu Formations in ascending order, dominated by the sandy/coaly strata and the muddy/fossiliferous strata, respectively (Figure 2; Hayasaka *et al.*, 1939; Ho and Tan, 1960; Chiu, 1972; Lo *et al.*, 1999). Lithological distinction is extremely obvious in the outcrops with sandstones and conglomerates concentrated in the Paileng, and mudstones and interbeds in the Shuichangliu. The succession measured in the western flank is composed of 300 meters of the Paileng Formation from the anticline axis, and 100 meters of the overlying Shuichangliu Formation. A deepening-upward trend in facies and a decreasing-upward trend in grain size and sand/mud ratio are significant in the succession (Fig. 2).

The Paileng Formation is generally low in fossil content, except some palm fragments and mollusks are recorded in the nearby areas, like fresh-/brackish-water *Corbicula baronensis*, *Taiwancorbicula chiuwongi*, *Ostrea* sp. *Cerithidae* sp. and marine-water *Troropicolpus sakitoensis* (Figure 3-A; Hayasaka *et al.*, 1939; Tan, 1944, 1971; Kanno and Chung, 1975). The Shuichangliu Formation is rather abundant in marine fossils, including nanofossils, foraminifers, echinoderms and mollusks (Hayasaka *et al.*, 1939; Tan, 1944, 1971; Chang, 1963; Kanno and Chung, 1973; Huang and Ting, 1979; Chi, 1979; Huang, 1986). The biostratigraphy based on micropalaeontology shows that the Shuichangliu Formation measured in the succession is early Oligocene in age with the delineation of P19-20 and NP23-24 biozones (Figure 2;

Huang and Ting, 1979; Chi, 1979; Huang, 1986). Therefore, the underlying Paileng Formation is most likely latest Eocene (?) to earliest Oligocene in age.

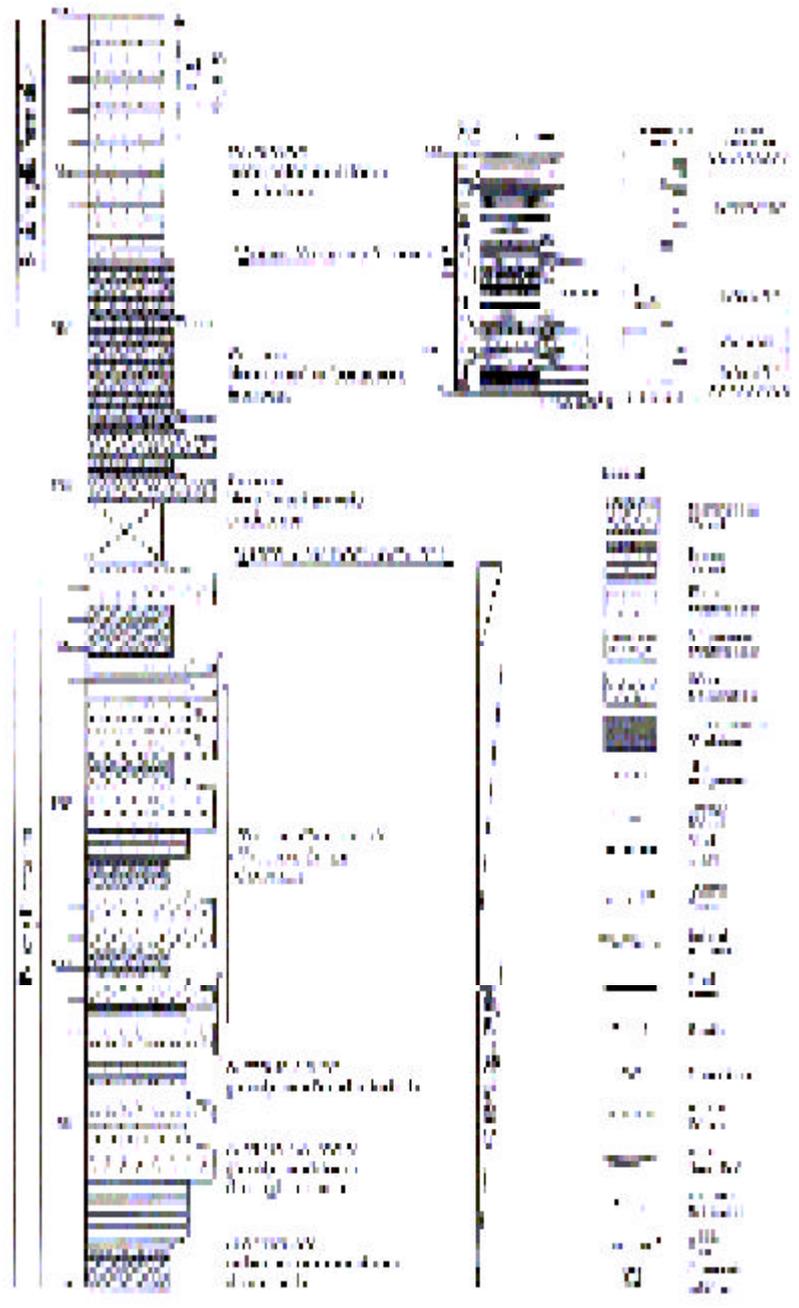


Figure 2. Stratigraphic and Facies columns of the measured lower Oligocene strata. Biostratigraphy of nannofossil and planktic foraminifer based on Huang and Ting (1979), Chi (1979) and Huang (1986). Bioturbation index after Dott and Bourgeois (1982). M: mud, S_I: silt, S_F: fine sand, S_M: medium sand, S_C: coarse sand, G: gravel.

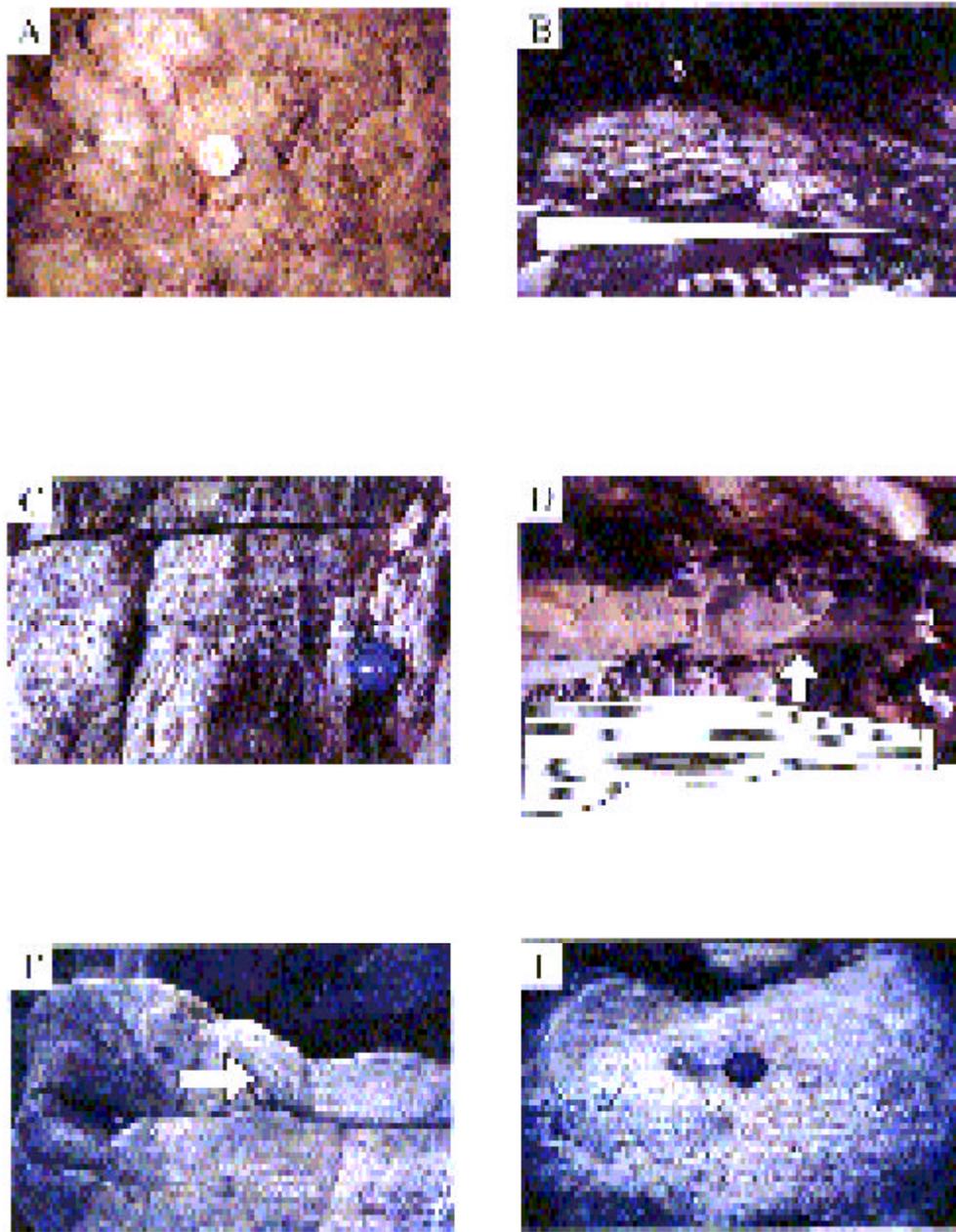


Figure 3. (A) Gastropods in the sandstone layers of the Floodplain association. (B) Erosion-based, fining-upward sequence (horizontal triangle) of conglomerates, sandstones and interbeds from the Fluvial Channel to Natural Levee associations. (C) Grain-supported, gravelly conglomerate with normal-grading planar stratifications in the Fluvial Channel association. (D) Mega-wave stratifications in the Fluvial Channel association. (E) Folded foreset of a trough cross bed in the Fluvial Channel association. (F) Normal-grading, planar stratifications in the Fluvial Channel gravelly sandstone.

FACIES ASSOCIATIONS

According to the facies characteristics observed in this investigation, the rock succession measured is evidently deposited in "Fluvial Plain, Estuarine Shoreline and Shelf" environments (Fig. 4). The lower 250m are composed of the fluvial plain strata with three facies associations including the fluvial channel, natural levee and floodplain (Figures 1-B, 2). The middle 70m are composed of the estuarine shoreline strata with 2 facies associations of the estuary and barrier. The upper 80m are composed of the shelf strata of the offshore facies association.

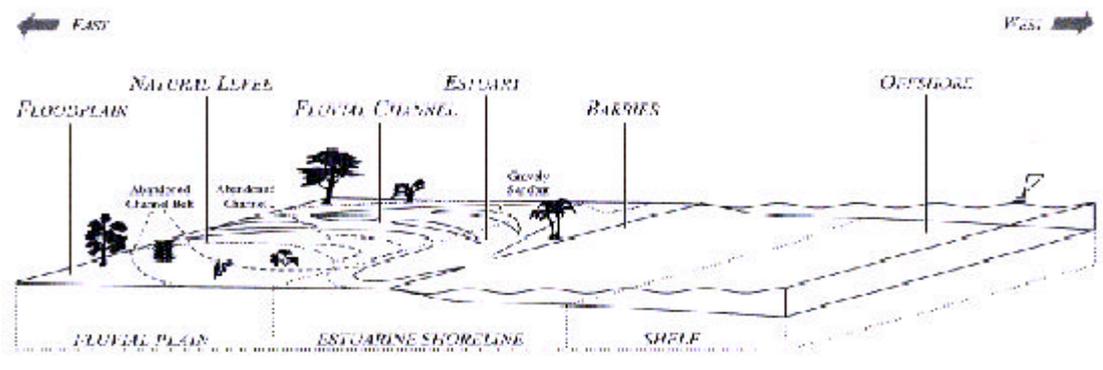


Figure 4. Schematic depositional model and facies associations of the lower Oligocene strata measured in Kuohsing.

Fluvial Channel

Description: The association is composed of sandstones and conglomerates in erosion-based, fining-upward successions of 5~15 meters thick (Figures 3-B, 5). The sandstones are medium to coarse in grain size. The conglomerates are grain-supported, subangular to subrounded, and fine to medium in gravel size (Figure 3-C). Sedimentary structures include trough cross beds, planar stratifications, mega-wave stratifications and some planar cross beds (Figure 3-D). The crossbeds, 20~40cm thick individually, usually form lateral-discontinuous, compound bed sets up to meters thick. The foresets are usually normal-graded, folded and climbing-stacked (Figures 3-E, F). Soft deformations are common, like load casts and slumping structures. The upper parts of the fining-upward successions are often associated with some rootlets, tiny tube-like traces and red beds (Figure 6-A).

Interpretation: The compound cross beds and fining-upward successions are indicative of shifting traction flows (Massari, 1983). The mega-wave stratifications are formed almost instantly during deposition of strong eddy currents (Cotter and Graham, 1991). The folded foresets are originated from the semi-dewatered foresets dragged by succeeding flows (Hendry and Stauffer, 1977; Roe and Hermansen, 1993). These sedimentary structures and soft deformations reflect abundant sediment supply in rapid deposition. The conglomerates are the winnowing-out deposits of sheet-like traction flows, which are usually aggregated in channel floor as gravel shoals or bars (Arche, 1983; Steel and Thompson, 1983). The rootlets and red beds are indicative of vegetation and weathering processes, which take place soon after the abandoned channels are filled.

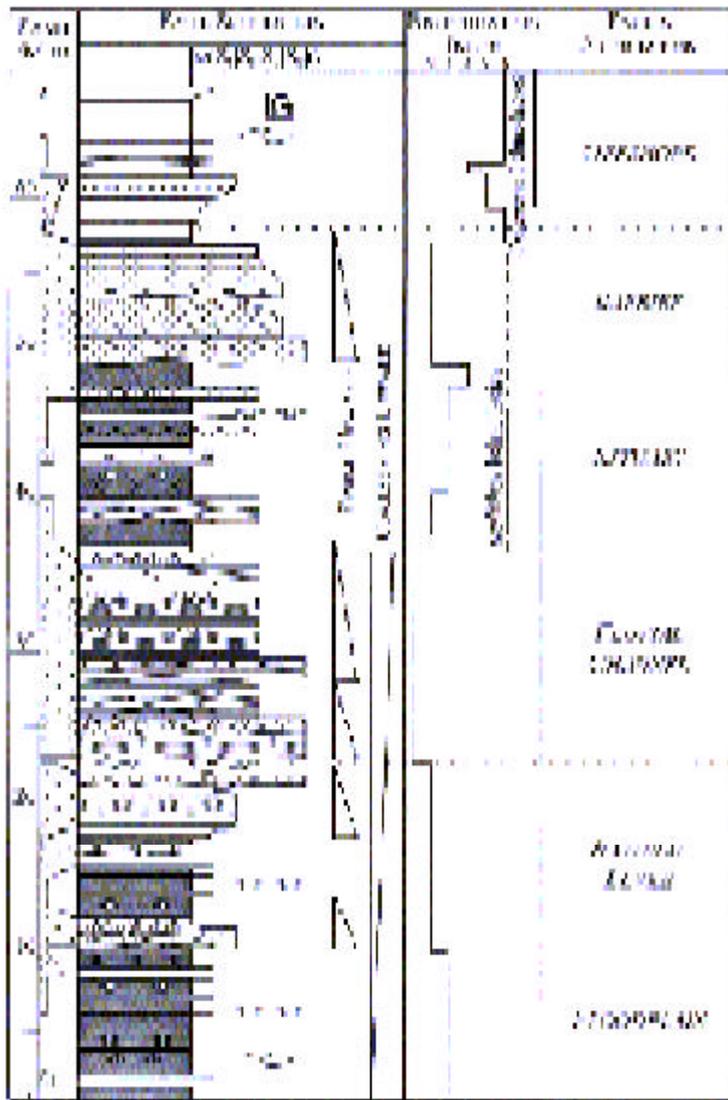


Figure 5. Idealized facies associations of the Lower Oligocene strata in Kuohsing. Bioturbation index after Droser and Bottjer (1988). See legend in Figure 2.

Thus, the association represents the sediment fills of abandoned fluvial channels, which are deposited by powerful traction flows with abundant coarse-grained bed loads (Fig. 4). These channels are usually migrating laterally and floored by sandy/gravelly shoals due to rapid deposition.

Natural Levee

Description: The association is composed of sand/mud interbeds with thin conglomerates of gravel or mud chip (Fig. 5). Fining-upward successions are common (Figure 6-B). Plant

fragments, calcareous and ferruginous concretions are plentiful. Soft deformations and subaerial-exposed features are often encountered, like climbing laminations, slumping structures, ball and pillow, rootlets and paleosols (Fig. 6-C). Sedimentary structures include normal-graded planar stratifications, flaser laminations and some mega-wave stratifications.

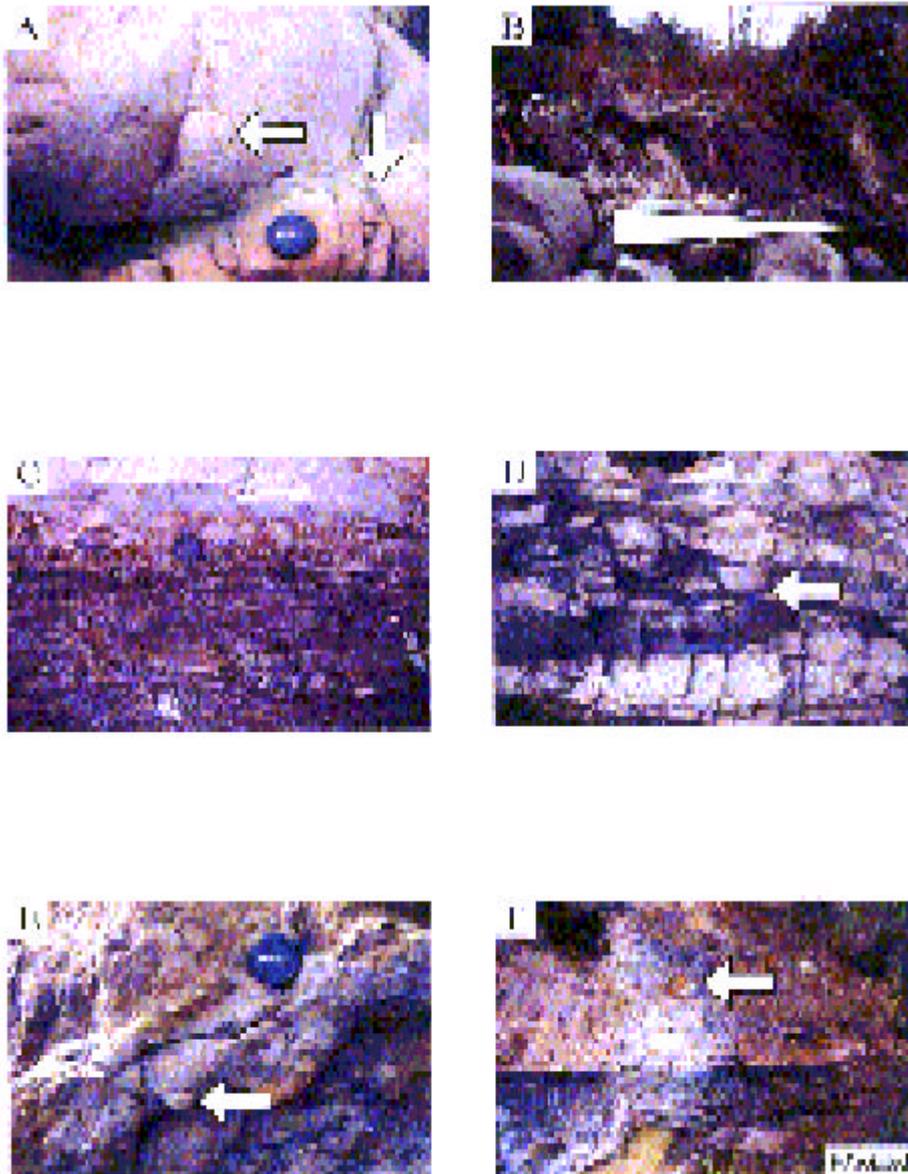


Figure 6. (A) Red bed (vertical arrow) and tiny traces (horizontal arrow) in the upper Fluvial Channel association. (B) Fining-upward sequence (horizontal triangle) of stratified to laminated interbeds in the Natural Levee association. (C) Ball-and-pillow structure (arrow) in the stratified interbeds of the Natural Levee association. (D) Planar laminations in the Floodplain mudstone. (E) Bioturbated laminated interbeds rich in sulfurous materials and trace fossils of *Skolithos* isp.; note the traces filled with coarse quartz sands (arrow). (F) A 1.5-meter-thick coal bed overlain by a planar bedded quartz sandstone and a coaly mudstone with ferrous concretion (arrow).

Interpretation: The concretions, rootlets and paleosols reflect a depositional site with insignificant perturbation, low water table and vegetation (Bown and Krause, 1987; Besly and Collinson, 1991; Krause and Aslan, 1993). The sandstone layers and sedimentary structures, however, indicate some instant deposition of intermittent flood currents.

Thus, the association represents the deposits in natural levees along fluvial channels (Fig. 4). In flood seasons, overbank currents frequently rip up previous alluvium and pave sheet-like sandy or gravelly deposits in the proximal riverbanks. As the currents drain, muddy deposits soon precipitate over the coarse-grained deposits. Out of flood seasons, vegetation grows on these deposits and causes pedogenesis, as water table is lower.

Floodplain

Description: The association is composed of massive mudstones and some sand/mud interbeds (Fig. 5). It is rich in plant fragments, calcareous and ferruginous concretions. Coal seams, horizontal tube-like traces and gastropods are occasionally encountered (Figure 3-A). Carbonaceous mudstone intervals are common. Sedimentary structures are rare and dominated by planar laminations (Figure 6-D). Soft deformations and subaerial-exposed features are recorded, like climbing laminations, ball and pillow, rootlets and paleosols.

Interpretation: The simple lithology, concretions, carbonaceous materials and coal seams reflect a quiescence depositional site with low bioactivities, stagnant water circulation and frequent water-table fluctuations (Fielding, 1984; Haszeldine, 1984). The sedimentary structures and soft deformations are indicative of occasional abundant sediment supply and instant deposition of low-energy currents.

Thus, the association represents the distal riverbank deposits in a floodplain surrounding fluvial channels (Fig. 4). Thick muddy deposits cover most of this low-lying area with abundant carbonaceous materials in small lakes, ponds or marshes, where water table is usually high. In flood seasons, thin-layer coarse-grained deposits pave over the areas where overbank currents reach. The lakes, ponds and marshes near the fluvial channel are more easily drained or filled up by sediments, which makes the deposits much easily influenced by pedogenesis. Those far from fluvial channels, receiving small amounts of siliclastic deposits, tend to be enriched in carbonaceous materials and become mires for peat formation.

Estuary

Description: The association is composed of sand/mud interbeds and carbonaceous mudstones with some coal seams (Fig. 5). Thin sandstones and mud-chip conglomerates are common. Ferruginous concretions, plant fragments and trace fossils filled with quartz grains are frequently encountered (Figures 6-E, F). The ichnofabrics include *Ophiomorpha* isp., *Skolithos* isp. and *Planolites* isp.. Sedimentary structures include planar stratifications, flaser and wavy laminations with some planar cross beds and HCS. The sandstone beds are associated with climbing laminations, slumping and ball-and-pillow structures. The interbeds are characterized by sulfurous materials, ball & pillow, rootlets and paleosols (Figures 6-E, 7-A).

Interpretation: The interbeds, coal seams, concretions and carbonaceous materials reflect a relatively quiescence depositional site with stagnant water circulation. Abundant sulfurous materials and trace fossils are indicative of marine water intrusion. The planar stratifications, wavy laminations and HCS suggest fair weather wave and storm wave activities. The flaser laminations with climbing features suggest rapid deposition of fluvial, tidal or wave-induced currents.

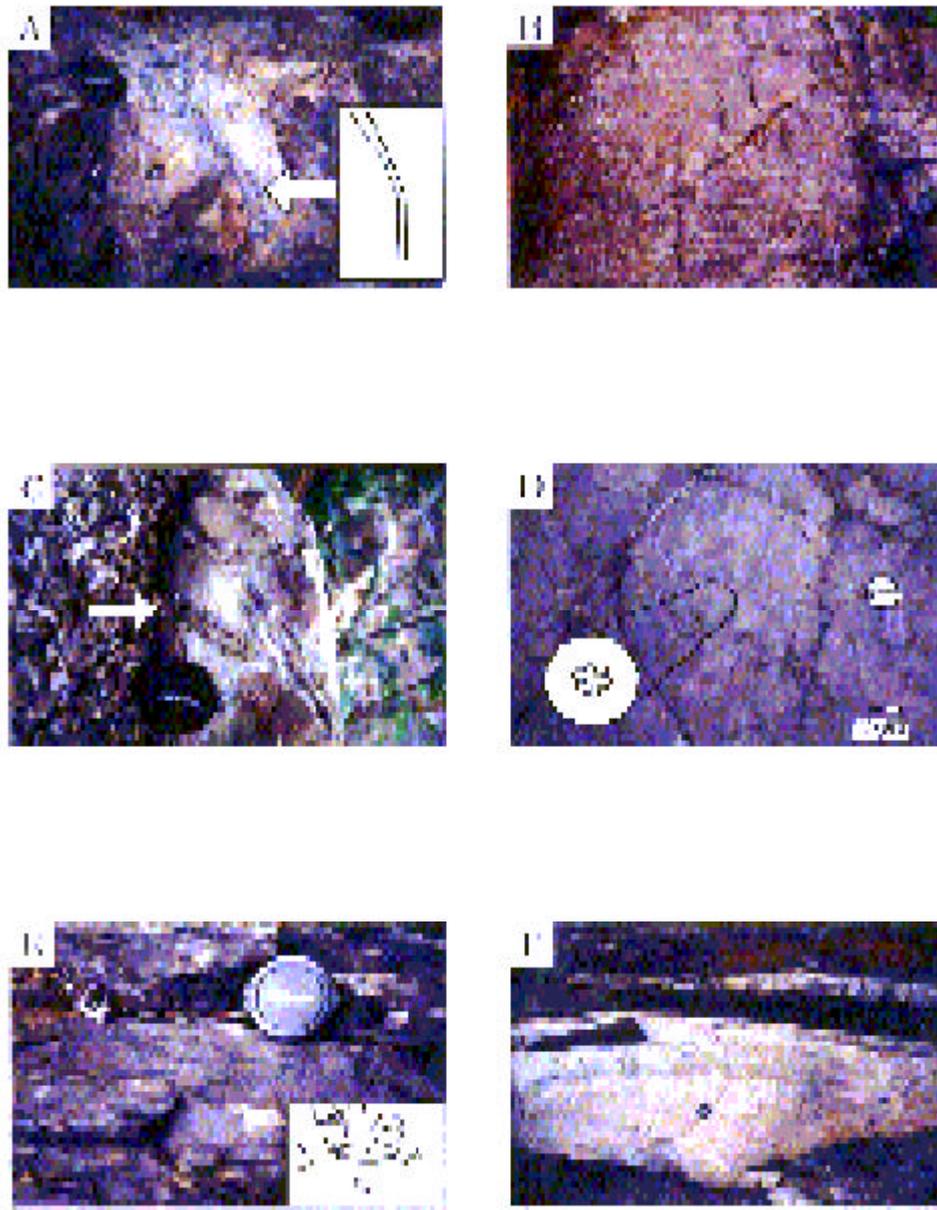


Figure 7. (A) A root structure penetrating a sandstone layer of the Estuary association. (B) Herringbone planar cross bed in the Barrier association. (C) Trace fossils of *Scolicia* isp. (arrow) of *Cruziana* ichnofacies on a sandstone top of the Offshore association. (D) Trace fossils of *Palaeodictyon* isp. (in circle) of *Nereites* ichnofacies on a siltstone top of the Offshore association. (E) Horizontal traces filled with glauconitic pellets in the Offshore mudstone. (F) Sandstone layers with singular (upper thin layer) or amalgamated (lower thick layer) hummocky cross stratification of the Offshore association.

Thus, the association represents the deposits in an estuary under combined influences of fluvial and marine processes (Fig. 4). The lagoon-like area receives plentiful mud-dominated sediments from fluvial channels and inlets of storm washover or tidal currents, which in turn create excellent water circulation beneficial for the intense bioactivities. As sediment fills gradually shrink the estuary, vegetation grows over the exposed areas and causes pedogenesis.

Barrier

Description: The association is composed of gravelly sandstones in fining-upward intervals with basal erosion surfaces and load casts (Fig. 5). Although the sandstones are in various grain sizes, most of them are quartzites showing fairly mature lithology. Trace fossils are rare and dominated by *Ophiomorpha* isp.. Sedimentary structures well-developed, including planar stratifications, cross beds and herringbone cross beds (Figure 7-B).

Interpretation: The well-developed structures and mature lithology reflect a depositional site with intense wave activities (Clifton *et al.*, 1971; Greenwood and Mittler, 1985). The herringbone cross beds are indicative of multi-directional currents in time-velocity asymmetry (Visser, 1980; de Mowbray and Visser, 1984). The domination of *Ophiomorpha* isp. is indicative of a high-energy depositional sites with excellent water circulation. The fining-upward successions with basal conglomerates and erosion surfaces are attributed to the sediment fills of tidal inlets.

Thus, the association represents the deposits in a barrier island (Fig. 4). These sandy deposits form a series of beach-shoreface shoals and bars fringing the seaward parts of the estuaries. They are dominated by fair-weather-wave activities and divided by tidal inlets, through which tidal currents flood into and ebb out of the estuaries.

Offshore

Description: The association is composed of mudstones, massive sandstones and stratified interbeds (Fig. 5). Intervals rich in glauconitic pellets and shell fragments are common. Bioturbation is usually intense with ichnofabrics like *Zoophycus* isp., *Chondrites* isp., *Scolicia* isp., *Palaeodictyon* isp., *Planolites* isp., *Skolithos* isp., *Teichichnus* isp., *Thalassinoides* isp. and *Ophiomorpha* isp. (Figures 7-C, D). Some traces are filled with glauconitic pellets (Figure 7-E). Sedimentary structures include HCS, planar stratifications and wavy laminations (Figure 7-F).

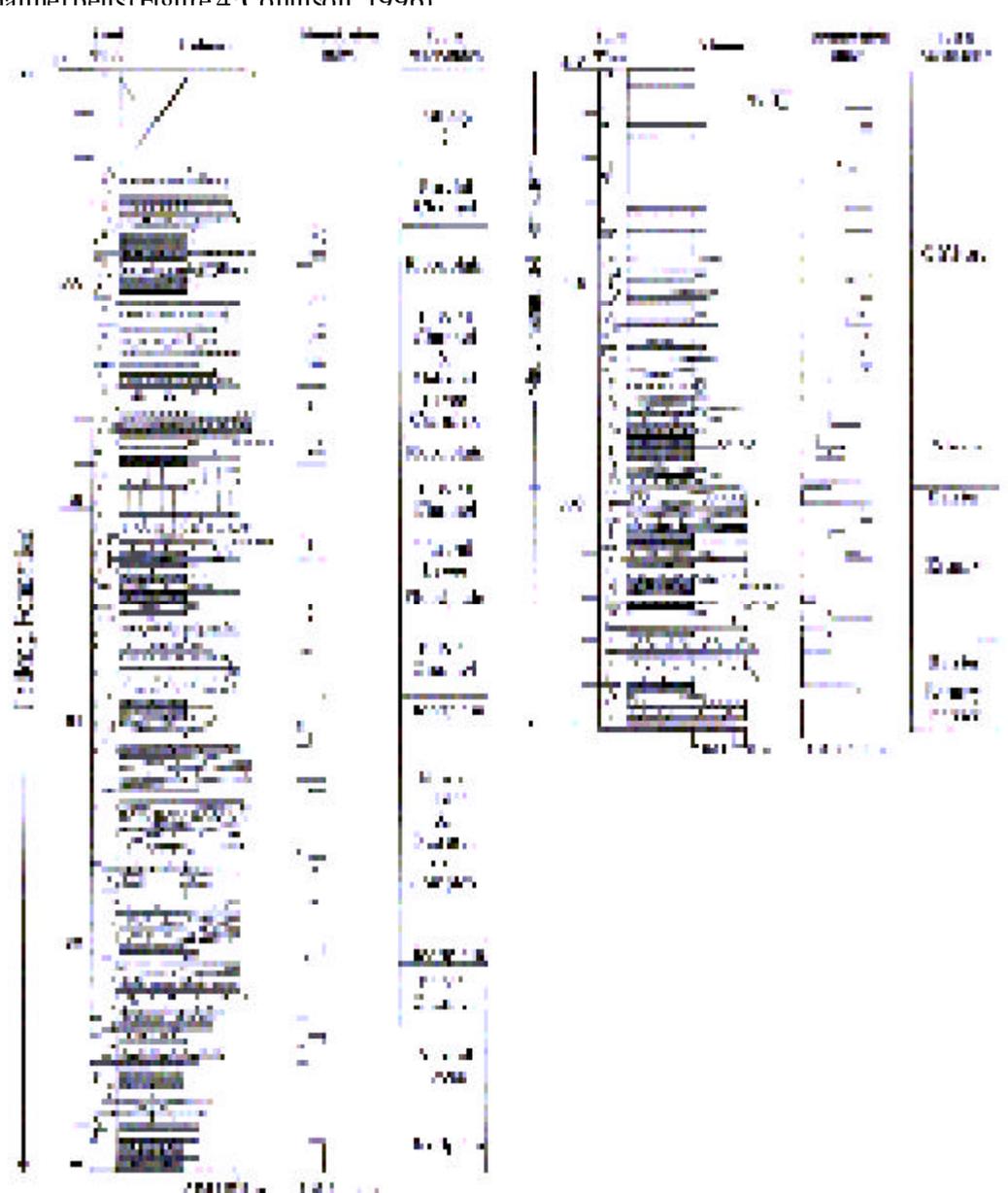
Interpretation: The sedimentary structures are evidently related to storm wave activities. The intense bioturbation suggests that wave activities are superseded by vigorous bioactivities between storms. The glauconitic intervals and in-situ glauconitic pellets are indicative of slow and quiescence deposition. Some traces are indicative of outer shelf to subabyssal environments, like *Zoophycus* isp., *Chondrites* isp., *Scolicia* isp. and *Palaeodictyon* isp..

Thus, the association represents the deposits in an offshore with occasional storm-wave influences and slow sediment supply (Fig. 4).

LOWER OLIGOCENE FLUVIAL SYSTEM

The fluvial succession in the section is composed of three coarsening-upward, 60~100m thick sequences, each of which displays an upward facies change from the floodplain, natural levee to fluvial channel (Figures 2, 5). These sequences demonstrate a gradual progradation of the fluvial channel toward the natural levee and floodplain, which might be related to lateral migrations of channel belts, or baselevel falls (Fig. 4).

In these sequences, it is obvious that the floodplain in the fluvial plain mainly receives muddy deposits (Figure 5; Appendix). Only little proportion of coarse-grained deposits is accumulated in this low-lying area around the natural levee, whereas the majority is concentrated in the fluvial channel. Meanwhile, the conglomerates and gravelly sandstones form point bar sequences with well-developed sedimentary structures of traction flows. Therefore, it appears that the fluvial plain is dominated by the middle-lower reaches of a river system with sinuous channel belts (Figure 4; Collinson 1996)



Appendix. Detailed Facies columns of the measured lower Oligocene strata. See legend in Figure 2.

It is also significant in these sequences that most of the fluvial channel and natural levee associations are amalgamated to form channel-levee complexes (Figure 2; Appendix). The feature suggests that the main belts of these fluvial channels are potentially broad enough to accommodate all these gravelly/sandy bed loads (Fig. 4). Within these particular channel belts, the individual channel in the belts is ever changing in direction and usually flooded by migrating gravelly shoals or bars, because the abandoned point-bar channel fills are stacked upward with compound cross beds and gravel beds (Fig. 5). These channel fills are characterized by well-developed features of rapid deposition, which in turn indicates that the traction-flow capabilities reduce considerably between floods without significant redistribution of the settled sediments.

Consequently by integrating these features, the fluvial system can be specified as "middle/lower reaches of a sandy bedload, low-sinuosity river system" associated with fluctuating water levels and tables (Fig. 4). Modern analogues are referred to the Platte River and the Calamus River, Nebraska, U.S. (Smith, 1970, 1971; Blodgett and Stanley, 1980; Bridge *et al.*, 1986), the South Saskatchewan River, Canada (Cant and Walker, 1978), and the Squamish River, British Columbia (Brierley, 1989, 1991).

LOWER OLIGOCENE ESTUARINE SHORELINE SYSTEM

The total thickness of the estuarine strata in the section studied is about 70~90m, because the lower 20 meters from 230 to 250m is covered by dense vegetation without distinguishable outcrops (Appendix). These covered strata are fine-grained most likely, and tentatively interpreted as the estuary facies (Fig. 2).

Nevertheless, these coastal strata are indicators of a deepening and westward environment shift from the fluvial plain to estuarine shoreline (Figures 2, 4). Under the circumstances, deposition is likely to retrograde and lead to a much gentle and graded stream profile in the area to compensate the rising base level. Fluvial processes decrease as marine processes begin to influence this low-lying fluvio-estuarine plain. A typical quiescent estuary is resulted and starts accumulating thick piles of muddy deposits (Figures 4, 5; Dalrymple *et al.*, 1992). River floods, storm washover currents and spring tides make thin laminated or sheet-like layers of sandy deposits available.

Further deepening and westward shift to the seaward part of the coastal environment takes place as sea level keeps rising (Figures 2, 4). It results in the fluvial processes totally superseded by marine processes, which is dominated by fair weather waves with some tidal currents. Mostly deposited are coarse-grained deposits along the shoreline due to the intense wave influences, which is evidenced by the mature lithology and well-developed sedimentary structures in the barrier facies association (Fig. 5). Hence, a typical barrier environment is formed in the shoreface areas and starts accumulating thick piles of sandy/gravelly deposits (Reinson, 1992; Reading and Collinson, 1996).

In terms of the coastal facies succession, the estuarine system can be specified as a "wave-influenced barrier-estuary" shoreline (Fig. 4). Although these sedimentary environments are rather distinguishable in geomorphology, nevertheless the formation and preservation of the barrier facies is affected by several important factors. It heavily depends on the depositional and erosional processes of fair weather waves, and indirectly on the critical balance between

sediment supply and rate of sealevel rise (Belknap and Kraft, 1981; Swift and Moslow, 1982; Galloway, 1986). Since the barrier facies association is well recognized in the section studied (Fig. 2), it in turn indicates that the sediment supply in this shoreline is sufficient to balance the rate of sealevel rise (Fig. 4).

FLUVIAL-ESTUARINE-SHELF SEQUENCE

In terms of the facies associations, the succession changes from the fluvial, estuarine to shelf deposits, which displays a transgressive sequence and verifies the similar variations reported in mollusk faunas (Kanno and Chung, 1975). Furthermore, two marine-flooding surfaces are recognized by the deepening-upward facies, and reveal the variations of sealevel rise in the whole sequence.

The lower surface, located at 230m in the succession, is characterized by the change from the fluvial to estuarine deposits (Fig. 2). The overlying estuarine succession up to 70~90m thick clearly suggests that this particular barrier/estuary system must have sustained for a period of time under the balance between the sealevel rise and sediment supply (Belknap and Kraft, 1981; Swift and Moslow, 1982; Galloway, 1986). During this duration, some sealevel fluctuations or lateral environment shifts still take place, which is indicated by the stacked barrier and estuary deposits. Since individual barrier or estuary association is distinguishable, the preservation of these coastal deposits appears rather complete during these sealevel fluctuations or environment shifts. It, in turn, suggests that these fluctuations or shifts are relatively minor and only associated with insignificant transgressive erosion, since the erosion is often able to cause total destruction of the coastal deposits (Swift, 1968; Reinson, 1992; Dalrymple *et al.*, 1992).

The upper surface, located at 325m, is characterized by the change from the estuarine to shelf deposits (Fig. 2). The offshore facies directly overlies the estuary facies with an intensely bioturbated coarse sandstones of 1m thick. The sandstone is characterized by relict HCS and low-angle planar stratifications, which are indicative of storm wave deposition in the offshore environment. On the other hand, its coarse-grained lithology reflects storm washover deposition in the estuary environment. The lack of intervening barrier facies might be due to none deposition during the sealevel rise, or none preservation after the sealevel rise. Regardless in either cases, this particular sealevel rise is likely rapid enough to overwhelm sediment supply and result in none deposition, or to cause intense transgressive erosion and result in none preservation (Belknap and Kraft, 1981; Swift and Moslow, 1982; Galloway, 1986).

Thus, it appears that the initial sealevel rise, at the first marine-flooding surface, not only results in the fluvio-estuarine succession, but also is superimposed by minor sealevel fluctuations or lateral environment shifts. The following sealevel rise, at the second marine-flooding surface, causes the coastal area inundated as an open shelf, but also ceases the eastbound fluvial progradation to the west of Kuohsing during Oligocene and the rest of Cenozoic.

The later drastic and rapid transgression is also recorded by early Oligocene environment deepening in many other areas in northern Taiwan, such as Wulai, Paleng, Pinglin and North Coast (Teng *et al.*, 1991). In Wulai, similar coastal inundation is displayed by the abrupt facies deepening from the barrier-lagoon to the offshore transition in the upper Szeleng Sandstone (Teng *et al.*, 1988). In North Coast, environment deepening is displayed by the abrupt facies

deepening from the shoreface to the offshore, at the boundary between the Szeleng Sandstone and Kankou Formation in Lungtung, and in the lower Wuchihshan Formation in Wanli (Tai *et al.*, 1994). These concomitant transgressive events are comparable to the Kuohsing event with a similar age range in lower NP23 or lower N19~20 biozones. Thus, it appears that the transgression is tectonically controlled and related to the late Paleogene rifting activities in the SE China continental margin (Tang *et al.*, 1991).

PALEOSHORELINE IMPLICATIONS

The sandy/coaly strata studied are the only recognized with fluvial deposits among the upper Paleogene strata, although comprising considerably minor proportion of the whole formation, over 4,000 meters thick (Ichimura, 1938; Chen, 1977; Chou, 1988). Thus, the comparison between these sandy/coaly strata is able to provide insights into the lateral facies changes as well as the paleoshorelines.

The most significant consistency in the facies comparison is the estuarine strata studied and the other coastal strata, because they are all indicative of deposition in shorelines under distinguishable wave influences (e.g. Huang and Huang, 1987; Teng *et al.*, 1988; Teng *et al.*, 1991; Huang and Lee, 1992; Liu, 1992; Ke, 1992; Tai *et al.*, 1994). Yet discrepancies emerge due to the existence of the fluvial strata studied in Kuohsing, which results in the remarkable differences from the fine-grained coastal deposits, especially. For example, the barrier strata are usually associated with the lagoon deposits without fluvial influences in many other areas, including the Paileng Formation in Paileng (Liu, 1992), the Szeleng Formation in Wulai, Szeleng and Paileng (Teng *et al.*, 1988; Teng *et al.*, 1991; Ke, 1992). Furthermore, the lack of fluvial influences is also observed in other similar barrier-lagoon Neogene strata in the Western Foothills and bear corresponding discrepancies, like the lower Miocene Mushan Formation and upper Miocene Sanfuchi Sandstone (Yu and Teng, 1995; Yue and Teng, 2000).

Concerning the fluvial strata studied, the facies changes become even drastic and appear deepening toward the north, south and east (Figure 1-A). To the north, the sandy/coaly strata of the Paileng Formation in Paileng are deepening in facies, like the barrier, lagoon, foreshore and shoreface deposits (Figure 1-A; Liu, 1992). Further down to the NNE in Szeleng and Wulai, they are also deepening in facies and intercalated by the muddy/fossiliferous offshore strata (Teng *et al.*, 1988; Ke, 1992). To the south and east, they are both composed of the wave-influenced paralic deposits and intercalated by muddy/fossiliferous neritic deposits in the Tachian Sandstone in Shuili and the Paileng Formation near Puli, (Huang and Huang, 1987; Tan and Youh, 1978). The Shuili Tachian Sandstone and the Puli Paileng Formation have been suspected attributed to deltaic progradation, albeit detailed facies characteristics remain to be investigated to verify the fluvial influences and corresponding river systems. In such case, it seems that the eastbound fluvial system in Kuohsing is likely related to the corresponding river system of the deltaic deposition.

By integrating these facies changes, the paleoshorelines, based on previous studies (Tan and Youh, 1978; Chou, 1988), is preliminarily redrawn in Figure 1-A with improvements on sedimentary processes and environments. It is obvious that the paleoshorelines, smoothly extending from northeastern to southwestern Taiwan, are composed of a series of wave-

influenced environments. However, the smoothness is interrupted with protrusion to the east of Kuohsing due to the fluvial and related deltaic deposition. This feature is very unique in the Tertiary sedimentation in Taiwan, and worthy of further investigations.

CONCLUSION

The sedimentary nature of the lower Oligocene sandy/coaly strata in Kuohsing is clarified by the facies reinvestigation of this study. The strata are deposited in a fluvio-estuarine environment, and overlain by the shelf muddy/fossiliferous strata. The fluvial deposits are accumulated in the middle-lower reaches of a low-sinuosity, sandy bedload river system, with three depositional sites of the fluvial channel, natural levee and floodplain. The overlying estuarine deposits are accumulated in the wave-influenced, estuarine shoreline with two depositional sites of barrier and estuary. The shelf deposits are accumulated in the wave-influenced offshore.

The fluvial-estuarine-shelf succession, displaying a transgressive sequence, is characterized by two marine-flooding surfaces, which represent the onsets of two stages of sealevel rise. The lower surface between the fluvial and estuarine strata is indicative of a slow-rising sealevel, which seems to be in balance with the sediment influx and leads to limited marine intrusion into the previous fluvial plain. The upper surface between the estuarine and shelf strata is indicative of a major and rapid sealevel rise which overwhelms the sediment influx, and is likely related to the tectonic rifting in the SE China continental margin.

The paleoshorelines are mostly composed of a series of wave-influenced environments, based on the comparison between the fluvio-estuarine strata studied and the other upper Paleogene strata. It is also significant that the eastbound fluvial deposits seem related to an eastward protrusion in the wave-influenced NE-SW paleoshoreline, and responsible for the deltaic deposition in the south and southwest.

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