# Fluvial wetland formations in South Korea

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**Abstract:** In Korean geomorphology wetland unconsolidated alluvial deposits are categorized as coastal alluvial deposits, fluvial channel deposits, alluvial plain deposits, erosional basin-type alluvial deposits and valley fill-type alluvial deposits. The formation of alluvial deposits (alluvium) are related to the geomorphic development of base level fluctuations, coastal processes and palaeosol formations in response to climatic changes during the Quaternary. Most fluvial wetland sedimentary sequence was formed since the last interglacial.

**Résumé:** En géophysique de la Corèe, dépots alluvials non-consolidés au terrain humide sont catégorisés comme les dépots alluvials cotier, les dépots des cannals fluvials, les dépots plains alluvials, les dépots alluvials en type de l'érosion et les dépots alluvials de type remplie en vallée. Le plus de la sequence sédimentée au terrain humide sont formée après l'interglacial dernier.

**Keywords:** geomorphology, alluvium, sand, gravel, floods, climatic changes

## INTRODUCTION

In the Korean peninsula, Holocene alluvial and/or fluvial deposits occupy quite a large surface area, while upper Pleistocene fluvial deposits are less extensive except in coastal, old fluvial and hillslope areas. With these latter deposits, terrace sequences were formed during the upper Pleistocene (since ca. 125Ka BP). Marine terraces in coastal areas and/or fluvial terraces along downstream river courses are found mostly at the level of about 10-20 m above the base level of mean sea level or river bottom (Lee 1987). During the last glacial period, however, slope processes were developed along the foot of mountain slopes. The most outstanding depositional sequences, however, occured in the latest Pleistocene and Holocene alluvial to fluvial deposits, either as infilling drowned valleys in coastal areas or at inland alluvial plains.

## LAST INTERGLACIAL PERIOD DEPOSITS

Late Quaternary depositional sequences comprise both last interglacial and last glacial deposits. Last interglacial deposits are represented by marine or fluvial terrace sequences, which display flat surfaces 10-20 m higher than the present mean sea level or above the river bottom of major rivers. These terrace sequences are mostly composed of sands and gravels, covered by fluvial or colluvial deposits toward top. Fluvial terraces are developed parallel to the river courses along five major river valleys. The radiometric ages of the organic mud 1ayers intercalated in the coastal terrace deposits are older than 52Ka BP (Lee 1987). In addition, recent study indicates that Aso-4 tephra (unpublished data and personal communication with Hanshin Consulting Company, 2003) were found in the upper part of marine terrace deposits at about 12m above the average sea level at Jeongja-ri in the south east coastal area, indicating that the formation age of this marine terrace was probably in the last interglacial period, most likely at 80-128Ka BP.

Sands and gravels are the most common components of the last interglacial fluvial sequences of coastal rivers. The river valleys were repeatedly infilled and eroded out during the late Pleistocene epoch. A set of fluvial terraces and/or old river deposits are present at many places in the main river valleys. The fluvial terraces are represented by an extended flat surface and the altitude of this flat surface is about 10-20m above river base, rising gently up valley in accordance with the present stream gradient. The height of each terrace above the present river-bottom remains quite constant along the valley profiles. Those fluvial terraces developed at the level of about +15 to +20m are the most conspicuous ones in the eastern coastal areas of Korea. As an additional last interglacial phenomenon in the Korean peninsula, red or reddish-brown soils are typically developed as saprolites (or saproliths) on the basement rocks. The reddish-brown soil is most pronounced in the gently sloping and undulating terrain in the western part of the Korean peninsula where Mesozoic granite and Precambrian granitic gneiss are the main bedrock lithologies. Except in the western coastal areas of Korea, the solum developed in the interglacial period is relatively thin and directly overlies weathered granite or granitic gneiss. The oldest reddish brown soil is interpreted to be older than the early Last Glacial period (ca 75 Ka BP). The reddish brown palaeosol is overlain by less weathered brown soil, yellowish brown soil and dark brown soil which constitute the last glacial pedogenetic layers.

 

# LAST GLACIAL PERIOD SEQUENCES

## *Old Fluvial Sequences (pre-Last Glacial Maximum (LGM))*

The Soro-ri fluvial sequences provide examples of pre-LGM fluvial deposits. They are composed of fluvial gravel, sand and organic mud. The fluvial deposits are interpreted to be associated with backswamp organic mud environments. The formation age is older than 36Ka BP, based on the 14C age of organic muds above a sand and gravel layer in the P38 and U24 pits at the Soro-ri site in Cheongwon county. The estuarine fill sequence in the Yeongsan River mouth is another example, seen in the MW-1 drill core (20.50-9.50 m depth). This is composed of: (1) lower fluvial coarse sand and pebbles with levee/backswamp homogeneous mud, partly cross-laminated mud, and massive sand (38-29Ka PB), and (2) upper floodplain brown-mottled clayey silt with occasional sand layers (flooding palaeosols, 29-27Ka BP). In the lower fluvial/backswamp sequence, arboreal pollens such as as Pinus, Abies, and Picea are abundant and non-arboreal pollens such as Cyperaceae and Gramineae are common, while in the upper floodplain deposits fragments of plant roots are abundant, and the deposits were subjected to intensive pedogenic processes.

Three major fluvial geomorphic responses, during the last glacial period, were marked firstly by the formation of sedimentary sequences, which were mainly derived from mass movements that prevailed along the previous hill slopes or at the foot of mountains. Secondly, the formation of fluvial/backswamp deposits during interstadials took place and, thirdly, several conspicuous horizons of soil-wedge structures, which developed in various depositional sequences, were formed during the last glacial maximum. The older soil wedge structures were interpreted to be developed in the period equivalent to the marine isotope stage 4 (MIS 4), i.e., ca. 65Ka BP, while the younger ones are correlated to the marine isotope stage 2 (MIS 2), i.e., ca. 18Ka BP (Kim, Lee & Choi 1998).

## *Slope deposits of pre-LGM age*

Slope deposits commonly intercalate the fluviatile deposits. These deposits contain weathered clastic particles, which have been slowly transported on to foothill or terrace surfaces by mass movement. They are very poorly sorted or even completely unsorted and include rock fragments together with fine-grained soils. Some degree of pedogenesis was experienced on the palaeo-surface under the prevailing palaeo-climatic condition prior to the next episode of deposition. ln this way, palaeo-climatic imprints are preserved within the slope deposits. These slope deposits frequently unconformably cover the old fluvial deposits.

## *Brown to dark brown Palaeosols of pre-LGM and LGM age*

Palaeosol layers composed of brown to dark brown soils are common in the slope deposits. The soil structure is very stiff and dense, becoming very hard on drying. It is different in texture and structure from the present near-surface brown soil. In contrast to the present light brown soil, which is very loose, less coarse and greyish to dark brown in colour, the underlying dark brown soil comprises sandy silts with rock fragments in the lower part and a fining-upward sequence. These are blocky but consistent palaeosols and therefore look like fragipan soils with lateral foliations of ferri-argillans. On top of the brown palaeosol there are soil-wedge structures, which are frequently filled with yellowish brown, loose soil material with a very irregular convolute structure. They vary in vertical depth up to several metres and on the horizontal plane there is a clear indication of polygonal structure. There are various explanations for the origin of these soil-wedge structures. They might be formed under dry/wet and cold climatic condition, characterized by seasonally freezing and thawing phenomena. No evidence of glaciation has yet been found in the Korean peninsula, except near Kyema plateau and Paekdu mountains in the north. However, current seasonal variations of climate in Korea are relatively high and, during the winter, the temperature is often several degrees below zero (Celsius) and palaeo-catena show some features of frost-heaving and frost cracking at the ground surface. If it is assumed that the annual mean temperature during the LGM was about 5 degrees (Celsius) lower than at the present, thus a discontinuous periglacial regime could have been developed in Korea. If, as is highly probable, the cold climate of the LGM in Korea was slightly less severe than that of postulated-above, soil-wedge structures will be dominant with lateral foliations and glassy textures in soil solum, rather than typical continuous periglacial ice-wedge structures that could have been also developed under the sub-boreal climatic regime.

During the LGM palaeosol layers, which are mostly intercalated with slope deposits, are typified by dark brown or dark pinkish brown palaeosols. Several upper palaeolithic stone artifacts were found near these palaeosol layers, the matrix of which formed pre-LGM. However, the palaeosol texture formed during the LGM. The formation age of the palaeosols were verified in many places by radiometric carbon dating and they are as old as 18Ka-22Ka B.P (Kim *et al.* 2002f). Based on the artifacts, landscape setting and dating results, these palaeosols are presumed to be upper palaeolithic settlement grounds, which were periodically buried by flooding episodes of river basins. The river-bed were fluctuated laterally, and river-bed erosion was severely activated until the end of the LGM (ca 17Ka BP) (Kim, Lee & Yang 2002a; Kim *et al*. 2002b).

## *Young Fluvial Deposits (post-LGM)*

During the later part of last Glacial period, the major rivers prograded towards the Yellow Sea, and this Sea almost disappeared ca. 18Ka BP when sea level was about 120 m below the present sea level (Lee, 1987; Lee 7 Kim 1992a). After the LGM, the sea level rose abruptly due to the rapid melting of ice around the polar region.

The latest Pleistocene fluvial sequence following the LGM is exemplified in the Jangheung-ri and Soro-ri sites (Kim *et al.* 2002a; Kim *et al.* 2002b). The Jangheung-ri site is subdivided into 2 typical sub-sequences, based on the lithofacies and radiocarbon ages. They are (1) young fluvial sands and gravels, and (2) backswamp organic muds. The lower part of the post-LGM sequence is typified by young fluvial sand and gravel that was deposited by perennial streams. The middle part of the post-LGM sequence, however, is characterized by organic muds, particularly formed after 12-14Ka BP. Local backswamps flourished and graded suspension materials in the flooding muds accumulating intermittently in the organic muds of the backswamps until ca. 11Ka BP. This episode was associated with the migration of the Nam River towards its present course. Pollens such as Abies/Picea-Betula with Ranunculaceae, Compositae, Cyperaceae are prevalent. The formation age of the organic mud layers is interpreted to belong from the Bolling to the Allerod (Kim *et al.* 2002c). The Soro-ri area of Miho River valley also reveals post-LGM organic muds and their formation age is 15-12Ka BP. Pollen zones are divided into three from bottom to top. The younger fluvial sequences, with several horizons of peaty clays and intercalation of flooding muds, have been formed since 17Ka BP. The various carbon radiometric ages that have been obtained from Soro-ri organic muds are 17,310±310 yr BP (GX-25495), 16,680±50yr BP (GX-28504) and 17,300±150yr BP (SNU01-297), through 14,820±250 yr BP (GX-25494), 14,800±210yr BP (GX-28421), 13,920±200yr BP (SNU01-291), 12,780±170yr BP (GX-28416), 12,500±200yr BP (SNU01-293, seed of old rice) (Lee, et al, 2002a) and 12,930±400yr BP (SNU01-286) (Lee & Woo 2002b). The vegetation of Soro-ri shows a change from (1) conifer and broad-leaved deciduous forest, or mixed forest (formed in warm and wet backswamp conditions from 16,680-13,010yr BP), through (2) deciduous and broad-leaved forest (typified by warm and swampy conditions older than 9,500yr BP), to (3) conifer forest and abundant fresh water diatoms, indicating relatively cool conditions, which later changed into a backswamp environment with Gramineae predominant (Kim *et al.* 2002b).

## *Young Palaeosol sequences of the Holocene Epoch*

The upper part of the post-LGM sequence includes palaeosol layers, which were formed under rather dry climatic conditions between each flooding period during Holocene times. Desiccation cracks were prevalent in the soil column and these were filled with minute secondary fragments due to pedogenic processes. The soil structure shows typical braided-type cracks in the root zone, and a more diversified pattern of cracks below. The ages of the young palaeosols at Jangheung-ri are 50 or 60ka BP, while those of Soro-ri are dated as 9,580±40 yrBP (GX-28505, S. wall), 9,450±40 yrBP (GX-28506, N. wall), and 8,800 yrBP (50 cm up from GX-26506) (Kim *et al.* 2002b).

## *Flooding/backswamp sequences of the Holocene Epoch*

Holocene coastal alluvial plain deposits are widely developed in shallow but broad drowned valleys in the western coastal area of the Korean peninsula (Kim *et al.* 1998). The alluvial plain deposits are composed of gravelly sands in the upper valleys and silty clay in the lower valley areas. Towards the coastal area, alluvial deposits gradually change into bluish silty clay in the lower part, directly overlying Pre-Cambrian bedrock, and brownish grey silty clay in the upper part. Peaty clays are found at a level of about 7-8 m above mean sea level between these two clay deposits.

### *Flooding deposits*

From 10ka BP to about 6-7ka BP, the Holocene sea-level rise elevated the base level to the present level, almost equal to the alluvial surface (Kim 2001). Since the mid. Holocene, the fluvial flooding level reached the top of the old fluvial deposits, leaving there flood deposits. In prehistoric times, people began to settle on these newly made flooding surfaces, living there until another devastating flooding episode. In such a way, there is a relatively continuous record of human occupation in the Holocene deposits.

### *Backswamp organic muds*

Holocene alluvial plain deposits vary depending on the geomorphology and distance from the main river. In the river channel, the sediments reach to a depth of about 50 m below mean sea level. At the river mouth, fluvial deposits are composed of marine sediments. In the lower part these are overlain by fluvial sandy silt deposits near the surface. Among the fluvial deposits, organic muds (or peaty clays) are intercalated at the depths of 0, 3, 5 and 8 m above the mean sea level in the western coast. Between each of these four peaty clay layers are intercalated by blackish muds or fluvial silty muds. The radiometric carbon dates of the layers are 6,440 ±245 yrBP, 5,500-5,000 yrBP, 3,000 - 2,500 yrBP, and about 1,500 yrBP in ascending stratigraphic order (Lee *et al*. 1992c; Shin *et al* 1993; Choi & Kim 1995). Based on the profiles of the Ilsan coastal plain area (Lee & Kim 1992b; Choi 1992; Hwang 1992), interpreted the geo-environment of these peaty formations as being a local marsh formed at the beginning of regression, during slightly warmer periods than the present time. Accordingly, these peaty layers would represent higher stands of sea level along the western coast of the Korean peninsula than at the present time, though there might be a tectonic influence. These peaty layers have become of interest to prehistory archaeologists because they may contain relics of ancient agricultural practices. It is already known that rice cultivation had begun by the time of the second peat formation about 5,400 yrBP.

A few research projects on Holocene palynology support the predomince of Quercus since 10Ka BP. The drastic climatic change and the sea level rise are distinctly associated with the period of 10-6Ka BP, based on the pollen diagram. At the Soro-ri site, pollen analysis indicates the presence of Pinus-Colyus forest (OS-2 zone, mixed conifer and deciduous broad-leaved forest) up to about 10Ka BP, Alnus-Quercus forest (OS-3 zone, cool temperate deciduous broad- leaved forest) from about 10-2Ka BP, and Pinus forest (OS-4, conifer forest) after about 2ka (Kim *et al.* 2002b; Kim *et al.* 2001; Kim *et al.* 2002f). Holocene vegetation is also exemplified by the pollen zonations of four different sites; (1) Oksan-ri in Hampyeong county (Kim *et al.* 2002e); HP-I: Alnus-Quercus zone (bottommost, 2.5ka), HP-II: Pinus-Quercus zone (90-156 cm depth), HP-II: Pinus zone (bottom), and (2) Sanggap-ri in Gochang county (Kim *et al.* 2002d); GC-I: the Alnus zone, deciduous broad- leaved forest, before about 5ka BP, GC-II: the Alnus-

Quercus zone, cool temperate deciduous broad-leaved forest about 5-2ka BP, GC-III: the Laevigatosporites zone, and GC-IV: the Pinus zone, temperate conifer forest, after about 2Ka; (3) Yeongsan River mouth (Nahm *et al.* 2002), the late Holocene pollen zonation characterized by Quercus zone (since ca. 10Ka BP) and Quercus-Pinus zone (since ca. 3-4Ka); (4) Gimhae fluvial plain (Yi *et al.* 2001), the late Holocene pollen zonation typified by Quercus-Pinus zone (since ca. 2-Kka BP). In conclusion the palynological zonations of Soro-ri, Oksan-ri, Sanggap-ri, Yeongsan River estuary and Gimhae fluvial plain, as illustrated in this current research, are similar to those of previous researchers (Choi 1997; Yi *et al.* 1996).

### *Anthropogenic layers*

In the coastal areas, artificial layers including reclaimed or artificially turbated layers and filled ground for either agricultural farm land or for reinforcing weak foundations, are common above the tidal mudflat or coastal and/or fluvial wetland deposits. However, episodic flooding invaded farm land or reclaimed horizons in the fluvial reaches so that ancient human occupations during historical times might have been damaged by inundation such that the inhabitants might have moved toward hill sides located at least 6.5 m to 7.0 m above mean sea level in order to avoid the next possible flooding hazard. In modern times, various artificial construction in the fluvial reaches, including construction of embankments, dykes, dams and hazard prevention facilities, have greatly diminished flooding damage though not everywhere has been fully protected from occasional flooding. Other modern artificial intervention affecting the river-beds or fluvial reaches is related to currently excessive extraction of sand and gravel aggregates, which incurs an artificial rising or lowering of the equilibrium height of the thalweg, and which in turn leads to the destruction of the natural fluvial erosion and sedimentation regime in the main river systems of South Korea.

## LATEST QUATERNARY AND HISTORICAL PERSPECTIVES OF FLUVIAL SEQUENCES

For the uppermost Pleistocene depositional sequences, inferred to be as old as 70-50ka BP, the old sand/gravel sequences and the last glacial slope deposits with palaeosols are the main depositional sequences prior to the LGM. Several horizons of organic muds, less than 1m in thickness, are interbedded with the fluvial sands and gravels, which are relatively widely distributed above the reaches of the Miho-cheon and Musim-cheon rivers near Cheongju City. The fluvial organic muds were found in two typical layers in the last glacial sequences. The lower one is intercalated with the old fluvial sequences, while the upper one is found in the young fluvial sequences formed in the post-LGM period. Since 18Ka BP, erosional processes had become more pronounced at the beginning of post-LGM period. From about 17-15Ka BP up to the end of the Last Glacial period, fluvial depositional processes prevailed. The young fluvial sequences were characterized by intercalations of organic muds, particularly formed after 12-14Ka BP. They were formed in local backswamps or abandoned channels, and were intermittently interrupted by flooding muds until ca. 11Ka BP. Pollens such as Abies/Picea-Betula with Ranunculaceae, Compositae, Cyperaceae were prevalent until ca. 10Ka BP. The young fluvial sequences intercalated with organic muds are associated with the Bolling and Allerod intervals (indicating MIS-1).

Holocene palaeosols with abundant desiccation cracks cover the top of young fluvial sequences and have been interpreted to have formed under dry conditions between flooding episodes until the middle Holocene. Middle and late Holocene fluvial sands and gravels are distributed at the base level below the young fluvial sequences or Holocene (young) palaeosols along five major river valleys in South Korea, including the Han River.

In coastal areas, on the other hand, due to rapid sea level fluctuations associated with the rapid melting of continental ice in the polar region, the coastal areas migrated landward, and the major parts of the lower reaches of the old river mouths in the western coastal plain were submerged beneath the Yellow Sea. By the time of the Climatic Maximum of the Holocene, ranging from 7 to 6Ka BP, sea level was almost at its present level. In the coastal and river mouth areas, exemplified in the Ilsan and Anjung-Pyeongtaek areas, dominant depositional sequences are associated with lowermost bluish grey tidal flat muds, grey organic muds in the old wetland due to migration or shifting of old mudflats and tidal channels formed in response to the fluctuation of mean sea level.

Frequent inundations of the coastal areas took place after the middle Holocene in the Korean peninsula. Sedimentary profiles of the alluvial archaeological sites along the major rivers show general flooding episodes after the Holocene Climatic Maximum. Repetition of floodplain deposits, with pedogenetic horizons during dry periods, indicates that particularly since 3Ka B.P and up to 2.2Ka B.P, the major rivers have been flooded several times in accordance of climatic fluctuations. In addition many cultural relics, including pottery and early human settlements, cultivation remains, and remnants of old land management systems, have been found in several alluvial archaeological sites of Bronze Age to Iron Age. Since about 2Ka BP, the coastal plains of S. Korea were inundated several times. Coastal areas and reaches of main rivers produce pottery fragments and other artifacts, which belong to the Koryeo and Chosun Dynasties of the Middle Age. Much archaeological and stratigraphical evidence has been reported for historical human occupations in the river reaches, especially on the reaches of major rivers in the coastal plains.

Finally as an example of ancient human practices and management in S. Korea, it is inferred that ancient human intervention mainly accompanied the process of old fluvial wetland management for the purpose of reclaiming land for cultivation. Subsequently such simple management has been complicated by such human practices as an over-management and reduction of wetlands in river reaches, excessive river-bed aggregate mining, and deforestation of catchment areas which are some of the causes of catastrophic erosion and the accumulation of the flood sediments in fluvial reaches.

# CONCLUSIONS

Late Quaternary depositional and pedological sequences are composed of last interglacial sequences and last glacial sequences. The last interglacial sequences are represented either by marine or fluvial terrace deposits, which display conspicuous flat surfaces about 10-20 m higher than the present mean sea level or above river bottoms of major rivers. The last interglacial pedological deposits are characterized by reddish brown soil, which are older than the early last glacial period (ca 75 Ka BP) and are overlain by less weathered brown to yellowish brown soil or dark brown soil of the last glacial period. The last glacial sequences are composed of old fluvial deposits (pre-LGM), slope deposits of pre-LGM age, brown to dark brown palaeosols of pre- and during-LGM age, and young fluvial sequences (post-LGM age). Late Quaternary (last interglacial and last glacial) environmental changes are reflected in the fluvial sedimentary sequences of South Korea. The sedimentary stratigraphy of the latest Quaternary sequences of several fluvial drainage basins is discussed. Several organic mud layers, intercalated in fluvial deposits, are interpreted as examples of the sedimentary sequence stratigraphy and these include those at Jangheung-ri on the Nam river, Soro-ri on the Miho River, the Yeongsan River mouth in Muan, Oksan-ri of Hampyeong and Sanggap-ri of Gochang. The methodology of this study includes analyses of sedimentary facies, carbon radiometric ages, and pollen data. The terrestrial sequences of post-Last Glacial Maximum (post-LGM) are interpreted to be a response to a millenium-scale fluctuation of fluvial environmental changes. In general, fluvial sequences display a cyclicity of fluvial sand and gravel derived from an old river-bed, organic muds of backswamp origin, and flooding muds with palaeosols.

Fluvial sedimentary sequences are interpreted to be associated with backswamp organic muds of various ages. The age of formation of the lower organic mud layer is greater than 36ka B.P, and that of the upper organic mud layer ranges from 12Ka BP, up to 17Ka BP at the Sorori site. The estuarine fill sequences are composed of: (1) lower fluvial coarse sands and pebbles, with levee/backswamp homogeneous mud, partly cross-laminated mud, and massive sand (38-29Ka), and (2) upper floodplain brown-mottled clayey silt with a few sand layers (flooding palaeosols, 29-27Ka) in the Yeongsan River mouth. In the upper organic mud layers derived from local backswamps, arboreal pollens such as Abies/Picea-Betula with Ranunculaceae, Compositae, Cyperaceae were prevalent until ca. 10Ka BP. The Holocene Upper flooding deposits contain a number of fragments of plant roots; these deposits were subjected to intensive pedogenic processes. Since 18ka BP, erosional processes became more pronounced at the beginning of the post-LGM period. From about 17-15Ka, fluvial depositional processes prevailed up to the end of the Last Glacial period. The young, late Quaternary, fluvial sequences, intercalated with organic mud layers, are associated with the late-glacial B lling and Aller d intervals, indicating the Marine Isotope Stage-1 (MIS-1) in Korea.

The Holocene fluvial sequences comprise a young palaeosol deposits of early Holocene age, and flooding-backswamp-anthropogenic deposits of middle to late Holocene age. The latter deposits are typified by flooding mud deposits, backswamp organic muds, and anthropogenic layers, in the ascending stratigraphic order. Flooding deposits with intermittent pedogenetic horizons have been formed in response to local climatic fluctuation and human intervention in river reach areas, evidenced by cultural relics including pottery and early human settlements, cultivation remains, and remnants of old land management systems since the Bronze Age (ca. 3.5Ka BP) and the Iron Age (ca. 2.3Ka BP) up to the present day.

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