The Journal of the Korean Society of Oceanography
Vol. 32, No. 3, pp. 138-144, September 1997

Difference of Clay Mineral Compositions between Holocene and Late Pleistocene Tidal Deposits in the Haenam Bay, Korea: Evidence of Subaerial Exposure and Weathering

YONG AHN PARK[1], JIN YONG CHOI[2], DHONG-IL LIM[1]
BOO-KEUN KHIM[1] AND SUN YOUNG HWANG[1]
[1]*Department of Oceanography, Seoul National University, Seoul 151-742, Korea*
[2]*Department of Oceanography, Kunsan National University, Kunsan 573-701, Korea*

The tidal deposits in the Haenam Bay, southwest coast of Korea, are stratigraphically divided at least into two units (Unit I of Holocene and Unit II of late Pleistocene) based on the obtained vibracoring sediments. In Unit I, clay minerals of illite, chlorite, kaolinite and smectite are observed as similar to those of the other modern tidal deposits. Of note, however, is the absence of smectite and chlorite in the upper part of Unit II compared with the clay mineral compositions of Unit I. It is concluded that the subaerial weathering and diagenetic effects rather than depositional processes are responsible for the positive and characteristic differences in clay mineral compositions between two units, that is, the upper part of Unit II was exposed subaerially and weathered diagenetically prior to the late Holocene transgression. Therefore, the bounding relationship between Unit I and Unit II is unconformable.

INTRODUCTION

Korean tidal flats along the west coast of Korean Peninsula are worldwidely famous for the macrotidal regime (> 5 m tidal range) and the extensiveness, which is about 5 km wide and about 1,000 km long in average. A variety of sedimentological, biological and geochemical studies on the modern tidal flat deposits along the west coast of Korea have been carried out (Chung and Park, 1978, Frey *et al.*, 1989; Wells *et al.*, 1990; Alexander *et al.*, 1991; Shin *et al.*, 1993; Lee *et al.*, 1994). Most of the studies deal with the distribution pattern of surface sediment types, clay mineral compositions, the dynamic morphologies and the transport and deposition of suspended materials in the macrotidal environments.

Recently, Park *et al.* (1995) investigated the stratigraphic sequences in the Namyang Bay tidal deposits in order to understand the evolutional stage of tidal deposits during the late Quaternary. According to their results, the late Pleistocene tidal deposits are overlain by the modern tidal flat sediments of Holocene age with sharp unconformable boundary. It was also suggested that the late Pleistocene tidal deposit was exposed to the subaerial conditions during the last glacial maximum (LGM) when the sea level was low (Kim and Park, 1988; Chang, 1995; Chun *et al.*, 1995). Therefore, in particular, the upper part of the late Pleistocene tidal deposit is characterized by yellowish brown color and oxidized signatures.

The Haenam Bay is a semi-enclosed coastal bay elongated in NW-SE direction with narrow entrance to the northwestern part (Fig. 1). Tidal flats are developed along both sides of the bay with average width of about 2.5 km. In 1993, the tidal flat reclamation project dammed the mouth of the bay resulting in the air-exposure of the intertidal flat surface. Representative of preliminary stratigraphic frameworks constructed from the twenty-three vibracoring sediments obtained in the tidal deposits of the Haenam Bay is depicted in Fig. 2. The depositional sequences consist of the intertidal muddy deposits (Unit I) of transgressive and/or high-stand sea-level sequence during the Holocene as well as the tidal muddy deposits (Unit II) of late Pleistocene in age. The sequence boundary between Unit I and Unit II is an erosive and distinct unconformity, which can be traced for the entire Haenam Bay.

The present study reports the clay mineral compositions of the Holocene tidal flat sediments (Unit I) and the upper part of the late Pleistocene tidal deposit (Unit II). Comparison of compositional differences between two units provides an evidence for the subaerial exposure and postdepositonal weathering of intertidal deposits.

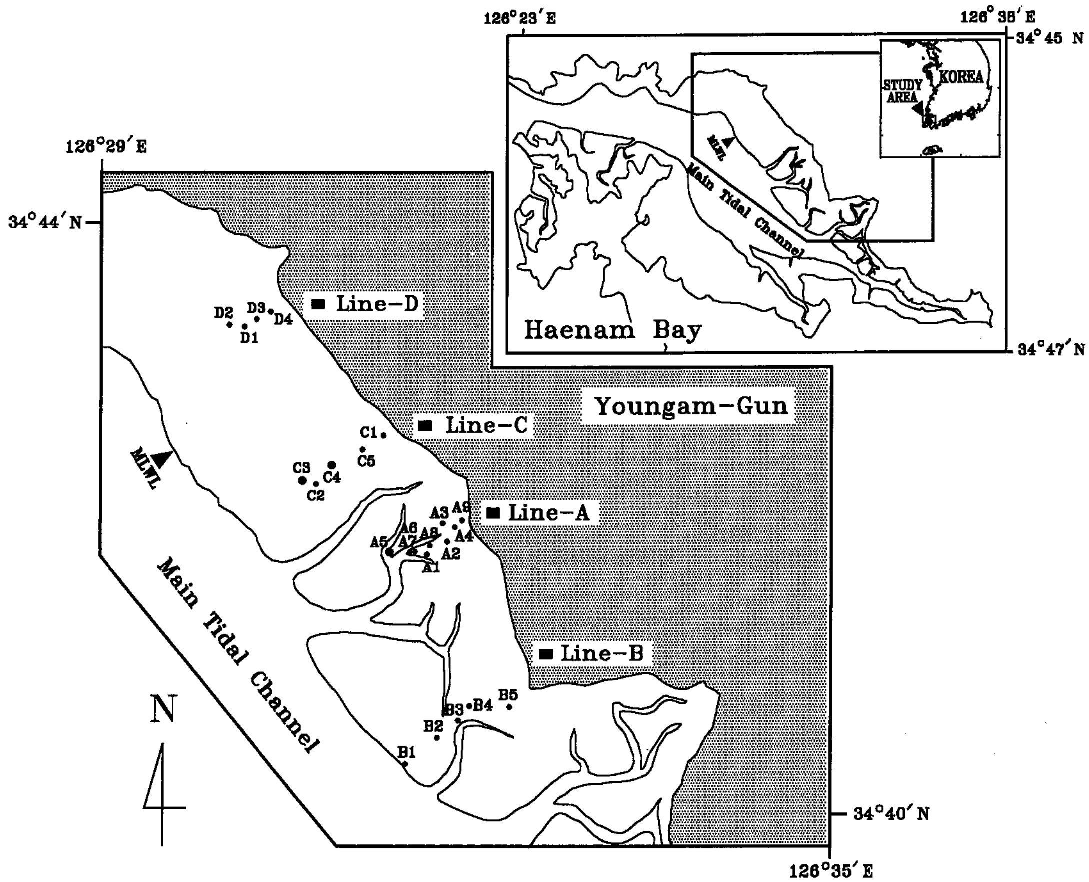

Fig. 1. Location map of the study area and sample stations.

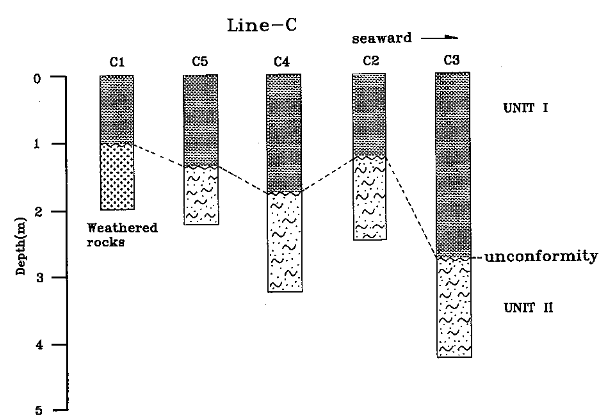

Fig. 2. Representative of stratigraphic framework constructed by the preliminary vibracoring specimens in the Haenam Bay. The Holocene intertidal deposits of Unit I overlies the late Pleistocene tidal deposits of Unit II by erosional unconformity.

MATERIALS AND METHODS

Three vibracoring specimens (HN-A5, HN-C3 and HN-C4) selected for the present study are almost up to 6 m in length, which comprise the oxidized yellowish-brown layer of upper part of Unit II and the Holocene tidal deposit of Unit I. Due to the limitation of mechanical apparatus, we are not able to retrieve all the complete section of Unit II. After splitting the cores in half, vane shear strength and water content were measured. Sediment samples, taken at the 10 cm intervals, were subjected to the granulometric and clay mineral analyses.

Two slide specimens were prepared for the clay mineral analysis; one is untreated and the other ethylene-glycolated. X-ray diffractions were conducted by the MAC X-ray diffractometer under the 40 kV and 30 mA condition attached Ni filtered Cu-Kα radiation with scanning speed of 3°2θ/min. After the identification of clay minerals, semi-quantitative calculations were made following the standard graphic area method by Biscaye (1965). In spite of mixed-layer clay minerals present in the diffractogram, four major clay minerals (illite, chlorite, kaolinite and smectite) are considered.

RESULTS

X-ray diffractogram patterns

Almost invariably the principal clay minerals (illite, chlorite, kaolinite and smectite) are observed in the Holocene intertidal sediments of Unit I. The pattern of X-ray diffractogram of Unit I and the upper part of Unit II shows the vertical changes of the clay mineral compositions (Fig. 3). In the core of HN-C3 (Fig. 3a), swelling smectite peaks at 5.2° (d=17 Å, peak S) are clearly present in ethylene-glycolated specimens of Unit I, but are completely absent in the upper part of Unit II. Concurrently, chlorite peaks at 6.6° (d=14 Å, peak C) are also absent in the upper part of Unit II. Such extinction of chlorite in Unit II is also observed at 18.4° (peak C) in the untreated samples. Furthermore, doublet peaks of kaolinite and chlorite at about 25° (peak K/C) in Unit I are changed into single peak of kaolinite in the upper part of Unit II.

The pattern of X-ray diffractograms in the core HN-A5 is similar to that of core HN-C3 (Fig. 3b). Smectite (peak S) and chlorite (peak C) are also absent in the upper part of Unit II. In this core, the doublet peaks of kaolinite and chlorite at about 25° (peak K/C) are altered into a single peak same as the pattern in core HN-C3. In addition, it is interesting that the illite peak from the untreated samples (8.8°, Peak I) in Unit II has the shoulder to the low angle side.

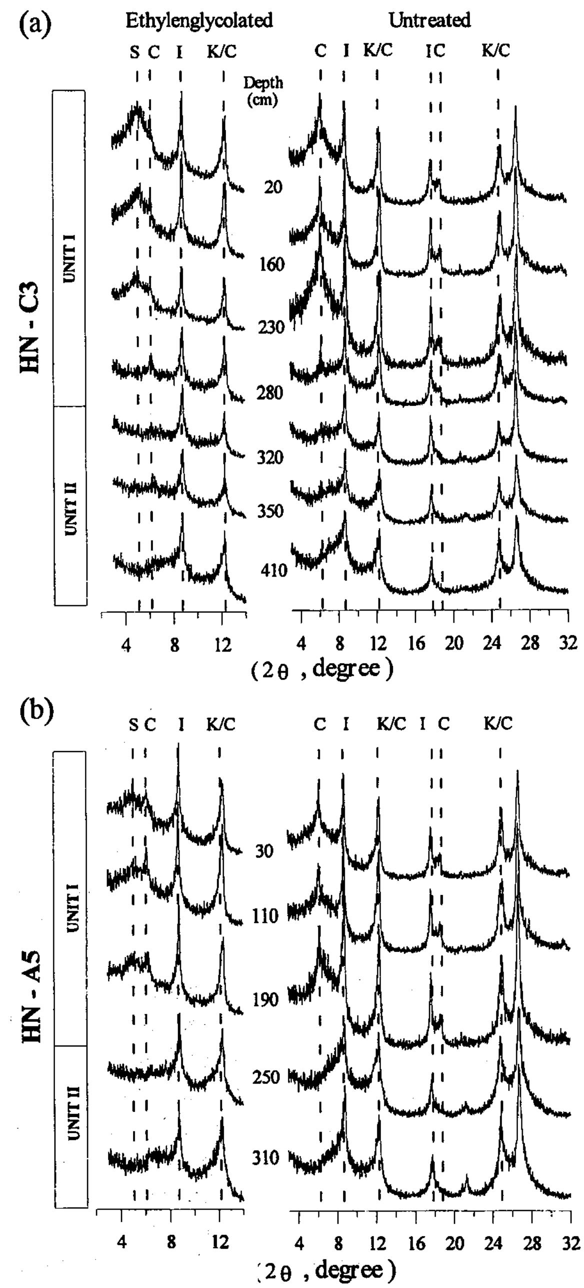

Fig. 3. Pattern of X-ray diffractograms of clay minerals; (a) core HN-C3, (b) core HN-A5. S: smectite, C: chlorite, K: kaolinite, and I: illite.

Clay mineral abundance, texture and geotechnical characters

Vertical profiles of clay mineral abundances from the HN-C3 and HN-C4 cores are illustrated in Fig. 4, together with the granulometric and geotechnical data. In core HN-C3, the yellowish brown sediments in the upper part of Unit II, showing typical cryoturbated structures, are mostly fine-grained with mean grain size more than 6 phi (Fig. 4a). This unit is characterized by semi-consolidation with shear strength higher than 1 kg/cm^2 and less than 30% of water content. However, the sediments of Unit I show up to 75% of water content and less than 0.1 kg/cm^2 of shear strength, respectively, which defines the typical properties of recent soft intertidal sediments. Abundances of chlorite and smectite in Unit I are about 16% and 12%, respectively. On the other hand, the upper part of Unit II is characterized by the absence of smectite and chlorite, and consists dominantly of 72% illite and 24% kaolinite (Fig. 4a).

In core HN-C4, the yellowish brown sediments in the upper part of Unit II, showing typical cryoturbated structures, are largely fine-grained with mean grain size between 5 and 8 phi (Fig. 4b). These semi-consolidated sediments in the upper part of Unit II has less than 30% of water content and up to 1.5 kg/cm^2 of shear strength, respectively. In contrast, the sediments of Unit I have similar values of water content and shear strength compared to those of Unit I of core HN-C3. Vertical changes in clay mineral compositions of HN-C4 are also similar to those of HN-C3. In fact, amounts of chlorite and smectite in Unit I are 16% and 11%, respectively. On the other hand, smectite is not found and less than 5% of chlorite is observed in the upper part of Unit II (Fig. 4b).

Results of such semi-quantitative analyses of clay mineral compositions in the sediments of Unit I and the upper part of Unit II are summarized in Table 1 as well as illustrated in the ternary diagram (Fig. 5). Clay mineral compositions between the intertidal sediments of Unit I and of the upper part of Unit II are grouped as the different clusters. Such separation is caused by the relative amounts of smectite and chlorite between Unit I and Unit II.

DISCUSSION

Semi-consolidated and yellowish brown deposits overlain unconformably by the Holocene intertidal deposits have been reported from the various parts

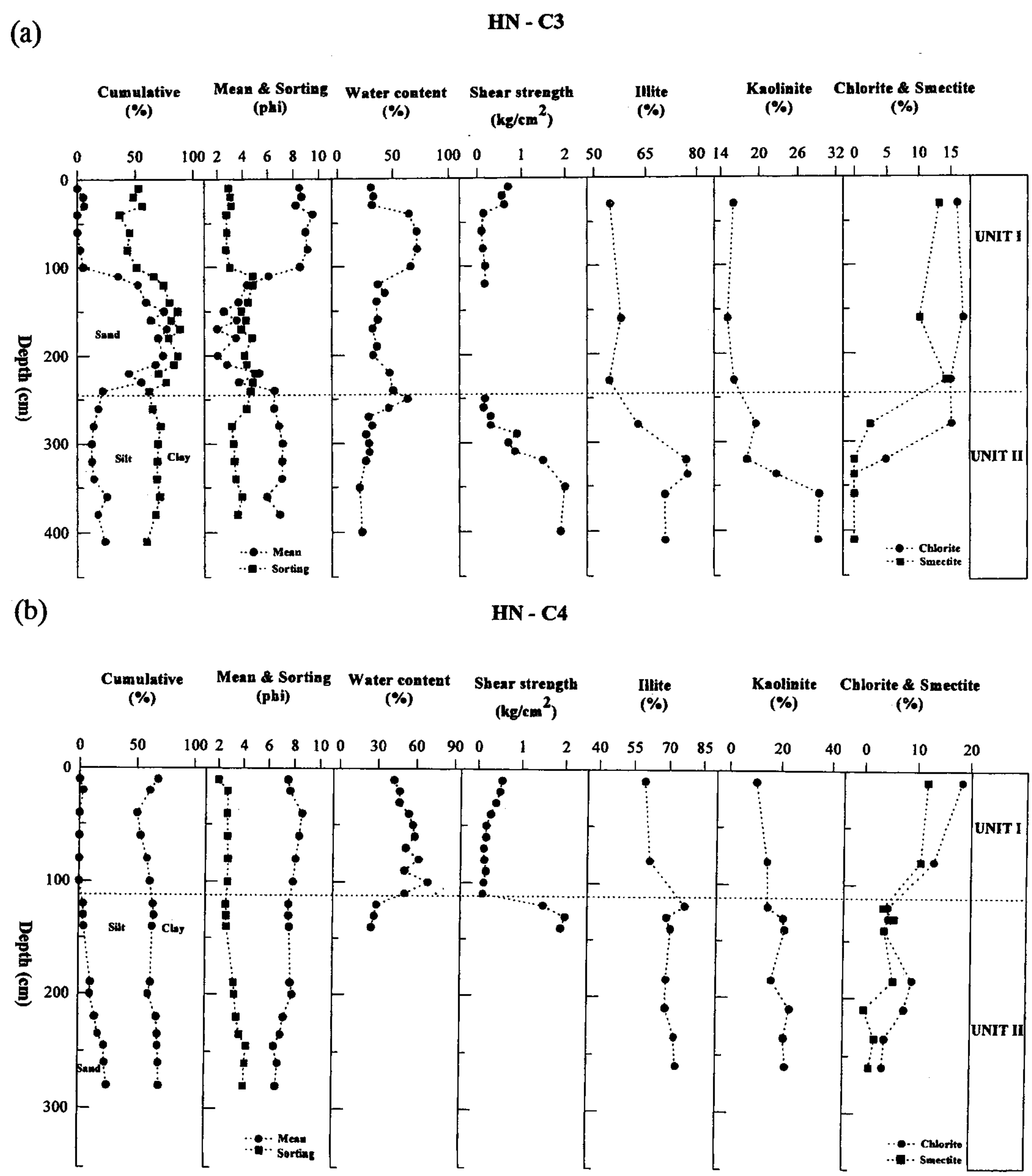

Fig. 4. Vertical variations of clay mineral compositions, grain size properties, water content and shear strength of (a) core HN-C3 and (b) core HN-C4.

Table 1. Clay mineral compositions analyzed from the Holocene tidal deposit (Unit I) and the upper part of late Pleistocene tidal deposit (Unit II)

Core	Clay Minerals (%)				Sequence
	smectite	chlorite	kaolinite	illite	
HN-A5	5	20	16	59	Unit I
	0	4	39	57	Unit II
HN-C3	12	16	16	56	Unit I
	1	4	24	72	Unit II
HN-C4	11	16	12	60	Unit I
	3	4	28	65	Unit II

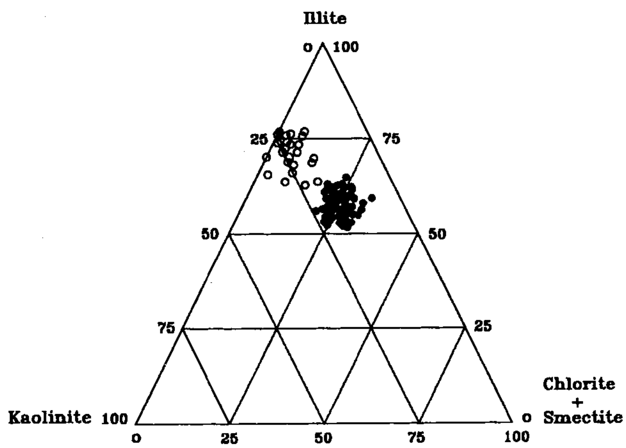

Fig. 5. Ternary diagram of clay mineral compositions of Unit I (closed circles) and upper part of Unit II (open circles).

of intertidal flats along the west coast of Korea; Cheonsu Bay (Kim, 1988), Namyang Bay (Park *et al.*, 1995), Hampyung Bay (Park *et al.*, 1997), Youngjong Island (Park and Choi, 1997) and Haenam Bay of this study. Kim and Park (1988) and Kim and Park (1992) interpreted these yellowish brown deposits (named Kanweoldo deposit) as the late Pleistocene tidal flat deposits. The depositional environment of Unit II is interpreted as the tide-dominated (intertidal flat) environment accounting for the characteristic ichnologic features of fossilized crab burrows and plant remains (Kim *et al.*, 1995). Oh *et al.* (1995) reported that cryoturbated sedimentary structures observed in the upper part of Unit II indicated the dry and cold climate conditions during LGM. Such boundary between the Holocene and late Pleistocene deposits can be traced in the various areas of the intertidal flats along the west coast of Korea as listed above.

In the Haenam Bay the Holocene muddy sediments of Unit I overlie the yellowish brown, semi-consolidated deposits of upper part of Unit II with sharp unconformable erosional boundary (Fig. 2). Based on the results of Ashmore and Leatherman (1984) and Weimer (1984), yellowish color of the upper part of Unit II is indicative of the subaerial exposure to reflect the experience of oxidation stage. As shown in Fig. 5 and Table 1, both smectite and chlorite are nearly absent in the upper part of Unit II, whereas these clay minerals are present in Unit I. Such difference in clay mineral compositions between Unit I and Unit II seems to be not because of the depositional processes but because of the diagenetic weathering of clay minerals when the upper part of Unit II deposit was exposed subaerially during LGM. Many previous studies explained that smectite and chlorite are very unstable clay minerals at the subaerial condition (Trudgill, 1983; Segal *et al.*, 1987; Chamley, 1989). Even these clay minerals are vulnerable to the destruction being transformed

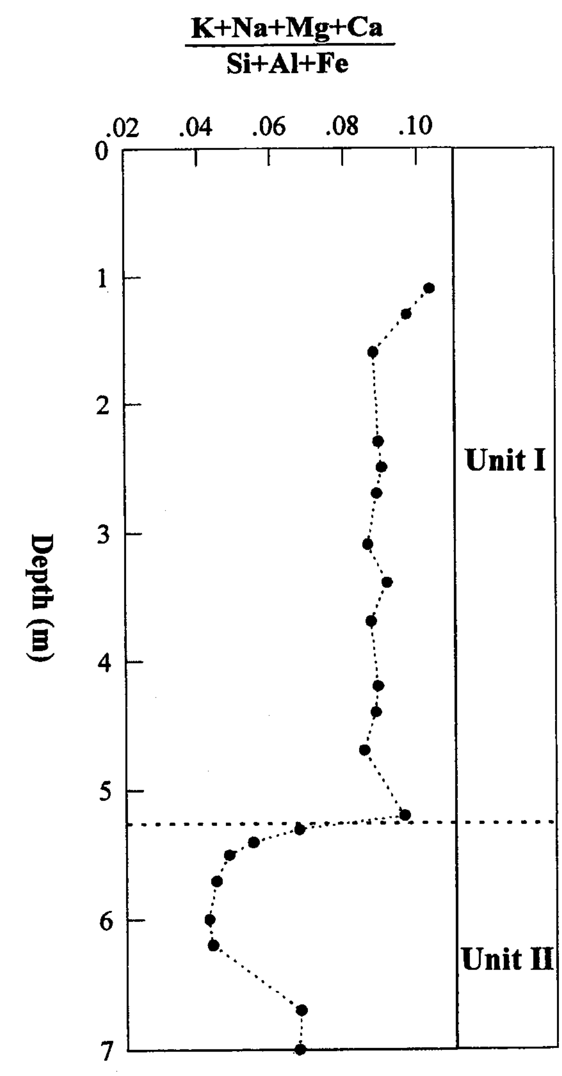

Fig. 6. Weathering index based on geochemical element analyses of Unit I and upper part of Unit II.

into illite and/or kaolinite as suggested by Altschuler *et al.* (1963).

Furthermore, the weathering index based on the concentrations of geochemical elements (Y.A. Park, unpublished) distinguishes the Holocene deposits of Unit I from the upper part of Unit II in the Haenam Bay (Fig. 6). Generally, some geochemical concentrations (K, Na, Mg, and Ca) of the upper part of Unit II are significantly lower than those of Unit I. Selective leachings of such weak elements from the upper part of Unit II may be caused by the subaerial weathering processes, which is similar to the destruction of unstable clay minerals such as smectite and chlorite. Therefore, under the cold and dry subaerial condition during the glacial period of LGM, the original properties of the sediment deposits (upper part of Unit II) such as color, clay mineralogy and geochemical compositions might have been altered by effective weathering and diagenetic processes.

CONCLUSIONS

Tidal flat deposits of the Haenam Bay, located in the southwestern coast of Korea, show two depositional units consisting of the Holocene tidal flat deposits (Unit I) and the overlying yellowish, semi-consolidated late Pleistocene tidal deposits (Unit II). The yellowish brown and oxidized layer comprises only the upper part of Unit II. When comparing clay mineral compositions of Unit I with those of the upper part of Unit II, it is found that smectite and chlorite are almost absent in the upper part of Unit II. From the clay mineralogical data, the oxidized and yellowish brown sediments of upper part of Unit II have experienced the subaerial exposure for a long time during LGM, resulting in the destruction of smectite and chlorite minerals by postdepositional weathering.

ACKNOWLEDGMENTS

We appreciate hardworking graduate students of Shallow Marine Sedimentology and Paleoceanography Lab for their field and laboratory assistances. Also we do thank Dr. Lee, Yoo-Dae (Pusan National University) and Dr. Kim, Seok-Yun (Pukyong National University) for the critical comments on the manuscript to improve understanding of this paper. The financial support from KOSEF (95-0703-02-01-3) granted to Prof. Yong-Ahn Park (Seoul National University) is greatly appreciated. Dr. Boo-Keun Khim (Seoul National University) acknowledges the 1997/1998 Postdoctoral Fellowship from KOSEF.

REFERENCES

Alexander, C.L., C.A. Nittrouer, D.J. DeMaster, Y.A. Park and S.C. Park, 1991. Macrotidal mudflats of the southwestern Korean coast. *J. Sed. Petrol.*, **61**: 805-824.

Altschuler, Z.S., E.J. Dwornik and H. Kramer, 1963. Transformation of montmorillonite to kaolinite during weatheing. *Science*, **141**: 148-152.

Ashmore, S. and S.P. Leatherman, 1984. Holocene sedimentation in Port Royal Bay, Bermuda. *Mar. Geol.*, **56**: 289-298.

Biscaye, P.E., 1965. Mineralogy and sedimentation of recent deep sea clay in the Atlantic ocean and adjacent seas and oceans. *Geol. Soc. Am. Bull.*, **76**: 803-832.

Chamley, H., 1989. Clay Sedimentology. Springer-Verlag, Germany, 623pp.

Chang, J.H., 1995. Depositional processes in the Gomso Bay tidal flat, west coast of Korea. Ph.D Thesis, Seoul National University, 191pp.

Chun, J.W., S.J. Han and J.H. Chang, 1995. Sedimentary environment and diagenesis of late Pleistocene oxidized mud deposits in Gomso Bay, western Korea. *J. Geol. Soc. Korea*, **31**: 546-559.

Chung, G.S. and Y.A. Park, 1978. Sedimentological properties of the recent intertidal flat environment, southern NamYang Bay, west coast of Korea. *J. Oceanol. Soc. Korea*, **13**: 9-18.

Frey, R.W., J.D. Howard, S.J. Han and B.K. Park, 1989. Sediments and sedimentary sequences on a modern macrotidal flat, Inchon Korea. *J. Sed. Petrol.*, **59**: 28-44.

Kim, J.Y., C.H. Cheong, C.J. Lee and B.S. Kang, 1995. Spongeliomorpha ichnosp. from the Quaternary deposits, Kyokpori, southwest coast of Korea. *J. Korean Earth Sci. Soc.*, **16**: 437-441.

Kim, Y.S., 1988. Sedimentary environments and evolution of intertidal deposits in Sajangpo coast, Chunsu Bay, west coast of Korea. Ph.D Thesis, Seoul National University, 169pp.

Kim, Y.S. and S.C. Park, 1992. Stratigraphy and evolution of the intertidal deposit in Gunhung Bay, west coast of Korea. *J. Korean Earth Sci. Soc.*, **13**: 41-52.

Kim, Y.S. and Y.A. Park, 1988. The stratigraphic and sedimentologic natures of the Kanweoldo deposit overlain by the Holocene tidal deposits, Chunsu Bay, west of Korea. *Korean J. Quat. Res.*, **2**: 13-24.

Lee, H.J., S.S. Chun, J.H. Chang and S.J. Han, 1994. Landward migration of isolated shelly sand ridge (chenier) on the macrotidal flat of Gomso Bay, west coast of Korea: controls of storms and typhoon. *J. Sed. Res.*, **A64**: 886-893.

Oh, K.S., Y.A. Park and Y.S. Kim, 1995. Paleoenvironment (LGM time) of the western coastal area of the Korea Peninsula (eastern margin of the Yellow Sea) based on characteristic cryoturbation evidence from the Kanweoldo deposits, Chunsu Bay, west coast of Korea. *Korean J. Quat. Res.*, **9**: 43-60.

Park, Y.A. and K.S. Choi, 1997. Stratigraphy of the macrotidal muddy deposits, Youngjong Island, west coast of Korea. Abstract for Muddy Coasts 97, Wilhelmshaven, Germany.

Park, Y.A., D.I. Lim, J.Y. Choi and Y.K. Lee, 1997. Late Quaternary stratigraphy of the tidal deposits in the Hampyung Bay, southwest coast of Korea. *The Sea, J. Korean Soc.*

Oceanogr., **2**(2): 138-150 (in Korean).

Park, Y.A., J.Y. Choi, D.I. Lim, K.W. Choi and Y.K. Lee, 1995. Unconformity and stratigraphy of late Quaternary tidal deposits, Namyang Bay, west coast of Korea. *J. Korean Soc. Oceanogr.*, **30**: 332-340.

Segal, M.P., D.E. Buckley and C.F.M. Lewis, 1987. Clay mineral indicators of geological and geochemical subaerial modification of near-surface Tertiary sediments on the northeastern Grand Banks of Newfoundland. *Can. J. Earth Sci.*, **24**: 2172-2187.

Shin, D.H., H.I. Yoon, S.J. Han and J.K. Oh, 1993. Distribution and provenance of clay minerals in tidal-flat sediments of the west coast of Korea. *Ocean Res.*, **15**: 123-136.

Trudgill, S.T., 1983. Weathering and Erosion, Sources and Methods in Geography. Butterworth and Co. Pub., 192pp.

Weimer, R.J., 1984. Relation of unconformities, tectonics and sea level changes, Cretaceous of Western Interior, USA. In: Interregional Unconformities and Hydrocarbon Accumulation, edited by J.S. Schlee, Am. Asso. Petrol. Geol. Memoir **36**: 7-35.

Wells, J.T., C.E. Adams, Jr., Y.A. Park and E.W. Frankenberg, 1990. Morphology, sedimentology and tidal channel processes on a high-tide-range mudflat, west coast of South Korea. *Mar. Geol.*, **95**: 111-130.