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Geochemical Compositions of Coastal Sediments around Jeju Island, South Sea of Korea: Potential Provenance of Sediment

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한국 남해 제주도 연안 퇴적물의 지화학적 특성: 퇴적물의 근원지

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Abstract: Surficial sediments from the northern coastal area of Jeju Island, southeastern Yellow Sea (South Sea of Korea) were analyzed for grain-size texture, some geochemical characteristics and clay mineralogy in order to assess their provenance. Rare-earth element compositions and some geochemical discrimination diagrams, especially of Ti/Al, Nb/Al and Rb/Al ratios, were revealed to be useful indices for identifying the origin of sediments. These indices, together with clay mineral compositions, suggest that the coarse-grained sediments originate from the volcanic rocks of Jeju Island, whereas the fine-grained sediments are derived from Chinese rivers, especially the Changjiang River. The oceanic circulation pattern and the physical-chemical properties of seawater in the Yellow and East China seas support the possibility that the fine-grained Changjiang (Yangtze River) sediments can reach the coastal area of Jeju Island (southeastern Yellow Sea).

Keywords: Surficial sediments, geochemical discrimination, provenance of sediment, southeastern Yellow Sea (South Sea of Korea)

요 약: 황해 남동해역의 제주도 연안에 분포하고 있는 퇴적물의 근원지를 조사하기 위해 표층 퇴적물의 입자조직, 지화학 성분 그리고 점토광물 분석이 이루어졌다. 본 연구에서 Ti/Al, Nb/Al 그리고 Rb/Al 비 등을 포함한 특징적인 원소 성분도(geochemical discrimination diagram)와 희토류 원소들의 함량 특성은 퇴적물의 근원지를 판단하는데 매우 유용한 지시자들로 제시된다. 이들 결과에 의하면, 연구해역의 세립질 퇴적물은 대부분 중국의 양자강으로부터 기원 · 운반 퇴적되었으며, 조질질 퇴적물은 주변 화산암의 풍화 잔류물인 것으로 해석된다. 황해와 동중국해에서 최근 조사된 해수의 순환 패턴과 물리-화학적 특성은 양자강으로부터 기원된 세립 퇴적물이 연구해역을 포함한 한반도 남해(황해 남동해역) 연안역까지 운반 퇴적될 수 있음을 보여준다.

주요어: 표층퇴적물, 지화학적 판별, 퇴적물의 근원, 황해 남동해역(한국 남해)

Introduction

The distribution and dispersal patterns of Changjiang (Yangtze River) and Huanghe (Yellow River) sediments in the Yellow and East China seas have been investigated by many researchers (Milliman *et al.*, 1985a, 1985b; Ren and Shi, 1986; Alexander *et al.*, 1991). It has been postulated that the coastal sediments around Jeju Island, located in the southeastern Yellow Sea (Fig. 1), are supplied mostly from the Huanghe River (fine-grained sediments) and from Jeju Island (coarse-grained sediments) (Nittrouer *et al.*, 1984; Milliman *et al.*, 1985a; Youn and Go, 1987; Alexander *et al.*, 1991). For example, a mud patch located just southwest of Jeju Island has been interpreted as the distal deposition of Huanghe-derived materials in the East China Sea, based on the diagnostic occurrence of

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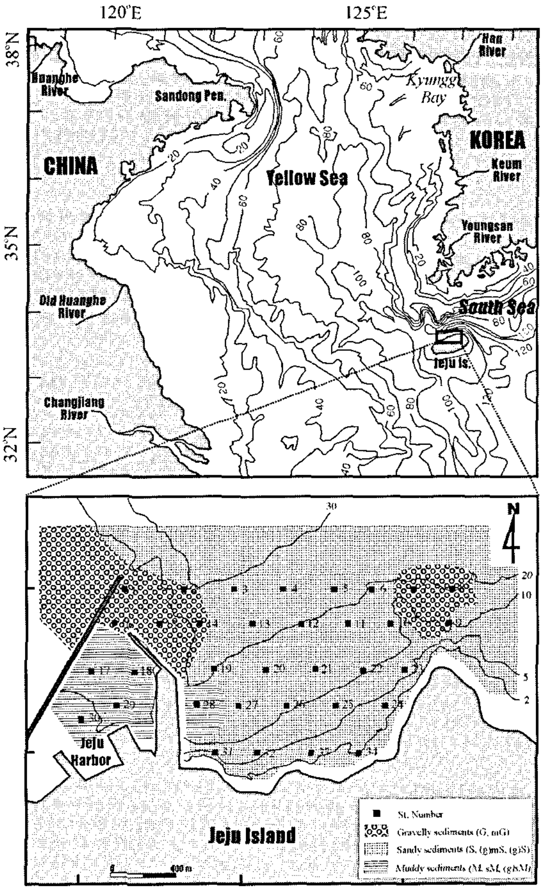

Fig. 1. Bathymetric map showing the study area, the sampling locations and the sediment types around Jeju Harbor. Water depth in meters.

calcite peaks (Milliman *et al.*, 1985a; Alexander *et al.*, 1991). On the other hand, it has been reported that most of the suspended particulate matter from the Changjiang River is dispersed southward, but some is transported northeastwards (as far as about 124° 30' E) by Changjiang dilute freshwater during the summer (Milliman *et al.*, 1985b; Zhang, 1999). Thus, the Huanghe sediments have been thought to dominate the southern part of the Yellow Sea, including most coastal areas around Jeju Island. However, more recent researches based on satellite images suggest that a turbid water mass may reach Jeju Island after mixing with a water mass from the Changjiang estuary in the East China Sea (Lee *et al.*, 1998; Ahn *et al.*, 1999). So, provenance of the coastal sediments (especially, fine-grained sediments) around Jeju Island is not clearly revealed yet.

Jeju Island is a Quaternary shield volcano, composed of hawaiite, alkaline basalt, mugearite and trachyte (Park and Kwon, 1993a and 1993b), and is the largest island in the Korean Peninsula region (80km long and 40km wide). Therefore, it is also possible that the coastal sediments in the vicinity of Jeju Island are partly derived from the island itself. In this study, the geochemical and clay mineral compositions of the sediments collected around Jeju Island are presented in order to identify the provenance of the sediments.

Materials and methods

A number of surface sediment samples were collected in and around Jeju Harbor, which is located on the northern coast of Jeju Island (Fig. 1). The grain size was analyzed using a Sedigraph 5100 analyzer and standard sieving methods, after pretreating the sediments with 10% H_2O_2 and 0.1N HCl. In some selected samples, sediments finer than 2μm were separated by using the pipette technique and subsequently smeared onto glass slides for clay mineral identification. Untreated and ethylene-glycolated slides were run on X-ray diffractometer (MAC Science, MXP-3) using Cu-Kα radiation (λ= 1.514Å) with a Ni filter. The relative abundance of the major clay minerals (illite, kaolinite, chlorite and smectite) was estimated by integrating the areas of each peak (Brindley and Brown 1980).

Elemental contents in labile and residual fractions of sediments were determined by ICP-MS (VG Plasma Quad model). To separate labile and residual fractions of elements from bulk sediments, 0.2g of bulk sediment was leached with 20ml 1N HCl for 24hours, and then the residues were totally digested with concentrated $HF-HNO_3-HClO_4$ in an airtight Teflon container (Kitano and Fujiyoshi 1980). The precision and accuracy of contents were monitored by repeated analyses of the international standard raw material (MAG-1). Differences between the

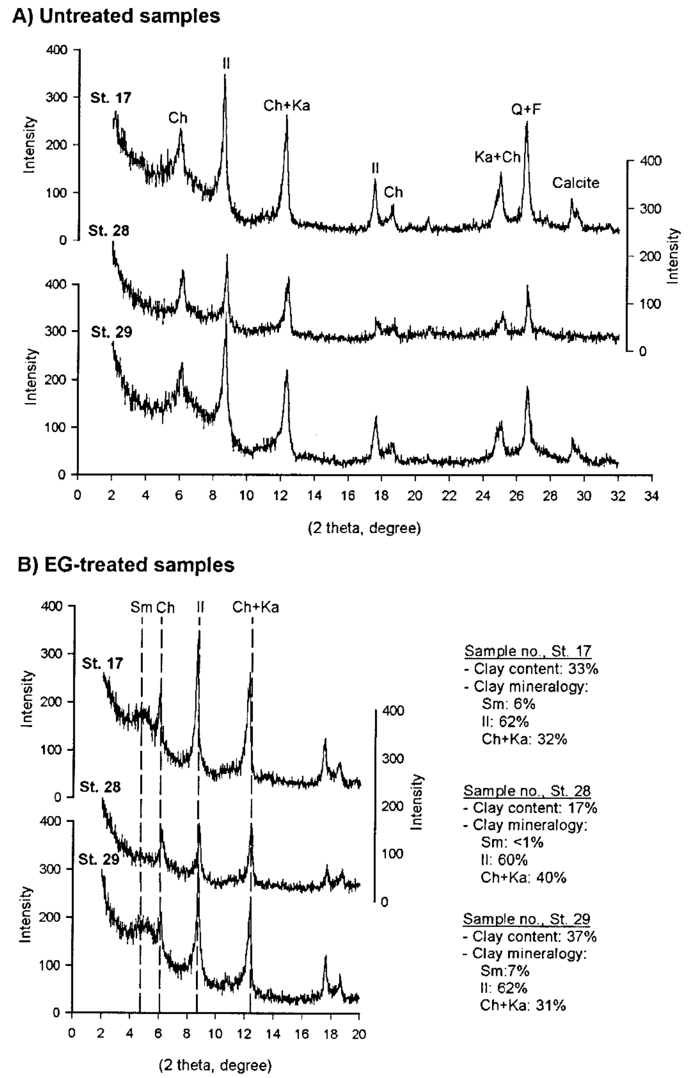

Fig. 2. Representative X-ray diffraction patterns and relative clay mineral contents of fine sediments around Jeju Island. Note the occurrence and lack of calcite peak in the patterns. Sm: smectite; Ch: chlorite, Il: illite, Ka: kaolinite, EG: ethylene glycol

determined and recommended values were generally less than 5%.

Results and Discussion

Geochemical characteristics

The sediments of Jeju Harbor are composed of fine-grained muds (mean grain size 6.8Φ, on the average), while coarse sands (mean grain size 1.1Φ, on the average) are dominant outside the harbor (Fig. 1). Clay sized-sediments consist primarily of illite (generally more than 60%), with moderate amounts of chlorite and kaolinite (more than 30%), and minor amounts of smectite (less than 10%) (Fig. 2). Most of elemental contents are negatively related to sediment grain size, except some elements (Table 1). It was particularly difficult to find a linear relationship between mean grain size and Al content (Table 1). This implies that the sediment grain size is not a prerequisite factor controlling elemental compositions of the Jeju Island's coastal sediments (JJ-sediments). Furthermore, the elements

Table 1. Correlation coefficients for relationships between element contents of bulk sediments and mean grain size in the Jeju coastal zone. All correlations are significant at $p<0.05$.

Element	Correlation coefficient	Element	Correlation coefficient	Element	Correlation coefficient
Al	-0.51	Sc	-0.34	Sn	0.87
Na	-0.12	V	-0.53	Cs	0.97
Mg	-0.73	Cr	-0.35	La	0.20
K	0.26	Zn	0.74	Ce	0.59
Ca	-0.34	Co	-0.68	Nd	-0.28
Ti	-0.75	Ni	-0.43	Sm	-0.56
Fe	-0.74	Rb	0.89	Eu	-0.87
Mn	-0.82	Y	0.10	Gd	-0.64
Sr	-0.46	Zr	0.01	Dy	-0.40
Ba	-0.81	Pb	0.84	Yb	0.31
Li	0.98	Nb	-0.36	Lu	0.52
P	-0.95	Cd	-0.01	Th	0.87

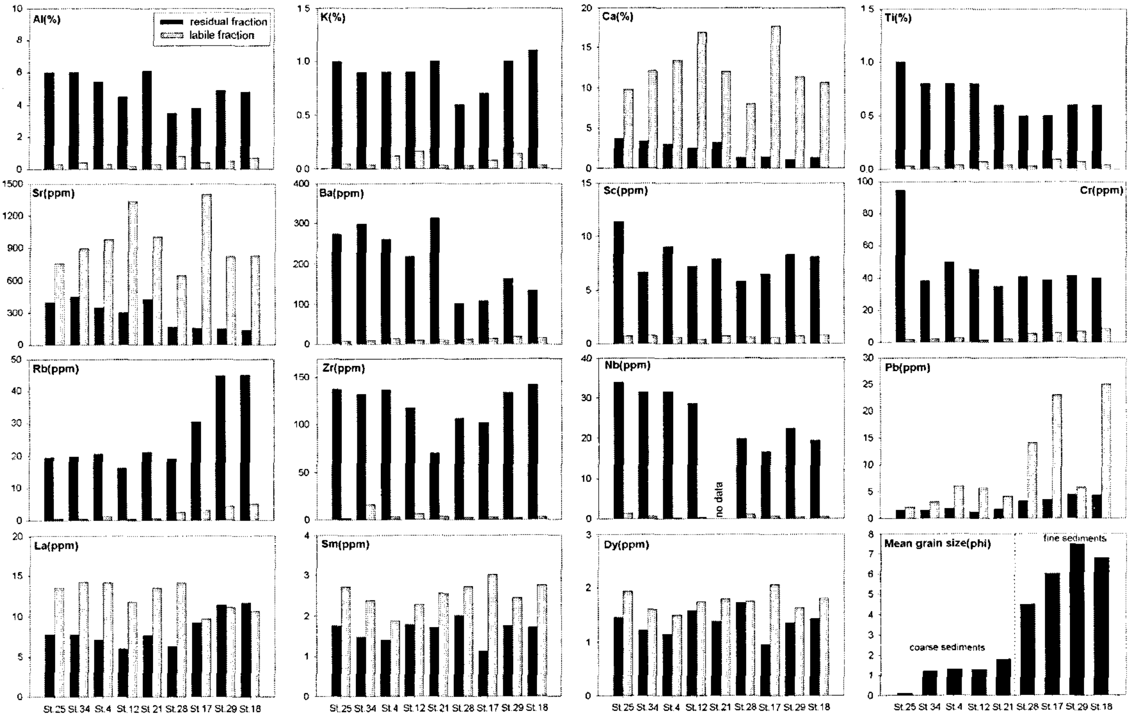

Fig. 3. Elemental compositions of labile and residual fractions in the Jeju coastal sediments. Note that different elements bear obviously different characters in the 1N HCl leaching fraction (labile fraction).

including K, Al, Ti, Ba, Sc, Cr, Rb, Zr, and Nb are primarily enriched in the residual fraction (>80%), indicating that they behave conservatively in the supergene environment and are less diagenetically active (Fig. 3). By contrast, Ca, Sr, Pb and the REEs (rare-earth elements) were more enriched in the labile fraction (>75%), indicating that these elements are mobile during and after deposition.

Based on the sampling locations and the previous references, we assume three potential sources for the sediments around Jeju Island: Jeju volcanic rock, Changjiang and Huanghe sediments. The geochemical compositions of Jeju volcanic rock and Changjiang and Huanghe sediments used in the

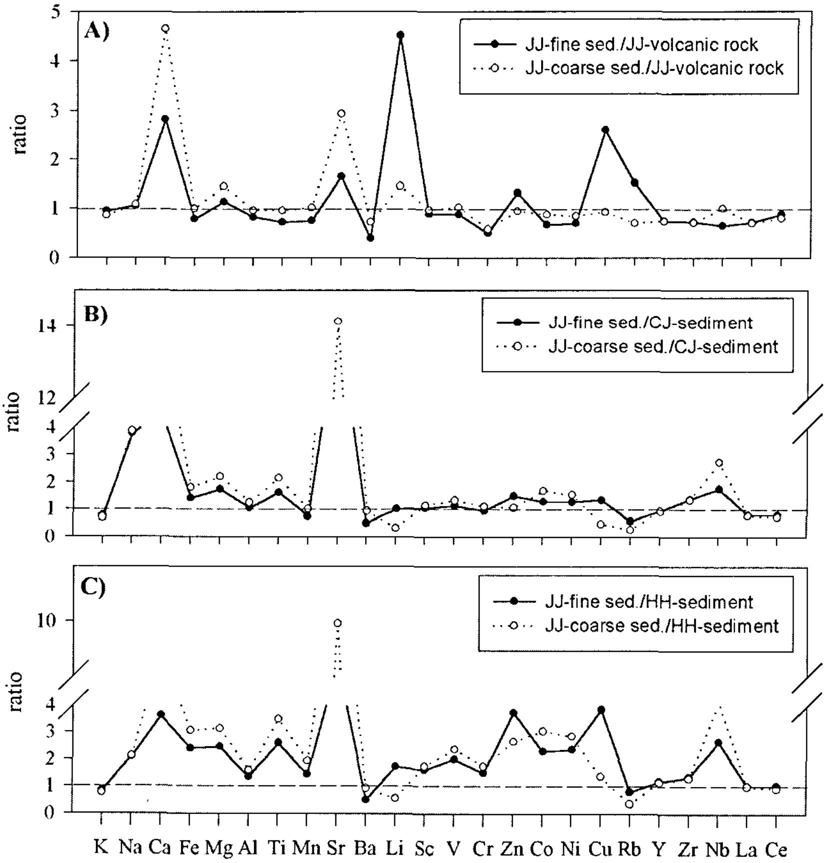

Fig. 4. Comparisons of elemental compositions in the fine and coarse sediments around Jeju Island with those of Jeju volcanic rocks (A), the Changjiang (B) and Huanghe sediments (C). Compositional data of Jeju volcanic rock and Changjiang and Huanghe sediments are taken from Park and Kwon (1993a and 1993b) and Yang *et al.* (2001a and 2001b), respectively. JJ: Jeju, CJ: Changjinag, HH: Huanghe

study are taken from the reports by Park and Kwon (1993a and 1993b), and Yang *et al.* (2002a and 2002b), respectively. The elemental contents in the JJ-sediments (with the exception of Ca, Sr, Li and Cu) are generally similar to those in the Jeju Island's volcanic rocks (JJ-volcanic rocks) and the Changjiang sediments, but they are much higher than those of the Huanghe sediments (Fig. 4). Especially, contents of Ca and Sr were much higher in the JJ-sediments than in the JJ-volcanic rocks or the Changjiang and Huanghe sediments, possibly because of the abundant shell fragments in the JJ-sediment samples. The REEs distribution patterns (normalized with upper continental crust (UCC)) do not exhibit any considerable enrichment, as in the Huanghe and Changjiang sediments (Fig. 5). However, the residual fraction of the coarse sediments (stations 4, 12, 21, 25 and 34) displays a distinct Eu-positive anomaly that is also clearly shown in the JJ-volcanic rocks, but not in the Changjiang or Huanghe sediments (Fig. 5). On the other hand, most of the elements, except for K, Li, Cu, Rb and the REEs, are clearly enriched in the JJ-volcanic rocks relative to the Changjiang or Huanghe sediments (Fig. 6).

Provenance discrimination

In this study, Al, Ti, Nb and Rb can be used to discriminate the source of the Jeju coastal sediments, because they are concentrated in residual

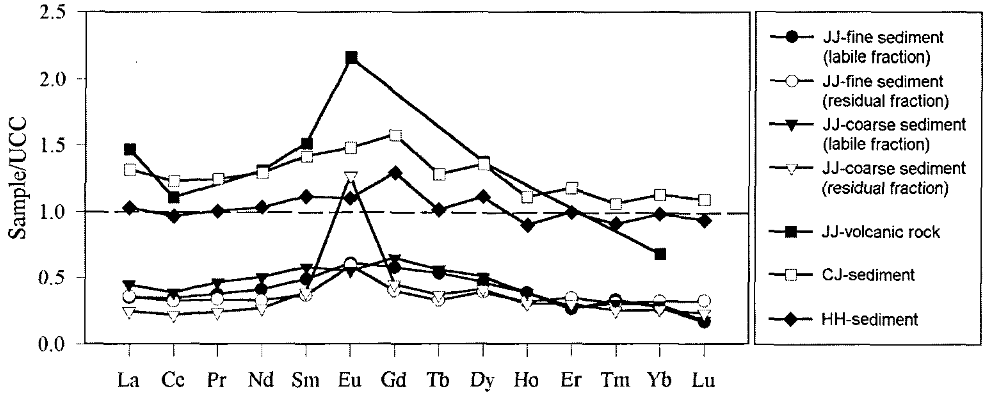

Fig. 5. Comparisons of UCC-normalized REE patterns between the Jeju coastal sediments, Jeju volcanic rocks, the Changjiang and Huanghe sediments. Note that the presences but different degrees of Eu positive anomaly between the Jeju coastal sediments and Jeju volcanic rocks. JJ: Jeju, CJ: Changjinag, HH: Huanghe

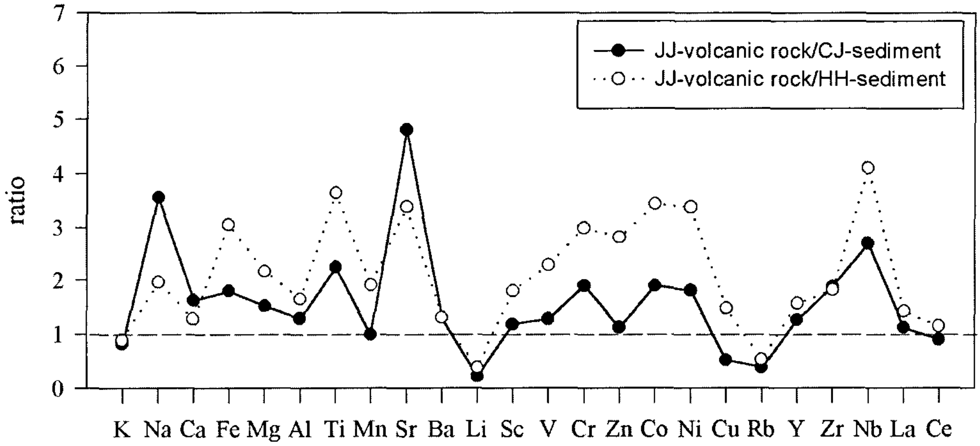

Fig. 6. Comparion of elemental compositions between Jeju volcanic rocks, the Changjiang and the Huanghe sediments. JJ: Jeju, CJ: Changjiang, HH: Huanghe

fractions and their contents differ significantly from the Jeju volcanic rocks, the Changjiang sediments, and the Huanghe sediments (relative deviations, larger than 30%) (Figs. 3, 4 and 6). Pair diagrams of Rb/Al vs. Ti/Al and Rb/Al vs. Nb/Al indicate that the elemental compositions of the fine sediments (stations 17, 18, 28, 29 and 30) are intermediate between those of the Changjiang sediments and the JJ-volcanic rocks (Fig. 7). On the other hand, the elemental compositions of the coarse sediment are very similar to those of JJ-volcanic rocks (Fig. 7). The coarse sediments, composed mainly of sand and gravel, contain rock fragments (up to 70%) in a large portion, which are transported by stream flow or storm erosion (Ji and Woo, 1995). In addition, the UCC-normalized REEs distribution pattern of coarse sediment shows a strong positive Eu anomaly, similar to that of the JJ-volcanic rocks (Fig. 5). The fine sediment REE pattern, by contrast, is not significantly different from those of the Changjiang and Huanghe sediments.

The calcite peak in the XRD patterns of the clay fraction of the Yellow Sea sediments has been suggested as an indicator of the Huanghe provenance (Milliman *et al.*, 1985a). In this study,

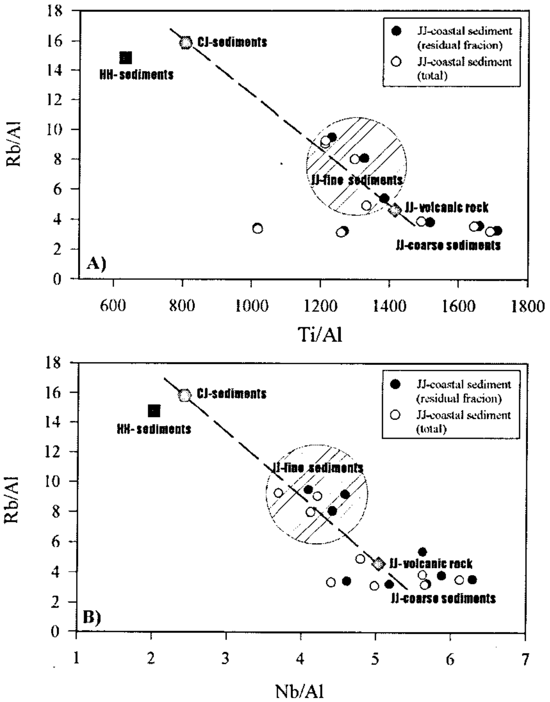

Fig. 7. Discrimination plots Ti/Al-Rb/Al and Nb/Al-Rb/Al. The compositions of the fine muddy sediments are just located between those of the Jeju volcanic rocks and the Changjiang sediments. The coarse sandy sediments have almost same compositions with the Jeju volcanic rocks. JJ: Jeju.

calcite peaks is observed in two Jeju Harbor samples (stations 17 and 29), but not in another sample (station 28) (Fig. 2). The sampling locations of these three samples are very close to one another (Fig. 1) and one would expect the clay mineral compositions to be similar, assuming that the three sediment samples are of the same origin. Therefore, the calcite peaks in the two sediment samples are assumed to have originated from biogenic calcite, which is ubiquitous in the JJ-sediments, and not from Huanghe sediments. Furthermore, the low smectite content of the JJ-sediment samples corresponds well with that of the Changjiang sediments (generally less than 10%; Ren and Shi, 1986), whereas the Huanghe sediments are characterized by high smectite (>10%; Ren and Shi, 1986). Aoki and Qinema (1983) also suggested that the fine-grained Changjiang sediments are distributed around Jeju Island on the basis of a clay mineral analysis of East China Sea sediments. However, smectite can also be derived from basaltic parent materials under temperate, warm to cool climate conditions, while kaolinite predominates in hot to temperate climate zones (Chamley, 1989). Jeju Island is located in the sub-tropical climate zone, with an annual average temperature of about 15.5°C and 1500mm precipitation. Therefore, chemical weathering under Jeju Island's hot and humid conditions yields meager amounts of smectite.

The oceanic circulation patterns in the Yellow Sea and the East China Sea are important for understanding of sediment transport passways to the Jeju Island coastal area. During the spring and summer, the northward Taiwan Warm Current may merge with residual tidal currents around the Changjiang estuary, and then split into two branches, with one flowing eastward through the Jeju Strait (Jung *et al.*, 2001). On the basis of drift data and model calculations, the Jeju Warm Current circulates clockwise around the island (Lee *et al.*, 2000; Lie *et al.*, 2000). Moreover, Yang (1997) suggested the Changjiang River effluents feed into the East Sea (Sea of Japan) through the South Sea of Korea during the summer. Figure 8 shows that the freshwater of low salinity originated from the Changjiang River is dispersed to the South Sea of Korea, including the study area. These studies imply that the oceanic circulation patterns in the Yellow and East China seas may transport the fine-grained Changjinag sediments to the nearshore area of Jeju Island. Satellite data also indicate that turbid water derived from the old Huanghe delta and the Changjiang estuary can intermittently reach the southeastern tip of the Korean Peninsula (Lee *et al.*, 1998; Ahn *et al.*, 1999).

Conclusions

The elemental characteristics of the coastal sediments around Jeju Island are generally similar to those of the Jeju volcanic rocks or to the

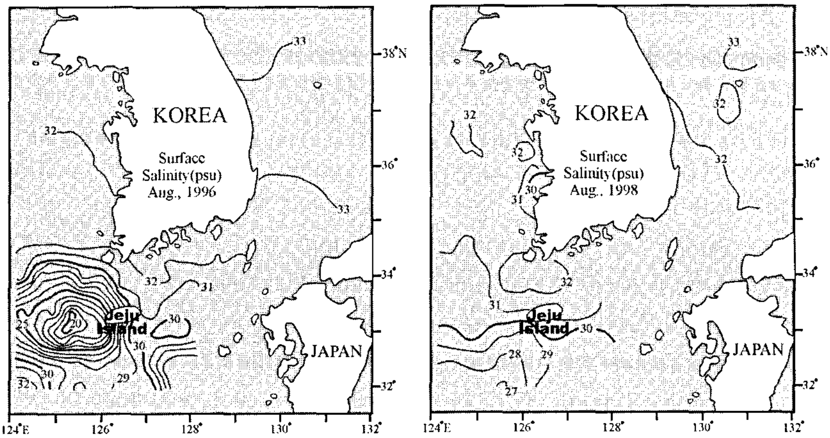

Fig. 8. Distributions of salinity (psu) in the seas around the Korean Peninsula. Note that the Changjiang River freshwater with low salinity is dispersed to South Sea of Korea (southeastern Yellow Sea). Data were provided by SSFRI.

Changjiang sediments, but are clearly different from those of the Huanghe sediments. Discrimination diagrams of Ti/Al-Nb/Al and Rb/Al-Nb/Al show that the sandy sediments around Jeju Island yield almost the same compositions as Jeju volcanic rocks, while the fine sediments bear elemental compositions that vary between those of the volcanic rocks and those of the Changjiang sediments. Furthermore, the clay mineral suites of the sediments are very similar to those of the Changjiang sediments. The XRD calcite peak of the clay fractions discussed in other studies cannot be used to identify sediments as of the Huanghe origin, because of the ubiquitous biogenic carbonate in the fine fraction. Therefore, we infer that very fine particles in the nearshore area of Jeju Island are transported from the Changjiang River, while the coarse sediments are derived from volcanic rocks on Jeju Island. Our preliminary study is supported by recent studies on oceanic circulation in the Yellow and East China seas, which suggest that a branch of the Taiwan Warm Current can transport the fine-grained sediment derived from Changjiang River to the coastal area of Jeju Island, the southeastern tip of the Korean Peninsula.

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