Note

Paleoenvironmental Analysis of a Core Sediment from the Toyooka Basin, Hyogo Prefecture, Japan. —A Study Using Diatom Analysis Combined with Selective Chemical Extraction—

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Abstract

A study using diatom analysis combined with selective chemical extraction was conducted to interpret paleoenvironmental changes in the core sediment obtained near the Maruyama-gawa River in Toyooka Basin, Hyogo Prefecture.

A sediment sample was leached subsequently with 1N HCl and 30% H₂O₂. The remaining silicate fraction was used for the diatom analysis. In the present study, pyrite-sulfur (FeS₂-S) content determined in the 30% H₂O₂ soluble fraction was employed to distinguish marine from freshwater depositional condition and a new diatom-based index of paleosalinity (DIPs) was proposed for the estimation of salinity changes in sedimentary environments. Because of the complementarity between pyrite and diatom analysis in muddy sediments, this method provided continuous and detailed information on the paleoenvironmental changes.

Based on the variation of the DIPs and pyrite content, six phases were distinguished in the present core sample, reflecting salinity changes in sedimentary environments probably caused by the marine transgressions and regressions. The phase variations were consistent with Holocene sea-level changes presumed by variations in $\delta^{13}\text{C}$ values and the C/N ratios in the same core sample (NAKAI *et al.*, 1989).

Key words: diatom analysis, selective chemical extraction, pyrite-sulfur, diatom-based index of paleosalinity (DIPs)

1. Introduction

Diatom analysis of sediments has been used to clarify the changes in sedimentary environments caused by the marine transgressions and regressions in coastal areas (SATO and KUMANO, 1985, 1986). Information on the variation of diatom assemblages, however, is not always obtained because the sediment sample has insufficient diatoms to accomplish a reliable analysis. In order to obtain continuous paleoenvironmental information, another analytical technique should be applied along with the diatom

analysis.

The sediment matrix itself also has a potential for providing detailed information on the changes in sedimentary environment. Variation of a particular chemical component in sediments was employed to elucidate the sedimentary environment (KOMA *et al.*, 1983, 1988, 1989). These studies indicated that sulfur content can be used to determine whether the sediment was deposited under marine or freshwater conditions. Sulfur in sediments can be fractionated into sulfate-sulfur soluble in water, sulfate-sulfur soluble in HCl, sulfides, elemen-

tal sulfur, disulfide-sulfur (mainly of pyrite) and organic sulfur (KOMA *et al.*, 1983).

Pyrite (FeS_2) is a major end product of sulfate reduction and sulfide precipitation in sediments. Pyrite formation depends on a variety of factors, including the abundance of dissolved sulfate, reactive iron minerals and organic matter that sulfate-reducing bacteria can respire (BERNER, 1984). Much more pyrite is usually found in brackish and marine muddy sediments in comparison with freshwater conditions (POSTOMA, 1982). In consequence, pyrite content in sediments was used to distinguish marine from freshwater depositional condition (*e.g.* NAKAI *et al.*, 1982). The pyrite analysis method is based on the difference in sulfate contents in fresh and seawater; seawater contains, on average, $28 \text{ mmol} \cdot \text{l}^{-1}$ of SO_4^{2-} , which is more than a hundred times more than in freshwater (BERNER and RAISWELL, 1984). Pyrite analysis is a useful tool in elucidating the sedimentary environment, particularly when the sediment sample contains few diatom frustules. However, possible pyrite oxidation may have to be taken into consideration, when utilizing the pyrite content as a clue to elucidate sedimentary environments (CHIGIRA, 1988, SATO, 1989).

Sulfate-sulfur and pyrite-sulfur can be separately determined by selective chemical extraction of a sediment sample with HCl and subsequently with H_2O_2 (KITANO *et al.*, 1980). Diatom analysis, if combined with selective chemical extraction, will provide more precise information for paleoenvironmental interpretations.

In this paper, a method using the diatom analysis combined with selective chemical extraction was presented for detailed paleoenvironmental interpretation. The method was applied to a core sediment obtained in an area near the Maruyama-gawa River in the Toyooka Basin, Hyogo Prefecture. Extractable sodium and potassium were also measured to understand their behaviors in depositional and diagenetic conditions.

2. Materials and methods

2-1. Samples

The core sample used in the present study was obtained from a hole bored near the Maruyama-gawa River in the Toyooka Basin in February 1988 (Fig. 1). The core sample (Holocene deposit), which has a total length of *ca.* 42 m, is composed mainly of silt, peaty silt and sandy sediments. Shell fossils were found in the horizons between -10 m and -28 m . By the radiocarbon method, the shell fossils at horizons of about -16 m and -17 m were dated as $5,150 \pm 320 \text{ yr. B. P.}$ and $6,900 \pm 580 \text{ yr. B. P.}$, respectively (NAKAI *et al.*, 1989). The Holocene transgression was shown to have

Fig. 1. Map showing the location of boring site (1; lowland, 2; upland).

culminated in these ages by analyses of the stable carbon isotopic composition ($^{13}\text{C}/^{12}\text{C}$) and the C/N ratio of sedimentary organic matter (NAKAI *et al.*, 1989). For the present study, twenty-seven samples were taken at approximately every 1.0 m interval from the horizons between -2 m and -30 m (Fig. 3).

2-2. Procedure

The selective chemical leaching technique developed by KITANO *et al.* (1980) was applied to the present analysis. The flow chart of chemical leaching procedure is shown in Figure 2. Sodium, potassium, iron and sulfur contents were determined in the 1N HCl soluble and 30% H_2O_2 soluble fractions for 27 sediment samples. Residual silicate fractions were used for the diatom analysis. Sodium and potassium in each fraction were determined by atomic absorption spectrophotometry. Iron was determined colorimetrically by the phenanth-

roline method and sulfate was determined by turbidimetric method (APHA *et al.*, 1985).

2-2-1. 1N HCl soluble fraction

One gram of dried sediment was treated with 10 ml of 1N HCl in a 200 ml conical beaker for 45 minutes on a hot plate set at 80–90°C. After adding 30 ml of distilled water, the whole sample solution was centrifuged (3,000 rpm, 15 min) and the supernatant was saved. The centrifugation was repeated twice and the supernatant was made up to 100 ml.

2-2-2. 30% H_2O_2 soluble fraction

The residue remaining after the first 1N HCl treatment was then digested with 10 ml of 30% H_2O_2 and 2 ml of 3N HCl for 2–5 minutes at 80–90°C and then left to stand overnight at room temperature. Pyrite in the sediments can be completely dissolved by this treatment (KITANO *et al.*, 1980). The sample solution was centrifuged (3,000 rpm, 15 min) and the super-

Fig. 2. Flow diagram of the selective chemical leaching.

natant was saved. The solution was made up to 100 ml.

2-2-3. Diatom analysis

After the HCl and successive H_2O_2 treatments, the residue consisting almost entirely of clay and other silicate minerals was used for the diatom analysis. The sample was dispersed in 200 ml of 1% sodium pyrophosphate solution. The fine mineralogenic material was removed by decantation. The diatom fraction was separated from the remainder by vibration and subsequent decantation of the suspension containing diatom frustules, which take longer to settle than the coarse materials. The diatom fraction was made up to a definite volume and 0.5 ml of the suspension was dropped with a pipette onto a cover slip. The sample was dried on a hot plate. The preparations were mounted in Mountmedia (Wako Chemicals, Japan). The above procedure and the subsequent microtransect counting method (APHA *et al.*, 1985) made it possible to estimate the concentration of diatom frustules per milligram of dry sediment.

The proportional counting was continued until more than 50 frustules of the most common taxon was found. Following the halobion system of LOWE (1974), diatoms were classified into six groups to reconstruct paleosalinity based on the diatom assemblages; halophobous (F1), indifferent (F2), halophilous (FB5), β -mesohalobous (BM10), α -mesohalobous (M20) and euhalobous (M30) (Table 1).

Classification and identification of diatoms were principally according to CLEVE-EULER

(1951-1955), HUSTEDT (1930-1966), PATRICK and REIMER (1966, 1975), VAN DER WERFF and HULS (1957-1974) and JOHN (1983).

In this paper, a new diatom-based index of paleosalinity (DIPs) that is similar in form to the salinity index S proposed by DENYS (1984) was calculated for the estimation of salinity changes in sedimentary environments. The form of DIPs is as follows;

$$\text{DIPs} = P_{F1} + 2P_{F2} + 5P_{FB5} \\ + 10P_{BM10} + 20P_{M20} + 30P_{M30}$$

where, for example, P_{M30} = the relative frequency of the group of euhalobous taxa (M30). According to the salinity range of six groups, each group was weighted with arbitrarily chosen coefficients. The smallest coefficient of 1 was given to the P_{F1} because the halophobous diatoms do not tolerate small amounts of salt. A coefficient of 2 was assigned to the indifferent diatoms tolerating small amounts of salt, 5 to the halophilous ones stimulated by small amounts of salt, 10 to the β -mesohalobous ones occurring in salt concentrations of 500 to 10,000 ($\text{mg}\cdot\text{l}^{-1}$), 20 to α -mesohalobous ones occurring in salt concentrations of 10,000 to 30,000 ($\text{mg}\cdot\text{l}^{-1}$), and 30 to the euhalobous ones occurring in salt concentrations of 30,000 to 40,000 ($\text{mg}\cdot\text{l}^{-1}$).

The DIPs value ranges from a minimum of 1.0 to a maximum of 30.0. For example, if the diatom assemblage is composed entirely of freshwater diatoms, the DIPs value will range from 1.0 to 2.0, since the DIPs is given by $P_{F1} + P_{F2} = 1$ and $P_{FB5} = P_{BM10} = P_{M20} = P_{M30} = 0$. Similarly, if the assemblage is composed entirely of

Table 1. Significant taxa of diatoms classified into six groups of the halobion system.

Euhalobous: <i>Thalassiosira eccentrica</i>	Oligohalobous
	halophilous: <i>Achnanthes crenulata</i>
	<i>Navicula hungarica</i>
	<i>Rhopalodia gibberula</i>
Mesohalobous	indifferent: <i>Achnanthes japonica</i> , <i>A. lanceolata</i>
α -range: <i>Actinoptychus undulatus</i>	<i>Cocconeis placentula</i>
<i>Palaria sulcata</i>	<i>Cymbella</i> spp.
<i>Cyclotella striata</i> , <i>C. stylonum</i>	<i>Gomphonema</i> spp.
<i>Grammatophora</i> spp.	<i>Navicula radiosa</i> , <i>N. viridula</i>
<i>Diploneis smithii</i> , <i>D. suborbicularis</i>	halophobous: <i>Ceratoneis arcus</i>
<i>Nitzschia granulata</i> , <i>N. lanceolata</i> , <i>N. punctata</i>	<i>Eunotia</i> spp.
β -range: <i>Cyclotella striata</i> var. <i>baltica</i>	
<i>Diploneis pseudovalis</i>	

brackish diatoms ($P_{FB5} + P_{BM10} = 1$) of marine diatoms ($P_{M20} + P_{M30} = 1$), the DIPs value will range either from 5.0 to 10.0 or from 20.0 to 30.0, respectively. Thus a low DIPs value indicates a predominance of freshwater influence and the increasing value will indicate the gradual increase of marine influence in sedimentary environments.

3. Results

3-1. Sodium and potassium

The amounts of sodium and potassium in the 30% H_2O_2 soluble fraction were negligibly small relative to those in 1N HCl soluble fraction (Table. 2). The sodium and potassium leached into 1N HCl soluble fraction are derived mainly from carbonate and from ion-exchangeable sites on clay minerals (KITANO *et*

al., 1980). Variation in sodium content tended to increase at the upper part of the profile. The largest amount was obtained in the sample No. 22 (−8 m), whereas potassium content profile showed larger amounts in the samples No. 11–14 (−16 m–19m) (Table 2, Fig. 3).

3-2. Sulfur and iron

The sulfur and iron contents of the chemically-separated fractions of sediments are shown in Table 2. The S/Fe ratio of the 30% H_2O_2 soluble fraction ranged from 0.92 to 1.20, the average of which was 1.08 except for samples No. 1, 22, 26, and 27 (Table 2). The sulfur and iron contents in the 30% H_2O_2 soluble fraction approximately agreed with the stoichiometrical S/Fe ratio of pyrite (1.15), and are therefore assumed to be derived mainly from pyrite.

Table 2. Sodium, potassium, sulfur and iron contents ($mg \cdot g^{-1}$) of chemically-separated fractions, the S/Fe ratio of the 30 % H_2O_2 soluble fraction, and DIPs value.

Sample No.	Na		K		S			Fe			S/Fe in H_2O_2	DIPs
	HCl	H_2O_2	HCl	H_2O_2	HCl	H_2O_2	HCl+ H_2O_2	HCl	H_2O_2	HCl+ H_2O_2		
1	0.96	0.06	0.86	0.08	2.1	0.0	2.1	24.4	1.4	25.7	—	3.5
2	0.81	0.05	0.70	0.05	5.9	15.	21.0	24.8	13.6	38.4	1.12	13.6
3	1.13	0.06	0.90	0.04	6.0	7.5	14.0	27.0	7.0	34.0	1.07	6.0
4	1.61	0.06	1.21	0.05	6.4	4.5	11.0	26.5	4.4	30.9	1.02	5.0
5	1.60	0.07	1.30	0.05	5.6	9.6	15.0	23.1	8.4	31.5	1.14	12.3
6	1.52	0.05	1.18	0.05	5.2	6.9	12.0	24.7	6.0	30.7	1.15	10.8
7	1.46	0.05	1.06	0.05	4.8	6.3	11.0	25.2	6.1	31.3	1.03	15.9
8	1.63	0.05	1.20	0.06	6.9	7.3	14.0	24.1	6.7	30.8	1.09	14.8
9	2.07	0.06	1.47	0.07	8.3	6.4	15.0	30.4	5.7	36.1	1.12	14.2
10	2.10	0.06	1.54	0.08	3.7	9.9	14.0	24.5	8.3	32.8	1.19	—
11	2.37	0.06	1.62	0.08	2.7	6.2	8.9	29.8	5.9	35.7	1.05	—
12	2.40	0.06	1.60	0.08	8.7	5.3	14.0	26.9	4.8	31.7	1.10	15.9
13	2.50	0.07	1.60	0.07	1.4	7.7	9.1	26.8	7.2	34.0	1.07	15.7
14	2.50	0.07	1.60	0.08	2.5	8.7	11.0	23.5	7.7	31.2	1.13	15.9
15	2.40	0.07	1.41	0.07	1.7	3.0	4.7	22.0	3.1	25.1	0.96	—
16	2.43	0.06	1.40	0.07	3.2	2.6	5.8	22.0	2.8	24.8	0.93	—
17	2.59	0.07	1.45	0.09	3.7	4.5	8.2	30.3	4.2	34.5	1.07	—
18	2.86	0.07	1.42	0.07	4.1	3.5	7.6	22.2	3.8	26.0	0.92	12.4
19	2.78	0.07	1.20	0.05	1.1	5.8	6.9	42.5	5.7	48.2	1.02	10.8
20	2.58	0.07	0.89	0.06	5.7	6.0	12.0	19.2	5.0	24.2	1.20	8.8
21	3.04	0.07	1.23	0.07	4.3	4.6	8.9	24.0	4.3	28.3	1.07	7.7
22	3.92	0.10	0.88	0.06	11.	0.0	11.0	19.6	1.9	21.5	—	3.1
23	2.54	0.07	0.85	0.06	17.	2.3	19.0	26.9	2.0	28.9	1.15	7.9
24	1.62	0.07	0.54	0.06	9.0	4.8	14.0	23.6	4.5	28.1	1.07	12.0
25	0.90	0.06	0.64	0.05	8.1	6.6	15.0	19.2	5.6	24.8	1.18	6.0
26	0.14	0.04	0.20	0.06	2.6	0.0	2.6	16.8	0.6	17.4	—	—
27	0.06	0.04	0.10	0.04	0.2	0.0	0.2	7.7	0.3	8.0	—	—

Fig. 3. The vertical profiles of the concentrations ($\text{mg}\cdot\text{g}^{-1}$) of sodium, potassium, sulfur and iron ($-\circ-$, 1N HCl and 30% H_2O_2 soluble fractions; $\bullet$, 30% H_2O_2 soluble fraction), number of diatom frustules and the diatom-based index of paleosalinity (DIPs). (A) Six phases in sedimentary environments distinguished on the basis of the DIPs and pyrite-sulfur content. (B) The vertical variation in acid-soluble sulfur content as an indicator for pyrite oxidation. Sedimentary facies: 1, gravel; 2, sand; 3, fine sand; 4, silt; 5, peat; 6, shell.

Thus, in this paper, sedimentary sulfur dissolved as sulfate into 1N HCl soluble fraction and that into 30% H_2O_2 soluble fraction are ascribed to acid-soluble sulfur and pyrite-sulfur, respectively. The acid-soluble sulfur is thought to be mainly derived from sulfate in sediments (KOMA *et al.*, 1983).

Since abundant reactive iron minerals, represented by 1N HCl extractable iron, were found in all the samples, the availability of reactive iron was not a limiting factor for pyrite formation throughout the profile (Table 2, Fig. 3).

Most of the samples contained more than $2.0 \text{ mg}\cdot\text{g}^{-1}$ of acid-soluble sulfur and pyrite-sulfur except for the sample No. 27 from the uppermost part of the profile (Table 2, Fig. 3).

Pyrite-sulfur was not found in the sample No. 1 from the lowermost horizon of -30 m , the sample No. 22 (-8 m) and the samples No. 26 and No. 27 from the uppermost part of the profile, whereas other samples contained more than $2.0 \text{ mg}\cdot\text{g}^{-1}$ of pyrite-sulfur (Table 2, Fig. 3).

3-3. DIPs

Enough diatom frustules for a reliable analysis could not be obtained in five samples (No. 10, 11, 15, 16, and 17) from the horizons between -11 m and -25 m , and in two samples (No. 26 and 27) from the uppermost part of the profile. Accordingly, DIPs could not be calculated in these samples. Other samples containing abundant diatom frustules showed DIPs values exceeding 5.0 except for sample No. 1

(-30 m) and sample No. 22 (-8 m), of which DIPs values were 3.5 and 3.1, respectively (Table 2, Fig. 3). Relatively high DIPs values in the range of 10.8 to 15.9 were obtained in the samples (No. 5-9, 12-14, 18 and 19) from the horizons between -11 m and -25 m (Table 2, Fig. 3).

4. Discussion

KOMA *et al.* (1983, 1988) studied the relationship between the total sulfur content in muddy sediments and the depositional environment. In these studies, they considered that the amounts less than 0.2% and more than 0.3% of total sulfur in muddy sediments might indicate deposition under freshwater and marine environment, respectively. Since pyrite-sulfur comprises more than 80% of total sulfur in most of the Quaternary sediments (KOMA *et al.*, 1983, 1988), the amounts more than 2.0 mg of pyrite-sulfur per gram sediment sample can be interpreted as an indication of marine deposit.

The low DIPs value of 3.5 and the absence of pyrite-sulfur indicated that sedimentation took place under freshwater conditions in the muddy sediment sample No. 1 from the lowermost part of the profile. At the horizons between -9 m and -28 m and at the horizons between -5 m and -8 m, the amounts of pyrite-sulfur were more than 2.0 mg·g⁻¹. This corresponds to DIPs values exceeding 5.0. Both pyrite-sulfur content and the DIPs value indicate the marine influence in sedimentary environments at the horizons between -9 m and -28 m and at the horizons between -5 m and -8 m. Relatively high DIPs values exceeding 10.0 were obtained in the samples containing abundant diatom frustules at the horizons between -11 m and -25 m (Fig. 3). Although five samples (No. 10, 11, 15, 16 and 17) from these horizons had too few diatoms to calculate the DIPs, the amounts exceeding 2.0 mg·g⁻¹ of pyrite-sulfur indicate the marine influence in sedimentary environments. Pyrite analysis made up for the lack of diatom data at these horizons. Accordingly, it is considered that the high salinity conditions had continued at the horizons between -11 m and -25 m. It is not uncom-

mon for sediments to have few diatoms. Among possible reasons for the paucity of diatom frustules at these horizons, the dissolution of diatom frustules, the small number of diatoms originally living at the time of sedimentation and/or rapid sedimentation rate are most likely.

According to NAKAI *et al.* (1989), radiocarbon dates at horizons of about -16 m and -17 m showed a period of 7,000-5,000 yr. B. P., coinciding with the culmination of the Holocene transgression. In their study, higher $\delta^{13}\text{C}$ values exceeding -25‰ and lower C/N ratios in the range of 20 to 15 were obtained at these horizons. The results indicate a larger contribution of marine plankton to sedimentary organic matter during the culmination of the Holocene transgression. Therefore, the high salinity conditions at the horizons between -11 m and -25 m are considered to indicate the Holocene transgression.

At the horizon of -8 m, pyrite-sulfur was not found and the DIPs showed the lowest value of 3.1 (Fig. 3). This is considered to indicate the predominance of freshwater influence in sedimentary environments. In the uppermost part of the profile, both pyrite-sulfur and diatoms were not found (Fig. 3). It is unlikely that sulfate reduction, which is responsible for pyrite formation, should occur in aerobic conditions such as sandy sediments (KOMA *et al.*, 1989). Generally, diatoms are rare in sandy sediments since they may have been washed out of the deposits by water currents. In sandy sediment, it may be difficult to make paleosalinity estimates directly either by diatom or by pyrite analyses.

Although seawater contains abundant sodium and potassium as dissolved ions, no apparent relationship was found between sodium or potassium content in sediments and presumed paleosalinity (Fig. 3). Many variables in addition to water composition may influence the retention of ionic species within the sediments, *e. g.*, high rate of ionic diffusion (ENGSTROM and WRIGHT, 1984).

The overall stoichiometry for complete pyrite oxidation is described as follows

(POSTOMA, 1983);

Pyrite oxidation is assumed to reflect the increasing sulfate sulfur content in sediments. The sulfur content profile showed that the amounts of acid-soluble sulfur, which include sulfate-sulfur in both sediments and interstitial water, were higher than those of pyrite-sulfur in the samples from the upper horizons between -5 m and -8 m (Fig. 3). This may indicate that pyrite oxidation occurred at these horizons.

Pyrite-sulfur was not found at the horizon of -8 m, where the DIPs value of 3.1 showed the predominance of freshwater influence, while abundant acid-soluble sulfur was found (Fig. 3). The predominance of freshwater influence seems to be largely responsible for the absence of pyrite-sulfur at this horizon; the decrease of sulfate supply may have limited the pyrite formation. On the contrary, the presence of acid-soluble sulfur at the horizon of -8 m should be understood in connection with the variation in sodium content. The largest amount of sodium at the horizon of -8 m may reflect water movements closely related to chemical weathering responsible for pyrite oxidation at the horizons between -5 m and -8 m (Fig. 3), since sodium usually exists as the form of water-soluble chloride, and chlorides are considered as indicators for water movements (KOMA *et al.*, 1983). The increase of sodium content suggests that acid-soluble sulfur may have migrated diagenetically from the upper or lower horizon to the horizon of -8 m by water movement. The profiles of acid-soluble sulfur and sodium contents may indicate increased solutional transport of these elements to the horizon of -8 m and pyrite oxidation having occurred diagenetically under oxidizing conditions prevailing at the horizons between -5 m and -8 m.

Because of the complementarity between pyrite and diatom analysis in muddy sediments, the present study using diatom analysis combined with selective chemical extraction can

provide continuous and more precise information on the changes in sedimentary environments than the individual analyses. Moreover, this method proved to be useful for understanding the diagenetic chemical processes that take place in the sediment after deposition.

5. Conclusion

In the present work, a boundary value distinguishing freshwater from brackish/marine depositional condition seemed to be 5.0 in DIPs value and 2.0 mg·g⁻¹ of pyrite-sulfur content in the sediments. Based on the variation in DIPs value, six phases in salinity conditions, each of which is considered to reflect the change in sedimentary environment caused by the marine transgression or regression, were distinguished as summarized in Figure 3A. Among six phases, phase III, including a period of 7,000-5,000 yr B. P., showed higher DIPs values exceeding 10.0. This phase is considered to reflect the culmination of the Holocene transgression, which is consistent with Holocene sea-level changes presumed by variations in $\delta^{13}\text{C}$ values and C/N ratios in the same core sample (NAKAI *et al.*, 1989). Variation in acid-soluble sulfur content was useful to estimate the extent of pyrite oxidation that occurred diagenetically under oxidizing conditions (Fig. 3B), which was also indicated by the increase of sodium content in the sediment.

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摘 要

分別化学抽出と珪藻分析を組み合わせた方法によるコア堆積物（兵庫県豊岡盆地）の古環境解析
分別化学抽出と珪藻分析を組み合わせた方法を

用いて、兵庫県豊岡盆地の円山川近くで採取されたコア堆積物について堆積環境変化のより詳細な古環境解釈を得ることを試みた。

堆積物試料を 1N HCl, 30% H₂O₂ の順で溶解し、残りのケイ酸塩画分を珪藻分析に供した。今回の分析では、30% H₂O₂ 溶解画分に溶出した黄鉄鉱イオン (FeS₂-S) の含有量から海成堆積物と淡水成堆積物を区別し、さらに、堆積環境の塩分濃度変化を数量的に評価するために新しく珪藻古塩分濃度指数 (DIPs) を算出した。泥質堆積物において黄鉄鉱イオン分析と珪藻分析が相互に補足し合うことにより、本法は古環境変遷について連続かつ詳細な情報を提供した。

黄鉄鉱イオン含有量と珪藻古塩分濃度指数値の変動に基づいて、本コアの堆積物から塩分濃度変化を反映する 6 つの堆積相が識別され、それぞれは海進あるいは海退を反映するものと考えられた。その堆積相の変遷は同一コアにおいて、中井ほか (1989) によって明らかにされた有機物炭素の $\delta^{13}\text{C}$ および C/N 比からみた完新世の海面変動と矛盾しない。

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