Sci. Rep. Kanazawa Univ.
Vol. 38 No.1,2 pp. 79～94
December 1993

# Mineralogical Assemblages and Distribution Trends of Deep-Sea Sediments from Izu-Bonin Arc Leg 126, ODP

Gouping ZHOU and Kazue TAZAKI

*Department of Earth Sciences, Faculty of Science, Kanazawa University, Kakuma, Kanazawa, 920-11, Japan*

**Abstract:** Sediments drilled on Ocean Drilling Program Leg 126 at Sites 790, 791, 788, 787 and 792 are discribed focusing on mineralogical assemblages and distribution trends. Mineralogical assemblages are mainly composed of calcite, quartz, feldspar, zeolite, gypsum and clay minerals. Distribution trends of mineralogical assemblages show that the catastrophic events of sedimentation history are reflected by the sharp changes in minerals abundances. In the backarc the sharp change in minerals abundances occurs during the Pleistocene volcano eruptions which have changed the sediments sources. In the forearc the change occurs in the period from 27 to 23.5 Ma, suggesting the evolution of tectonic movements from the late Oligocene episodic fluctuations to the early-middle Miocene relative stability due to a proposed rise in global sea level during this period. The alteration of volcanic glass and feldspar during diagenesis results in secondary zeolites and smectite, of which the occurence of wairakite indicates the presence of hydrothermal alteration exceeding 200 ℃.

## 1. Introduction

Holes drilled on Ocean Drilling Program (ODP) Leg 126 completely penetrated the sediments and recovered basement rocks at sites in the Sumisu Rift and the Izu-Bonin forearc basin. Sites 790 and 791 were drilled wthin the Sumisu Rift and Site 788 on the rift flank. Other three sites (Sites 787, 792 and 793) were drilled in forearc basin. The cores collected from these holes provide a unique opportunity to study the history of sedimentation, arc volcanism, microstructural deformation, and plate motion ( TAYLOR and FUJIOKA, et al., 1990 ). The diagenetic and hydrothermal mineral alteration of deep-sea sediments at Sites 792 and 793, and the diagenetic trends of sandstones in Leg 126 have been discussed ( TAZAKI, 1991; 1992; TAZAKI and FYFE, 1992; MARSAGLIA and TAZAKI, 1992 ).

The purposes of this study are (1) to document the mineralogical assemblages and distribution trends of deep-sea sediments in backarc basin ( Sites 790 and 791 ), Rift flank ( Site 788 ) and forearc basin ( Sites 787 and 792 ); (2) to discuss the effects of sedimentation on the mineralogical assemblages and the alteration after deposition.

## 2. Geological Setting and Lithostratigraphy

Sites 790 and 791 are located near the center of Sumisu Rift (Fig. 1). Site 788 is located on the eastern margin of the Sumisu Rift between the active Izu-Bonin arc volcanoes Sumisu Jima ( 58 km north ) and Tori Shima (55 km south-southeast)( Fig. 1).

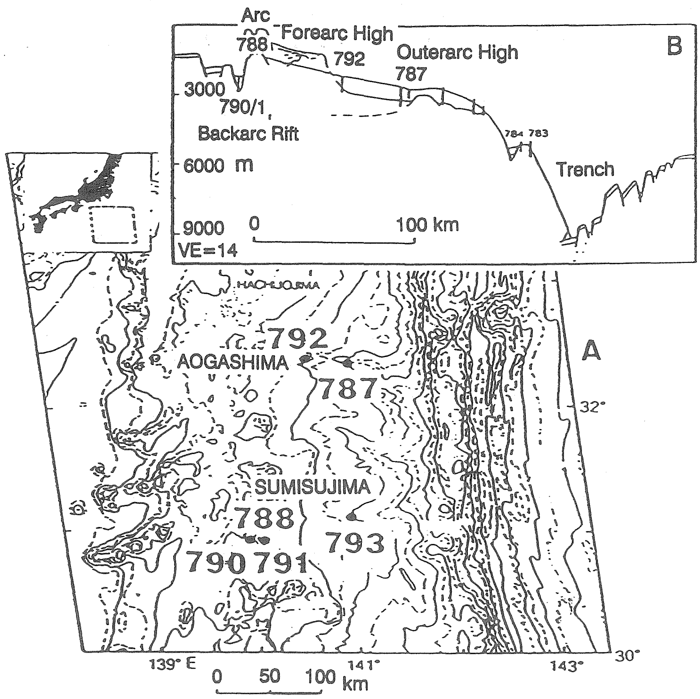



Fig. 1 Location map of Leg 126 drill sites(A). Counter intervals in thousands of meters. Schematic section of Izu-Bonin Arc with drill site locations(B) (after FUJIOKA, et al., 1992). VE=verticle exaggeration.

The sedimentary section at Site 791 is about three times thicker than the time-equivalent section at Site 790 ( Fig. 2 ). Nevertheless, lithotypies and generalized stratigraphy at two sites are similar ( TAYLOR and FUJIOKA, et al., 1990; DADEY and KLAUS, 1992 ). The stratigraphic succession at Site 788 consists of two lithologic units, both of which are mainly volcanogenic components with much of gravel and conglomerate ( Fig.2). No igneous basement rock was recovered.

Sites 787 and 792 were drilled in the forearc basin of Izu-Bonin Arc (Fig. 1). Both sites have similar Oligocene to Pleistocene lithologies (Fig. 2). The thickest stratigraphic unit at both sites is a lower to upper Oligocene turbidite succession derived from the contemporay Izu-Bonin intraoceanic arc ( FUJIOKA and SAITO, 1992 ). The lower to middle Miocene of the forearc is represented by fine-grained, deep-water sediments, most of which are rich in biogenic carbonate (TAYLOR, FUJIOKA,.et al., 1990; FUJIOKA, et al., 1989). Clay is the significant terrigenous component in the sediments. The total section of lower to middle Miocene is thin because of low sedimentation rates and multiple unconformities ( HISCOTT, et al., 1992).

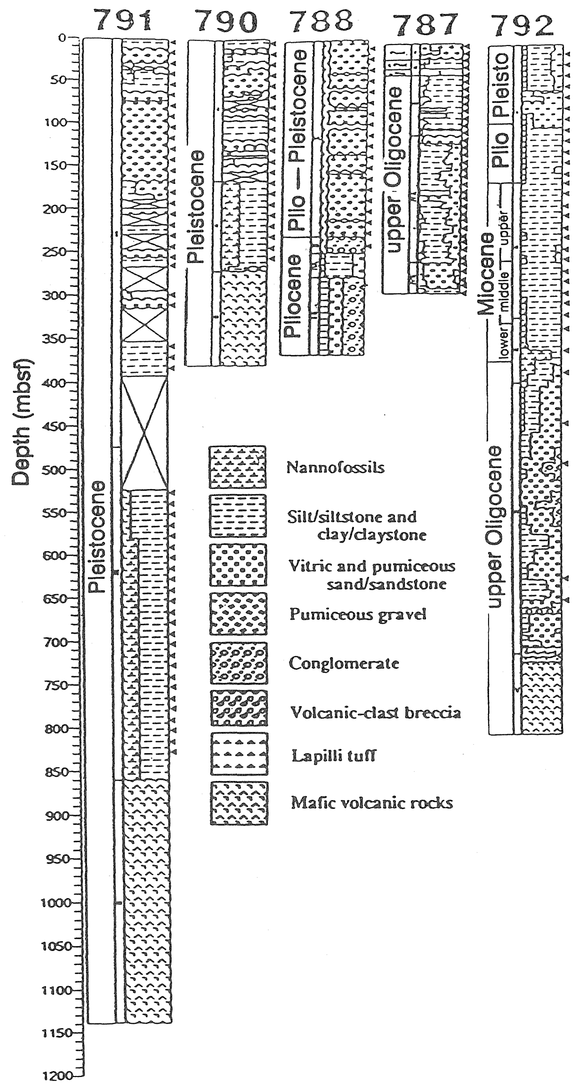



Fig. 2 Lithologic columns of Sites 790, 791, 788, 787 and 792 in Izu-Bonin Arc (after FUJIOKA, et al., 1992). Arrows show sample locations.

## 3. Samples and Methods

A total of more than 300 bulk samples from Sites 790, 791, 788, 787 and 792 were analyzed by X-ray powder diffraction ( XRD ) method and < 2$\mu$m fractions of selected samples were isolated by sedimentation method to make clay minerals investigation by XRD. The samples were analyzed on a Rigaku RAD-C System X-ray diffractometer using $CuK\alpha$ radiation and accelerating voltage of 30 kV, 10 mA. Analysis range for identification of clay minerals, zeolites, feldspars, sulfur and sulphate minerals and iron oxidized minerals in the interval between 2°- 70°(2 $\theta$). For the examination of clay minerals, ethylene glycol was used to saturate the samples and then heating treatment was made on 500 ℃ for 2 hours.

Semiquntitative estimates of major minerals and clay minerals( TAZAKI, 1991) were determined using the strongest peak intensity under same analytical conditions (measured in counts per second; CPS) of each mineral, for example, calcite 3.03 Å; quartz 3.34 Å; feldspar 3.17-3.20 Å; gypsum 7.67 Å; erionite 11.4 Å; offretite 11,5 Å chabazite 9.4 Å; ferrierite 9.6 Å; laumontite 9.5 Å; clinoptilolite 8.9 Å; mordenite 9.10 Å; phillipsite 7.2 Å; analcime 5.6 Å; faujasite 14.3 Å; wairakite 5.8 Å; cristobalite 4.05 Å; smectite 14 Å; illite ( 10 Å clay minerals ) 10 Å. For the detailed research on the morphology and alteration relationship between minerals and the characteristics of secondary minerals, smear slide and thin section were prepared of some selected samples and observed by optical microscope and scanning electron microscope(SEM). SEM observation was conducted using a JEOL-JSMT 220A scanning electron microscope with an accelerating voltage of 15 kV.

Identification of minerals is based on the characteristic peaks of each mineral with helping of observation by thin section and SEM. Volcanic glass abundance was estimated from the intensity of broad peak dome at 20°-30° (2$\theta$).

## 4. Results

### 4.1 Mineralogical Assemblages

The results of identification by XRD analyses of major and minor minerals at five sites are summarized in Table 1. In major minerals, zeolite, partial clay minerals and gypsum are secondary minerals. Species of zeolite are different at five sites characterized by dominant phillipsite in backarc basin and varieties of species including phillipsite, wairakite, analcime, ect. in forearc basin. Zeolite usually occurs irregularly in samples by thin section observation, and sometimes occurs locally as irregular nodulars.

Clay minerals include dominantly smectite and illite ( 10 Å clay minerals ). In the oriented XRD samples of $< 2\ \mu m$ fractions, smectite shows a very strong 001 refraction peak at 14 Å. The peak moves to 17 Å after saturation with ethylene glycol and a distinct 002 refraction peak at 8-9 Å occurs. The peak at 17 Å moves to 10 Å after treatmet at 500 ℃ for 2 hours. Zeolite and partial clay minerals, particularly smectite, result from the alteration of volcanic glass and feldspar after deposition and during early diagenesis. SEM observation shows that the alteration of glass is characterized by smectite forming on surface or in cavities of glass and zeolite growing from the inside of glass towards the outside ( Plate 1-A, B and C ). Gypsums generally occur as irregular nodulars or small veins in grains and are characterized by euhedral crystals by thin section and SEM observations ( PLate 1-D ). Pure gypsum nodulars show sharp peaks at 7.64 Å, 2.97 Å,

Table 1 Mineralogical assemblages at five sites of Izu -Bonin Arc.

| | SITES | BACKARC | | RIFT FLANK | FOREARC | |
|---|---|---|---|---|---|---|
| MINERALS | | 790 | 791 | 788 | 787 | 792 |
| Major Minerals | Calcite | ● | ● | ● | ● | ● |
| | Smectite | ● | ● | ● | ● | ● |
| | Illite | ● | ● | ● | ● | ● |
| | Gypsum | ● | ● | ● | ● | ● |
| | Phillipsite | ● | ● | | ● | ● |
| | Wairakite | | | | ● | |
| | Mordenite | | | | ● | |
| | Analcime | | | | | ● |
| | Laumontite | | | ● | | |
| | Clinoptilolite | | ● | | ● | |
| | Ferrierite | | ● | | ● | |
| | Erionite | | | | ● | |
| | Offretite | | | ● | ● | |
| | Chabazite | | | ● | | |
| | Faujasite | | | | | ● |
| | Quartz | ● | ● | ● | ● | ● |
| | Feldspar | ● | ● | ● | ● | ● |
| | Cristobalite | ● | ● | ● | ● | ● |
| | Volcanic glass | ● | ● | ● | ● | ● |
| Minor Minerals | Pyrite | ● | ● | ● | ● | ● |
| | Pyrolusite | ● | ● | ● | ● | |
| | Troilite | ● | | ● | | |
| | Sulfur | ● | ● | ● | ● | ● |
| | Diaspore | ● | | | | |
| | Barite | ● | ● | ● | | |
| | Siderite | ● | ● | | | |
| | Alunite | | ● | | | |

3.03 Å and 4.27 Å in XRD patterns.

### 4.2 Distribution Trends of Major Minerals

The results of semiquntitative estimates of major minerals at five sites are summarized in Fig. 3, 4, 5, 6 and 7.

#### Backarc Sites 790 and 791

The distribution of major minerals at both sites 790 and 791 is similar. Minerals distribution trend allows the distinction of two groups of mineralogical assemblages ( Fig. 3 and 4 ). (1) Unit 2 assemblage in Pleistocene is dominated by abundant calcite, quartz and clay minerals; (2) Unit 1 assemblage in Pleistocene is characterized by abundant volcanic glass with significant amount of feldspar and small amount of calcite, quartz and clay minerals. In Unit 1 at Site 790, calcites show a flauctuating increase (Fig. 3) and this flauctuating increase is, sometimes, present in Unit 1 at Site 791 (Fig. 4). Thin section and SEM observation shows that most of the calcites are resulted from abundant calcareous nannofossils in nannofossil-rich silt/siltstone or clay/claystone in Unit 2 (FIRTH, et al., 1992). According to the observation with thin section, foraminifer tests show the fibrous calcitization in skeleton shell and the dissolution in chamber with occuring of secondary pores or filling by pyrite framboids.

From whole section, calcite abundance has a trend of gradually upward decrease (Fig. 3 and 4). Sharp decrease of the abundance occurs on the bundary from Unit 2 to Unit 1, reflecting a catastrophic event of sedimentation. This resulted from the volcano eruption around Zumisu rift ( KLAUS, et al., 1992; FUJIOKA, et al., 1992; NISHIMURA, et al., 1992; TAYLOR, 1992 ).

Species of zeolite is simple at both sites, consisting mainly of phillipsite. It occurs scatterly in Unit 1 and frequently in Unit 2 at both sites. Ferrierite, rarely clinoptilolite, sometimes occur in Unit 2 at Site 791 (Fig. 4). The associated relationships between phillipsite and calcite are clear at Site 790 as well as at Site 791 (Fig. 3 and 4).

Clay minerals at sites 790 and 791 are characterized by smectite and illite which occur

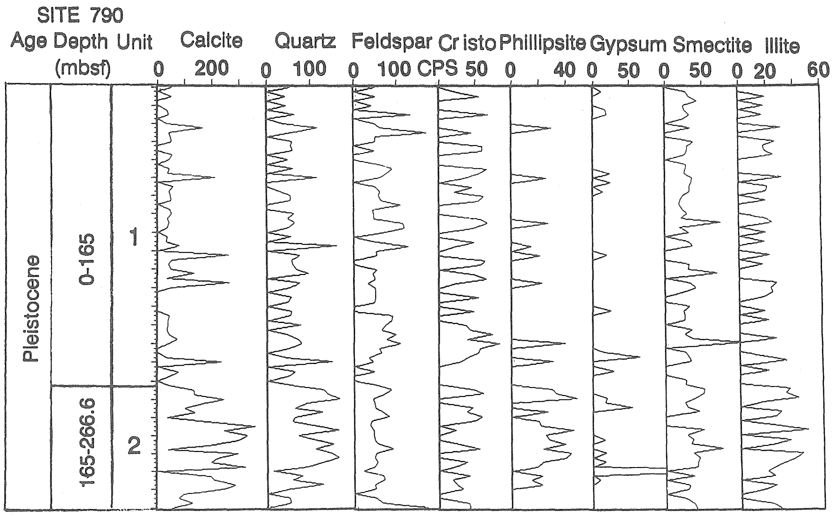



Fig. 3 Distribution trends of major minerals at Site 790.

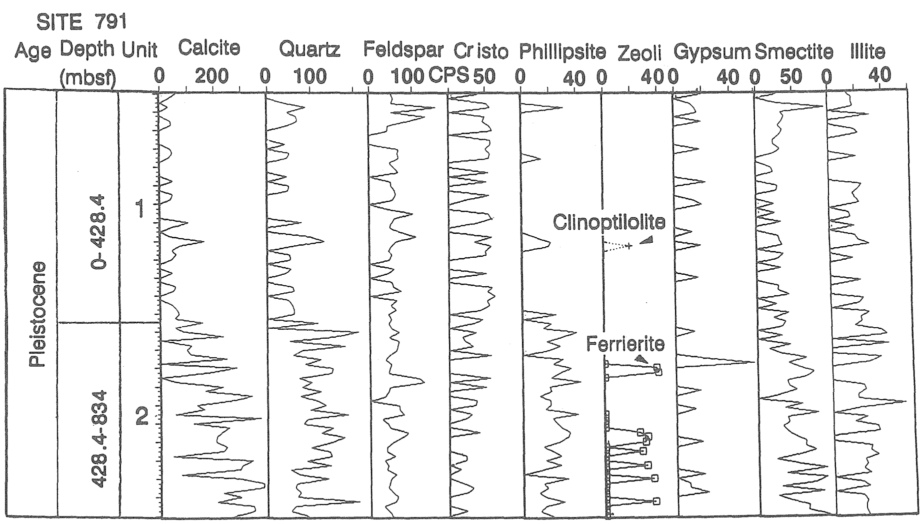



Fig. 4 Distribution trends of major minerals at Site 791.

predominantly in clayey silt, silty clay, especially in nannofossil-rich clay. Smectite has an increasing trend in Unit 2 at Site 791. This trend is not evident at Site 790. Gypsum is common in whole section at both sites and generally more abundant in Unit 2 ( Fig. 3 and 4 ).

**Rift flank Site 788**

Abundance of calcite at Site 788 decreases sharply. The largest counts of calcite are less than 80 CPS, much smaller counts than that in the backarc sediments (Fig. 5). Calcites only occur in middle to lower parts of Unit 1A and 1B with abundance increasing with depth. Upper part of Unit 1A is mainly characterized by abundant amorphous volcanic glasses with minor quartz and feldspar. At the backarc Sites 790 and 791, calcite occurs mainly in nannofossil-rich lithologies which are rarely be seen at Site 788 ( Fig. 5 ).

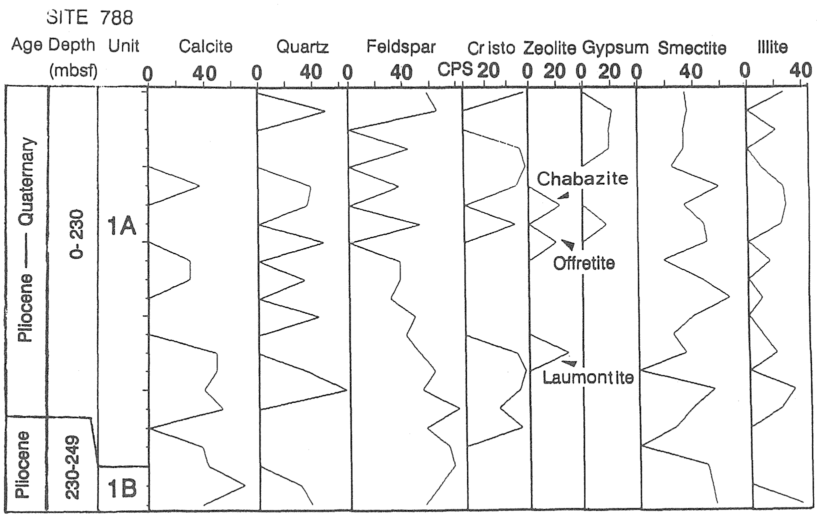



Fig. 5 Distribution trends of major minerals at Site 788.

Concentration of zeolite, especially phillipsite is evidently low or absent in rift flank. Zeolite identified by XRD analyses in sediments at Site 788 include chabazite, laumontite and offretite (Fig. 5). From middle part of Unit 1A feldspar increases sharply which might reflect the primary component of Pliocene pumiceous gravels.

In clay minerals, smectite is principal at Site 788. Clay minerals show irregular changes in the vertical distribution and the abundance is lower than those in the backarc basin. Gypsum concentration is lower, occuring mainly in upper section of Unit 1A in Pleistocene at Site 788 ( Fig. 5 ).

**Forearc Sites 787 and 792**

At Site 787, mineralogy is generally divided into three assemblages ( Fig. 6). (1) late Oligocene assemblage characterized by abundant feldspar and smectite with small amount of calcite, quartz and illite, which results from the occuring of vitric and pumiceous sandstones ( turbidite deposits ) in Unit 4; (2) latest Oligocene to Miocene and Pliocene assemblage rich in calcite, quartz and illite; This assemblage represents a hemipelagic deep

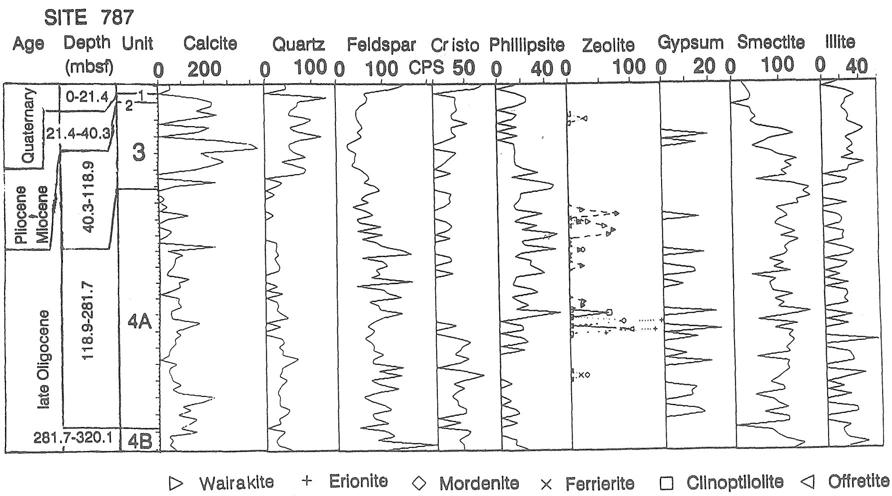



Fig. 6 Distribution trends of major minerals at Site 787.

-water deposition; (3) Quaternary assemblage with very thin succesion marked by feldsapr, cristobalite and volcanic glass. A sharp change in abundance of mineralogical assemblage occurs in the bundary between Unit 4 and Unit 3, reflecting a catastrophic event of sedimentation from turbidite deposition to hemipelagic deep-water deposition. The catastrophy of sedimentation is reflected by distribution trends of calcite, quartz, feldspar and clay minerals.

At Site 792, three main mineralogical assemblages are generally recognized (Fig. 7). (1) Oligocene to early Miocene assemblage consisting of abundant feldspar and smectite; (2)

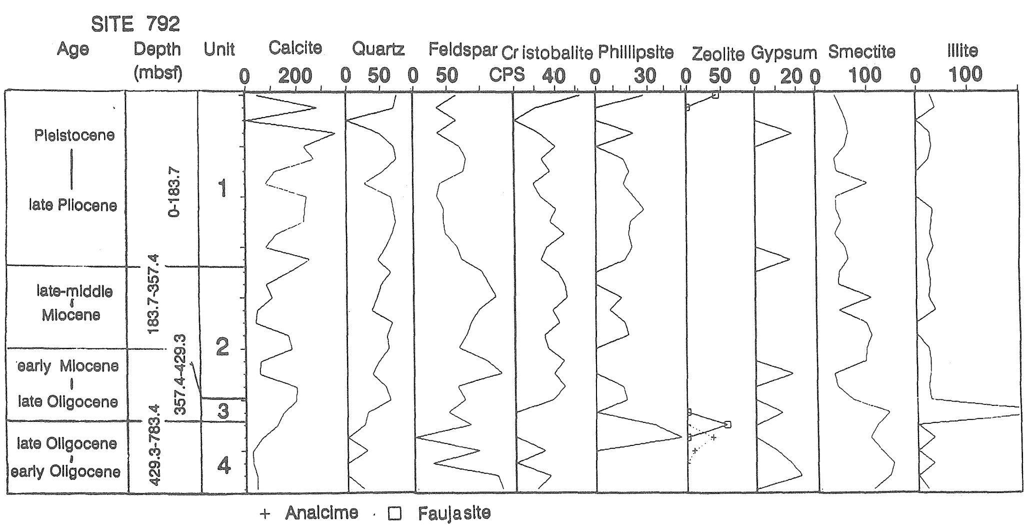



Fig. 7 Distribution trends of major minerals at Site 792.

late-middle Miocene assemblage rich in feldspar and smectite with some quartz and cristobalite; (3) late Pliocene to Pleistocene assemblage marked by abundant calcite and quartz. It is noticed that illite has a sharp increase in Unit 3. This may result from a change of sediments sources.

Sediments in forearc basin contain varieties of zeolite. At both Sites phillipsite is still principal, occuring in whole section. (Fig. 6 and 7). At Site 787, the upper Oligocene sediments contain higher abundance of phillipsite in upper part of Unit 4A. Partial intervals in Unit 4A contain wairakite, clinoptilolite, mordenite, ferrierite and erionite. At Site 792, faujasite and analcime occur in Unit 3 (Fig 7). According to the results by TAZAKI (1991, 1992), sediments from Unit 4 at Site 792 also contain wairakite, analcime, heulandite and clinoptilolite.

In forearc basin, intervals abundant in smectite have an older age, dominantly late Oligocene turbidite sediments. Smectites occur mainly in sandstone, siltstone, silty sandstone and vitric silty claystone. Color of sediments containing smectite varies from light-green, light-brownish green, brownish green to dark-brownish green. The abundance of smectites in sediments generally varies as a function of sediments color: dark-brownish green > brownish green > light- brownish green> light-green.

At both sites, phillipsites generally show similar distribution trends to smectite but illite shows a nearly opposit trend to smectite, suggesting that phillipsite and partial smectites result from the alteration of volcanic glasses

## 5. Discussions

### 5.1 Mineralogical Assemblages and Evolution of Sedimentation History

Distribution trends of mineralogical assemblages of sediments from Izu-Bonin Arc show that the catastrophic events in sedimentation history are reflected by the abundances variation of mineralogical assemblages of sediments. The mineralogical assemblages of the backarc Site 791 (Fig. 8) are compared with the timing of tectonic events (KLAUS et al., 1992; HISCOTT, et al., 1992). In backarc basin, dominant catastrophic event occured during the pleistocene period changing from Unit 2 to Unit 1. This change was resulted from the volcanoes eruptions which resulted in the change of sediments sources (KLAUS, et al., 1992; HISCOTT, et al., 1992). Before this catastrophic event, nannofossil clays and fine-grained volcanic ash have been deposited by air fall and submarine mass flows ( NISHIMURA, et al, 1992 ). Mineralogical assemblages are characterized by higher abundance of calcite, quartz and clay minerals ( Fig. 8 ). Unit 2 at both sites was then overlain by thick pumiceous and vitric gravels, sands and silts by volcano eruption, resulting in the sharp change in mineralogical assemblage distribution. Contents of calcite, quartz and clay minerals decrease sharply. During the intereruptive period nannofossil clays and fine-grained volcanic ash might deposited by pelagic flows and air fall from more distant volcanoes ( KLAUS, et al., 1992 ).

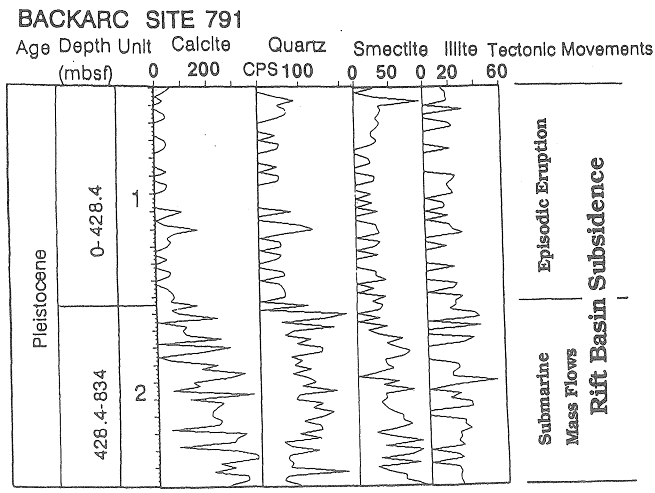



Fig. 8 Mineralogical assemblages from the backarc Site 791 in regarding with the timing of tectonic events from KLAUS and HISCOTT (1992).

In backarc basin, abundance of quartz in Unit 2 at both sites is largely higher than those in forearc basin ( Fig. 3, 4, 6 and 7 ), suggesting that the contribution of terrigeneous inputs to hemipelagic sediments is probably several times as large as those in pelagic environments. According to the results by NISHIMURA et al (1992), the values of SiO2 in the backarc are higher than in the forearc, which aggrees with our result. We infer that higher abundance of quartz in the backarc might contributes a part of higher contents of $SiO_2$.

In forearc basin, the mineralogical assemblages of Site 787 (Fig. 9) are compared with the timing of tectonic events (KLAUS, et al., 1992; HISCOTT, et al., 1992). The Oligocene sediments are characterized by higher abundance of feldspar and clay minerals (smectite) and lower abundance of calcite and quartz ( Fig 9 ). In Unit 4 at Site 787, sharp increase in feldspar abundance implise the presence of thick sand bodies. HISCOTT, et al (1992) considered that earthquakes were a probable triggering mechanism for sedimentary gravity flows in forearc basin. Very thick sandstone beds may have been resulted from large earthquakes.

The last important stage in the evolution of the forearc basin is the sharp decline in sedimentation rates and increase in the abundance of mudstones and nannofossil-rich lithologies in the time period from latest Oligocene to Miocene and Pliocene ( 27 to 23.5 Ma ) ( HISCOTT, et al., 1992 ). These deep-water depostions with low sedimentation rates are reflected by high abundance of calcite, quartz and illite ( Fig.9 ). The change in mineralogical assemblage distribution implise the evolution of tectonic movements from

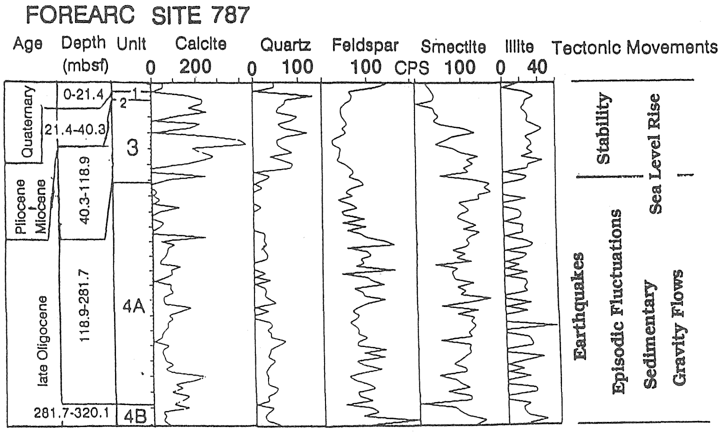



Fig. 9 Mineralogical assemblages from the forearc Site 787 in regarding with the timing of tectonic events from KLAUS and HISCOTT (1992).

the late Oligocene episodic fluctuations to the early-middle Miocene relative stability. This change may be the result of a proposed rise in global sea level during this period ( HISCOTT, et al., 1992 ).

### 5.2 Alteration after Deposition and During Early Diagenesis

Dominant changes of sediments after deposition and during early diagenesis are reflected by occurence of the secondary products of zeolites and smectite which result from the alteration of volcanic glass and feldspar. The alterations of glass to zeolites are better developed in older intervals than in the younger both at the backarc sites and the forearc sites ( Fig. 3, 4, 6 and 7 ), implying that the alteration are largely affected by diagenesis ( CZYSCINSKI, 1973; IJIMA, 1978; KANSTER, 1981; KANSTER and STONECIPHER, 1978 ). In forearc basin, alteration occurs frequently in the late Oligocene and species of zeolites are richer than the backarc basin. Most of the zeolites occur in the upper Oligocene sediments, suggesting a relation to the older age of sediments ( KOLLA and BISCAYE, 1973 ). Higher abundance of smectite, phillipsite and other zeolites suggests that secondary minerals mainly occur in the sandstone matrix and form cementing materials around primary mineral fragments ( GLACCUM and BOSTROM, 1976; HAY, 1966; ODIN, 1988 ).

In both backarc and forearc basins, occurence of gypsums is generally consistant with that of zeolites, implying the posibility of CaO enrichment ( NISHIMURA, et al., 1992 ) from secondary minerals formed through a diagenesis alteration.

### 5.3 Effects of Hydrothermal Alteration

At forearc Site 787, wairakite occurs in Oligocene sediments ( Fig. 6 ) and previous results have reported the occurence of this mineral in sediments with same age at Site 792 ( TAZAKI and FYFE, 1992 ), suggesting the presence of hydrothermal alteration exceeding 200 ℃ according to other laboratory and petrographic data ( COOMBS, et al., 1959; NAKAJIMA and UEDA, 1990; TSITSISHVILI, et al., 1992 ). In minor mineral components, the occurences of minerals such as barite, alunite ect. suggest a source of hydrothermal fluids in the sediments. This hydrothermal circulation at least has locally effects of higher temperature on the sediments, resulting in the occurence of wairakites and hydrothermal manganese minerals ( USUI, 1992; UTADE and SHIMIZU, 1990 ).

HISCOTT, et al. (1992) considered that the major source of detritus during the late Oligocene was along the western basin margin. Wairakites at Sites 787 and 792 occur coincidently in turbidite sediments of the late Oligocene. Considering above data, we speculate that wairakites may have been formed before sediments are transported into forearc basin.

## 6. Conclusions

The mineralogical assemblages of deep-sea sediments in the Izu-Bonin Arc shows the following features:

1. Mineral composition in the Izu-Bonin deep-sea sediments mainly composed of calcite, quartz, feldspar, zeolites, gypsum, clay minerals and volcanic glass with some minor minerals including pyrite, barite, diaspore, ect.. The associated assemblage of calcite, quartz and clay minerals represents the dominant component of hemipelagic and pelagic sediments.
2. The catastrophic events of sedimentation history are reflected by the sharp change in abundance of mineralogical assemblages. In backarc basin, the change occurs on the bundary from Unit 2 to Unit 1 in the Pleistocene, suggesting that the volcano eruption has changed the sediments sources.
3. In forearc basin, the change occurs on the bundary from Unit 4 to Unit 3, the time period from the latest Oligocene to Miocene and Pliocene ( 27 to 23.5 Ma ), suggesting the evolution of tectonic movements from the late Oligocene episodic fluctuations to the early -middle Miocene relative stability due to a proposed rise in global sea level during this period.
4. The alteration of volcanic glass and feldspar after deposition and during diagenesis results in secondary zeolites and smectite. The better development of secondary minerals in the older sediments suggests that the alteration is highly affected by diagenesis.
5. The occurence of wairakite in the forearc sites suggests the presence of hydrothermal alteration exceeding 200 ℃. We speculate that wairakites may have been formed before the sediments are transported into forearc basin.

## Acknowledgements

This study was parts of MS thesis of first author at Shimane University, supporting by Japanese Government ( Monbusho ). We thank Prof. Y. SAWADA and Prof. S. IIZUMI for their valuable discussions and advices, and Prof. M. AKASAKA for his useful help in XRD analysis. Thanks are also due to the Department of Geology, Faculty of Science, Shimane University for providing good measuring machines and useful helps from all professors and staff.

## References

COLLELA, A., D'ALESSANDRO, A. and De ROSE, R., (1992). Deep-water trace fossils and their environmental significance in forearc and backarc Cenozoic successions around the Izu-Bonin Arc, Leg 126. in *Proceedings of the Ocean Drilling Program, 126-Scientific* Results, 209-230.

CZYSCINSKI, K., (1973). Authigenic phillipsite formation reaction rates in the central Indian Ocean and the Equatorial Pacific Ocean. *Deep-Sea Res*., 20, 555-559.

DADEY, K. A. and KLAUS, A., (1992). Physical properties of volcani-clastic sediments in the Izu-Bonin area. in *Proceedings of the Ocean Drilling Program, 126 -Scientific Results*, 543-550.

FIRTH, J. V. and ISIMIGER-KELSO, M., (1992). Pleistocene and Oligocene-Miocene calcareous nannofossils from the Sumisu Rift and Izu-Bonin forearc basin. in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 237-262.

FUJIOKA, K., TAYLOR, B., NISHIMURA, A., KOYAMA, M., KAIHO, K., TAZAKI, K., JANECEK, T. et al, (1989). Drilling across the Izu-Bonin Arc --Results of ODP leg 126 rise--. *Journal of Geography* 98, No. 4, 4-78 ( In Japanese with English abstract)

FUJIOKA, K., MATSUO, Y., NISHIMURA, A., KOYAMA, M. and RODOLFO, K. S., (1992). Tephras of the Izu-bonin forearc (Sites 787,792 and 793). in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 47-74.

FUJIOKA, K., NISHIMURA, A., MATSUO, Y. and RODOLFO, K.S., (1992). Correlation of Quaternary tephras throughout the Izu-Bonin areas. in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 23-46.

FUJIOKA, K. and SAITO, S., (1992). Composition of heavy minerals from sands and sandstones of the Izu-Bonin Arc, Leg 126. in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 155-170.

GlACCUM, R. and BOSTROM, K., (1976). (Na, K)-phillipsite: its stability conditions and geochemical role in the deep sea. *Marine Geology*, 21, 47-58.

HAY, R. L., (1966). Zeolites and zeolitic Reaction in Sedimentary Rocks. *Geol. Soc. Am. Spec. Pap*. 85.

HISCOTT, R. N., COLELLA, A., PEZARD, P., LAVELL, M. A. and MALINVERNO, A, (1992). Sedimentalogy of deep-water volcanoclastics, Oligocene Izu-Bonin forearc basin, based on formation microscanner images. in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 75-96.

IJIMA, K., (1978). Geological occurences of zeolites in marine environments. In *Natural Zeolites*, eds L. B. Sand & F. A. Mumpton, Pergamon Press, Oxford, 75-98.

KANSTER, M., (1981). Authigenic silicates in deep-sea sediments: formation and diagenesis. In *The Sea, 7, The Ocean Litho-sphere, ed*. C. Emilani, Wily Interscience, New York, 15-80.

KANSTER, M. and STONECIPHER, S. A., (1978). Zeolites in pelagic sediments of the atlantic, Pacific and Indian Oceans. In *Natural Zeolites*, eds L. B. Sand & F. A. Mumpton, Pergamon Press, Oxford, 199-220.

KLAUS, A., TAYLOR, B., MOORE, G.F., MAEKAY, M.E. and BROWN, G.R., (1992). Structural and stratigraphic evolution of the Sumisu Rift, Izu-Bonin Arc. in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 555-573.

KOLLA, V. and BISCAYE, P. E., (1973). Deep-sea zeolites: variations. in space and time in sediments of the Indian Ocean. *Marine Geology*, 15, 11-17.

MASARGLIA, K. M. and TAZAKI, K., (1992). Diagenitic trends in Leg 126 sandstones. in *Proceedings of the Ocean Drilling Program*, 126-Scientific Results, 139-154.

NAKAJIMA, W. and UYEDA, S., (1990). Syntheses of natural zeolites: syntheses of heulandite-clinoptilolite, analcime-wairakite, mordenite and ferrierite. *Nendo Kagaku* 30, 57-75( In Japanese with English abstract )

NISHIMURA, A. MITA, N. and NOHARA, M.,(1992). Pelagic and hemiplagic sediments of the Izu-Bonin region, Leg 126: geochemical and compositional features. in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 487-504.

ODIN, G. S., (1988). Green Marine Clays. *Developments in Sedimentalogy* 45, Elsevier Amsterdam-Oxford- New York-Tokyo, p445.

TAYLOR, B., (1992). Rifting and the volcanic-tectonic evolution of the Izu-Bonin -Mariana Arc. in *Proceedings of the Ocean Drilling Program, 126-Scientific Results*, 627-652.

TAYLOR, B. and FUJIOKA, K., et al, (1990). *Proc. ODP, Init, Repts., 126:* College Station, TX(Ocean Drilling Program).

TAZAKI, K., (1991). Microprocesses of hydrothermal alteration in the Izu-Bonin Arc. *Ocean*, 11, 27-35. ( in Japanese )

TAZAKI, K., (1991). Hydrothermal Alteration of deep sea sediments from the Izu-Bonin Forearc Basin, Leg 126, ODP. *Journal of Geology*, 100, 487-502(In Japanese with English abstract).

TAZAKI, K., (1991). Microprocesses of hydrothermal alteration in the Izu-Bonin Arc. *Earth*, 6, 211-216. ( in Japanese )

TAZAKI, K., (1992). Hydrothermal activities and the altered products of deep-sea sediments from the Izu-Bonin Arc, Leg 126, ODP. *Earth*, 6, 206-211. ( in Japanese )

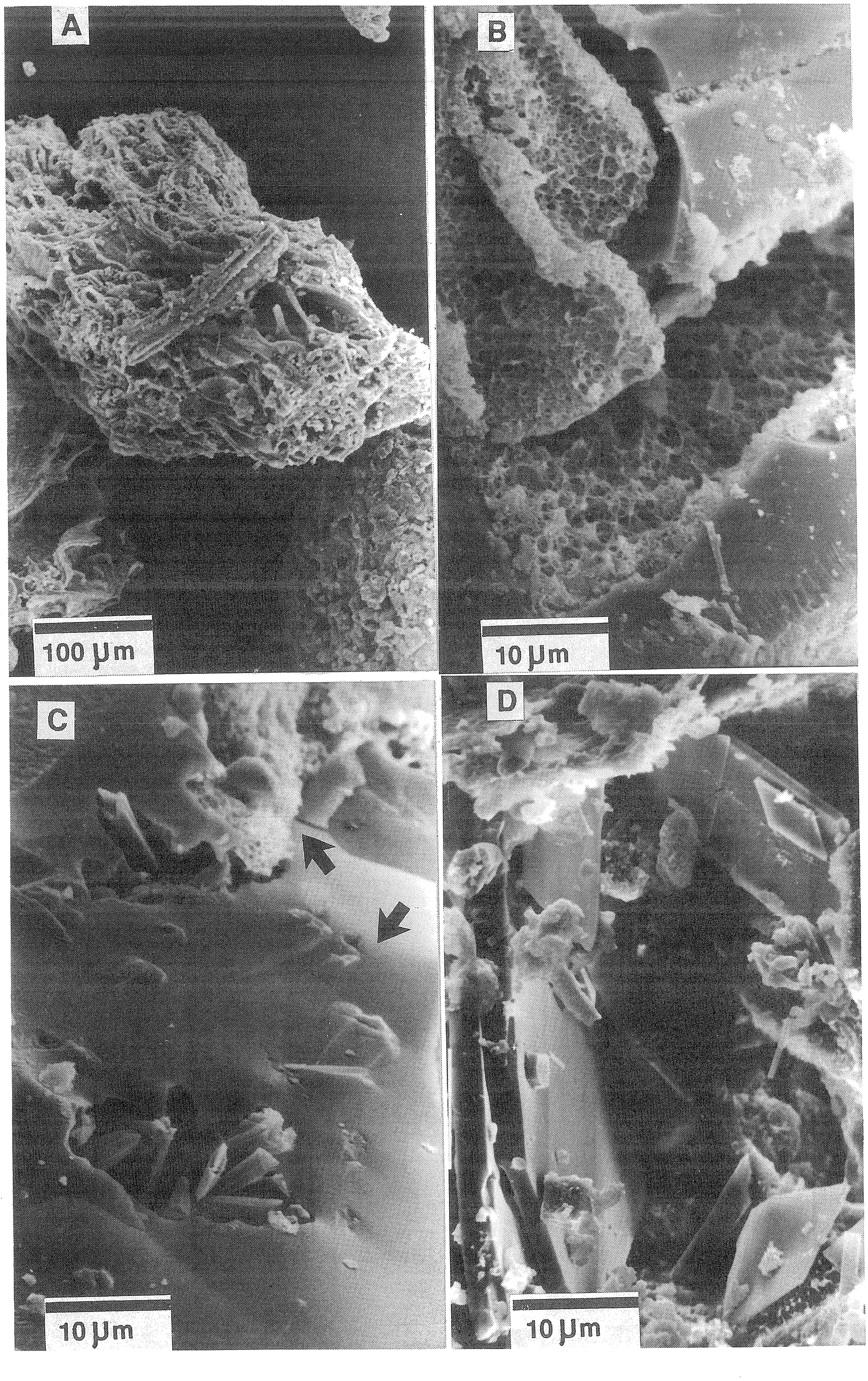
TAZAKI, K. and FYFE, W. S., (1992). Diagenetic and hydrothermal mineral alteration observed in Izu-Bonin deep-sea sediments, Leg 126. in *Proceedings of the Ocean Drilling Program*, 126-Scientific Results, 101-112.

TSITSISHVILI, G. V., ANDRONIKASHVILI, T. G., et al, (1992). *Natural Zeolites*. E. Harwood, Newyork; London 1992, p295.

USUI, A., (1992). Hydrothermal manganese minerals in leg 126 cores. in *Proceedings of the Ocean Drilling Program,126-Scientific Results*, 627-652.

UTADA, M. and SHIMIZU, M., (1990). Occurence, distribution, and genesis of zeolites in the Izu Peninsula, central Japan. *Nendo Kagaku* 30, 11-18 (In Japanese with English abstract)

Plate-1 SEM photomicrographs. A: An pumice debris with smectites developing on the surface (sample 126-788C-22H-1, 103-105cm). B: Enlarged image of A, showing unmodified siliceous structure and smectites filling the cavities ( sample 126-788C- 22H-1, 103-105cm ), C: Phillipsite grows begining from cavities or inner part of pumice debris ( arrows ) (sample 126-787B-13R-2, 6-7cm), D: Euhedral rhombic gypsum crystals occuring in the cavity of volcanic glass shards ( sample 128-787B-22R-1, 20-21cm ).


A
100 μm
B
10 μm
C
10 μm
D
10 μm