Textural and Mineralogical Investigations on Deep Sea Manganese Nodules from the Equatorial Pacific

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Texture and mineralogy of different microlayers of deep-sea manganese nodules are investigted to reveal the environmental changes of nodules during a nodule formation. Basically a nodule can have three types (A, B and C) of microlayer. Some nodules show only one or two types of microlayer. The classification is based primarily on the texture. The suface texture of type A is coarsely porous globular microstructure whereas type B and C are intermediate to finely porous textures. The type A is characterized by its highest Mn content (30.6%) and relatively well-crystallized todorokite as well as the rapid growth rate. Smectite and biogenic silica (radiolaria) are also easily observed in the type A layer. It appears that the hydrothermal activity is one of the favorable mechanism of formation for the type A layer. The hydrothermal solution is possibly supplied from nearby fracture zone and spreading center.

Introduction

A number of researches have been conducted on deep-sea manganese nodules since the pioneeric study of Murray and Renard (1891). Most of the studies were concentrated on the growth behavior of nodules involved with the origin of nodules (Arrhenius et al., 1964; Cronan, 1969; Pautot and Melguen, 1979).

In accordance with their economic importances the geochemical environment of nodule formation was studied. Some studies documented the variance of major elements content in terms of their oceanographic environment (Bischoff and Piper, 1979; Skornyacova, 1979). Thus possible influencing factors such as biological activity, sediments type, water depth, sedimentation rate, behavior of bottom current, and hydrothermal activity have been considered to understand the geochemistry of nodules by many authors (Glasby et al., 1975; Exon, 1981; Glasby; 1981; Usi, 1983).

Studies of variations of geochemistry and mineralogy in each microlayer of a nodule, however, are relatively rare compared to those studies of bulk chemistry of individual nodule (Andrews and Margolis, 1974; Sorem and Fewkes, 1977; Burns and Burns, 1978). This type of research has an advantage to reveal the local environmental variations during the growth of individual nodules. Modern analytical techniques have been applied to investigate the individual microlayer of nodules.

The ultimate goal of this study is to establish a relationship between the texture and the mineralogy of nodules in individual microlayer.

Sample Location and Description

Samples were dredged between the Clarion and Clipperton Fracture Zones in the eastern equatorial Pacific. The samplings were performed by the Korea Ocean Research and Development Institute (KORDI) on board R/V Kana Keoki of Hawaii Institute of Geophysics in 1983. This area is characterized by generally high content of Cu and Ni in nodules together with their high population density (Arrhenius at al., 1964; Berzukov, 1971; Skornyakova, 1979). The sampling depths are in between 4782 and 5450 *m* (KORDI, 1986).

Some regional sedimentary hiatuses indicate that influence of the Antarctic Bottom Water (AABW) dominates the area. Evidences of winnowing due to AABW are not rare. For example, the exposed Oligocene sediments are found in some channels owing to erosion in the valley. Except for some elevated areas the calcium carbonate content is very low in surface sediments. It is presumably a result of erosion and dissolution due to bottom water flow. The dominant types of sediment are muddy siliceous ooze, zeolite-bearing clays, and siliceous debris rich pelagic clays (Andrews et al., 1983).

Experiment Technique

The manganese nodules were cut through the center and polished in order to study the internal microstructures and mineralogy. A detailed internal microstructures were observed under reflecting microscope to determine the genetic evolution.

X-ray diffraction study for some selected samples has been carried out to analyze the mineral composition. A dental drill was used to obtain powder specimen for different layers (microstructures) from each nodule. Scanning Electron Microscope (SEM) study was perfomed to understand the mineral composition and orientation. Element analysis was carried out using ICAP Spectrometer.

Results and Discussion

The textures of nodules studied are divided into banded, cuspate and globular units. The internal structures are shown core, concentric layering, unconformity, and fracture filling structure. According to the texture, we classified the nodule into three different types (Fig. 1); 1) a coarsely porous globular part (Type A), 2) an intermediate porous and cuspate part (Type B), and 3) a finely porous and banded part (Type C). Of course it is not necessary to have all the three types in a nodule. Some nodules are composed of only one or two different textural types.

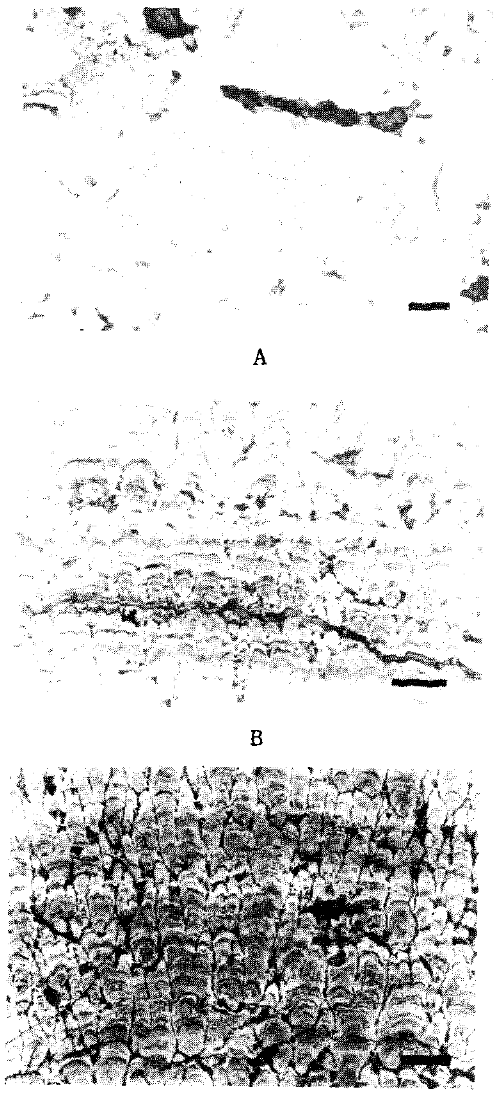

Fig. 1. Photographs of polished section of manganese nodules.
A: Dendritic microbotryoids of type A microlayer showing aggregates of crystalline oxides of detrital material partially surrounding thin layers of amorphous oxides. B: Microfeatures of type B microlayer showing fairly coarse dendritic segregation. C: Typical microfeatures of type C microlayer showing columnar and laminated texture. Scale bars indicate 400 *μm*.

Buser and Grutter(1956) indicated that the manganese and iron oxide minerals in manganese nodules are typically poorly crystalline. The X-ray diffraction pattern in this study of the samples shows the variation of crystallinity in connection with those three internal microstructures(Type A, B and C) and average Mn content. X-ray diffraction analysis of the samples in this study revealed little information on the structures of the manganese and iron oxide minerals because of the its poor crystallinity.

Fig. 2 shows X-ray diffraction patterns of three different textural types of a nodule. Todorokite is a major mineral phase for type A layer. The minor components are phillipsite and silicate minerals (quartz and feldspar). The type B layer shows similar patterns to the type A layer. The type C layer, however, is believed to be composed of only δ-MnO_2. The peak intensity is the most distinctive in the type A layer. This is connected with the widening of the lines as a result of decrease in the crystallinity, and metal content on each genetic types.

Among the three different textural types, the type A is the most interesting(Fig. 3). Compared to the other types, the type A shows the highest content of Mn and clay minerals (especially smec-

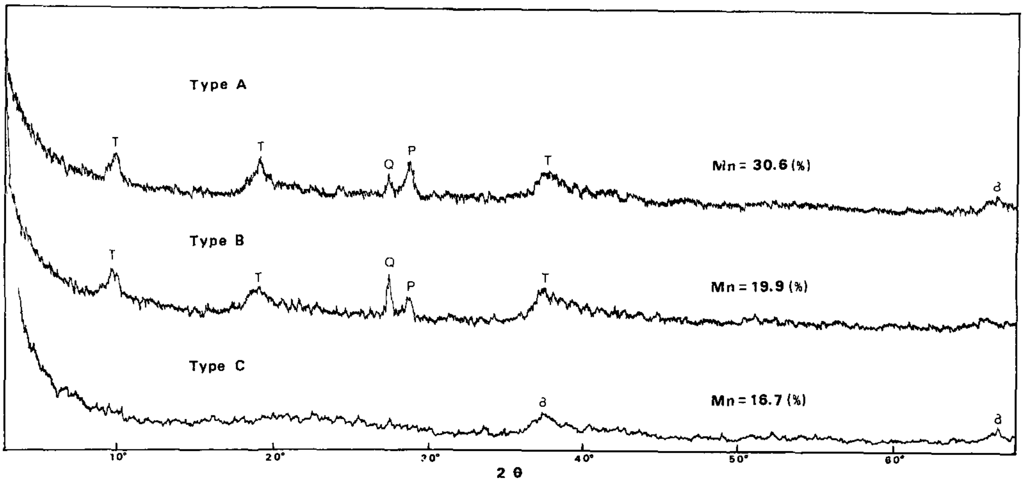

Fig. 2. X-ray diffractograms of different types of microlayer for some selected manganese nodules. Average Mn content (weight percent) for each microlayer is indicated in the figure. Note the variation of crystallinity for each genetic types. Abbreviations are, T: todorokite, δ: δ-MnO_2, Q: quartz, and P: phillipsite.

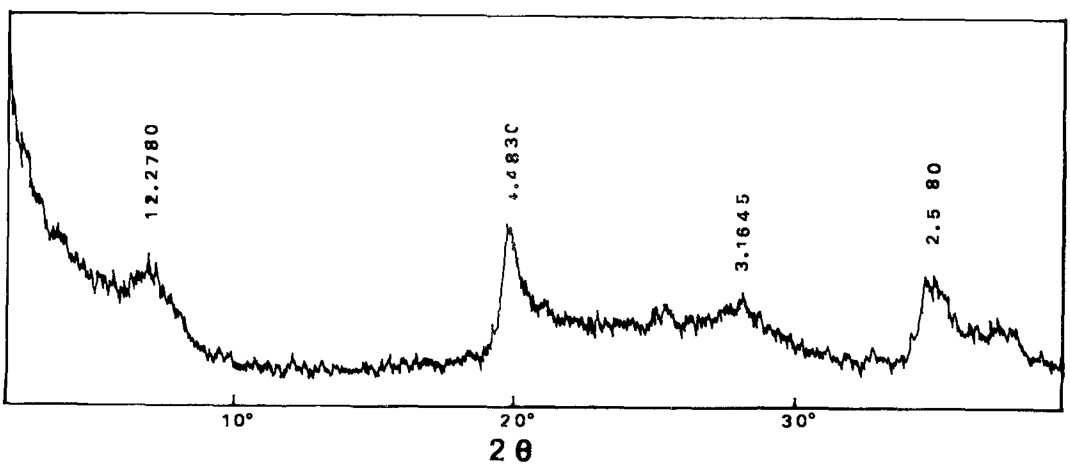

Fig. 3. X-ray diffractogram of type A microlayer. Note the smectite peaks (12.2780, 4.4830, 3.1645 and 2.5780 Å).

Fig. 4. Scanning electron micrograph for type A microlayer showing a radiolarian fossil and blades of todorokite.

tite). It is generally known that some pelagic smectites are related with submarine volcanism. The relatively high silica content, either bigenic or nonbiogenic origin, for the type A layer indicates an active hydrothermal activity during the period of nodule formation. This can be an evidence of high growth rate of nodule related wlth hydrothermal activtity (Calvert, 1978; Toth, 1970). Scott et al. (1978) suggested that the manganese deposit from the mid median valley of the Mid-Atlantic Ridge is hydrothermal origin by observing the unusually high Mn content and the rapid growth rate. Siliceous fossils trapped for a number of samples in the type A layer also can be utilized as a supporting evidence of rapid growth rate.

Although it is not a confirmed theory, the occurrence of well-crystallized todorokite in the type A layer strengthen this idea. Calvert (1978) also reported that the Mn-rich nodules contain todorokite and δ-MnO_2 whereas the Fe-rich nodules only δ-MnO_2. Recently, the todorokite-rich manganese crust found in the vicinity of fracture zones and spreading centers is considered as an indicator of hydrothermal origin (KORDI, 1986).

More efforts should be done including detailed geochemical study to determine the origin of manganese nodules. It may be true that the mechanism of nodule formation varies from time to time. Existence of different types of microstructures (e.g., types A, B and C) even in a nodule should be interpreted in this point of view. It is not difficult to assume that changing paleoceanogrphic condition affects easily the characteristics of geochemistry and morphology (i.e., microstructure) for such extremely slow-growing nodules. The origin of type B and C layers, however, should be investigated in the future.

Conculusions

Three different types of microlayer of deep-sea manganese nodules are classified depend upon the texture. The type A layer, which shows coarsely porous globular surface texture, has some unique features such as the highest Mn content and relatively well-developed todorokite. Also the comparatively abundant smectite and siliceous fossils in the type A layer suggest that growth rate of the layer was higher than the other two types (i.e., types B and C). It seems that type A layer is related with hydrothermal activity combined with submarine volcanism and hot springs.

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태평양 심해저 망간단괴의 조직 및 광물학적 연구

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태평양 심해저로부터 채취된 망간단괴는 미세구조의 특징을 기준으로 하여 세가지 유형(Type A, B 및 C)으로 분류되며, 이들 미세구조들은 단일 단괴에서도 혼합구조로서 흔히 산출된다. 각 유형은 상이한 화학성분과 구성광물 및 결정도를 나타내며 이 중 A형은 조립질 조직을 갖고있고 다른 유형에 비해 결정도가 높은 Todorokite 로 주로 구성되고 Mn 의 함량도 높은 반면에 B와 C형은 중간 내지는 세립질 조직을 갖고 있다(Mn=30.6%). 또한 A 형은 상대적으로 빠른 성장속도를 나타내며, 보트리오이드 사이의 공극에서 Smectite 와 규질화석이 나타난다. 이러한 특징은 A 형 구조를 갖는 미세한 층(micro-layer)의 성인이 해저에서의 열수작용과 관련된 것으로 생각되며, 열수용액은 주변 단열대와 해저확장대로부터 공급된 것으로 추정된다.