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# Textures, Mineralogy and Genesis of Manganese Nodules on the Blake Plateau, Northwestern Atlantic Ocean

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**Abstract:** The manganese nodule from the Blake Plateau consists mainly of microcrystalline to cryptocrystalline todorokite, with minor quartz, clays, carbonates and phillipsite.

The nodule in cross section shows concentric layers, core structure, unconformity and fissure-filling structure megascopically, and colloform, fragmental and diagenetic textures microscopically. A new classification of colloform textures which are applicable to any nodule of any source shows that the colloform textures consist of three basic textural units: banded, cuspate and globular. They occur independently or in combination with each other to form various types of textures. The presence of three predominant textural types suggests that there are three different major modes of nodule growth which are controlled by physical and chemical environments.

## Introduction

A study has been made of the manganese nodule dredged from the Blake Plateau, northwestern Atlantic Ocean, lattitude 31°01.6′N, longitude 78°18.8′W at the depth of 849 meters. The nodule was supplied from the Wood's Hole Oceanographic Institution by courtesy of Dr. K. O. Emery and Dr. J. Broda.

According to Manheim (1972), the manganese nodule deposits at the Blake Plateau began forming in the middle Tertiary time concurrently with the establishment of the Gulf Stream. The Gulf Stream has played an essential role in their genesis. It has prevented deposition of carbonates and other sediments on the Blake Plateau thus permitting accumulation of very slowly accreting metal oxides in an unusual shallow and nearshore environment.

The heterogeneity and cryptocystallinity of materials in manganese nodules prevent easy access to the resolution of their mineralogy and textures. However, X-ray diffraction analysis has been the principal method for determining the mineralogy of manganese nodules. Microscopic study on the polished section under high magnification shows details of the general textural patterns of constituent materials. Analysis of textural patterns of minerals gives important data for interpretation of the mechanism of growth of manganese nodules and thereafter evolution in mineralogy and textures.

## Methods of Study

The round manganese nodule having the size of 5.5×6.0 centimeters was cut through the center in order to study on the internal structures and textures, and on mineralogy. The surfaces of cross section were polished. The polished surfaces were photographed, and studied under both stereomicroscope and reflecting microscope. Samples for X-ray analysis were taken under the microscope. Detailed textural study was made under the microscope in order to know the process of growth of manganese nodules and their diagenetic evolution.

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## Mineralogy

The manganese oxide minerals most commonly occurring in manganese nodules are todorokite and birnessite. In the manganese nodule from the Blake Plateau, todorokite is the only crystalline manganese oxide identified in the X-ray powder diffraction photographs. The manganese nodule studied consists mainly of todorokite with minor quartz, clay, calcite, aragonite and phillipsite.

Todorokite was recognized by two diagnostic lines at 9.6 and 4.8Å. In addition, it shows diffraction lines at 2.46, 1.42 and 1.14 Å.
Todorokite occurs as two types in the manganese nodule from the Blake Plateau. They are a) microcrystalline todorokite, and b) cryptocrystalline todorokite. These two types of todorokite have quite different optical properties in the reflected light. The microcrystalline todorokite occurs as very fine-grained flakes, showing distinct anisotropism and white in color on the reflected light. The cryptocrystalline todorokite occurs as dense homogeneous mass, showing no distinct anisotropism, or even isotropism and light grey in color on the reflected light. Two types of todorokite occur in close association with each other but in different layers or zones. They are easily distinguished by the difference in their reflectivity. Microcrystalline todorokite has higher reflectivity than the cryptocrystalline todorokite.

## Megascopic Structures

**External textures:** The manganese nodule studied has spherical shape with slightly waving surface. It has very compact surface with white coating in places.

**Internal structures:** The characteristic internal structures of manganese nodules from the Blake Plateau are: concentric layering, core structure, unconformity, and fracture-filling structure.

Concentric layering — The concentric layering is the most characteristic feature of the manganese nodule which can be easily seen with naked eye in the cross esction. Individual layer is distinguished from others by the color and reflectivity due to the variation in mineralogy and textures. It is characteristic of the manganese nodule from the Blake Plateau that the colloform layers are very thin, laminated and compact. Individual layer is considerably continuously developed, encrusting the inner layer.

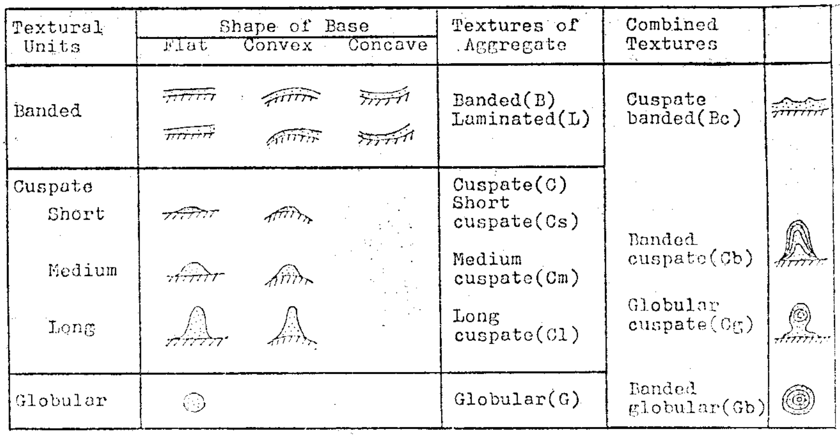
Core structure — The manganese nodule studied includes angular nodule fragment of older generation. The characters of the core fragment are quite different from those of the encrusting materials in structure. The core fragment shows diffusely laminated strrcture.

Unconformity — The unconformity is also one of internal structures of manganese nodules from the Blake Plateau. Unconformable contact is seen where the broken structure of an older nodule fragment is overlain at a sharp angle by new layers which encrust the entire fragment. Two different unconformities are found in the different horizon in one cross section of a nodule. The unconformity is scarcely recognized where the layers in the older fragment lie parallel to those of the encrusting material. Similar observation was made by Sorem and Forster (1969). Another type of unconformity is found along the fracture. Nodule materials overlie unconformably on both walls of fracture, showing well-developed colloform bands.

Fracture-filling structure — Fracture-filling structure is abundantly found in the nodule studied. There are two types of fractures: random fracture and concentric fracture. The surfaces of larger fractures are lined with manganese oxides, showing banded and/or cuspate texture. Open spaces are filled with carbonates and clay(Fig. 2). It seems that these fractures are shrinkage cracks resulting from aging of older oxide materials.

## Microscopic Textures

Sorem and Forster (1972 a, b) classified the



| Textural Units | Shape of Base: Flat | Convex | Concave | Textures of Aggregate | Combined Textures | |
|---|---|---|---|---|---|---|
| Banded | | | | Banded(B) Laminated(L) | Cuspate banded(Bc) | |
| Cuspate | | | | Cuspate(C) | | |
| Short | | | | Short cuspate(Cs) | | |
| Medium | | | | Medium cuspate(Cm) | Banded cuspate(Cb) | |
| Long | | | | Long cuspate(Cl) | Globular cuspate(Cg) | |
| Globular | | | | Globular(G) | Banded globular(Gb) | |

**Fig. 1** Classification of primary colloform textures in manganese nodules. Symbol for each type is given in parenthesis.

textures of manganese nodules into the massive, mottled, compact, columnar and laminated zones.

The manganese nodule from the Blake Plateau also shows massive, mottled, compact, columnar and laminated zones. Among these, massive, laminated and mottled zones are most abundant.

Zones by Sorem and Forster are terms indicating the shapes of aggregations of nodule materials. Therefore, they are simply descriptive terminology without genetic meaning, which can be used to describe the general habit of the nodue materials. The present author proposes a new scheme of classification of primary nodule textures which can be used without limitation in scale.

Microscopic study shows that the textures of nodules can be classified into two groups: a) primary growth textures, and b) secondary diagenetic textures.

**Primary growth textures:** Colloform textures and their classification — The smooth surface is a characteristic feature of colloform growth. Although the concentric colloform layering is the major structure in manganese nodules, other types of colloform textures are also found in the mangaese nodules. The general curvature of the concentric layers of nodules is usually governed by the shape of the older mass on which nodule materials are encrusting, but the shape of the surface of the individual layer is considerably controlled by the difference in the growth rate at different sites. The cause of differential growth rate in the same environment is not fully understood. The concentric layering in megascopic scale is seen under the microscope as either true continuous layer or concentric arrangement of discontinuous units.

Complexity in textures of manganese nodules from the Blake Plateau can be systematized by the systematic classification of colloform shapes. Colloform shapes can be classified into three geometrical basic types on the basis of the variation in the horizontal and vertical dimensions of individual colloform; thay are a) banded, b) cusspate, and c) globular (Fig. 1).

The banded type of colloform indicates the parallel layer of colloform material with roughly uniform thickness which is developed parallel to the older surface. This texture suggests the uniform accretion of nodule materials on the whole surface area, resulting in the layer with roughly uniform thickness. Subparallel bands are also abundantly found. Depending upon the shape of the older surface, the following subdivision is possible: flat banded, convex banded, and concave banded (Fig. 1).

The cuspate type of colloform indicates the concavo-convex lens-shaped or bowl-shaped growth of nodule materials. The central part of the cusp is usually thicker than both margins. Continuous successive growth of cusps results in the long cusp resembling the column. The cusp may consist of either homogenous material or heterogenous parallel bands depending upon the environment of formation. Dunham and Glasby (1974) described the concentric growth cusps within the nodule. They show that crystallization of these cusps begins at nuclei perhaps 0.05 mm apart. As the cusps grow upward, they also grow sideways but leave delta-shaped areas between cusps. Finally cusps coalesce. When the cusps reach some critical size, two or more new nucleating centers form, causing the cusp to bifurcate. The various types of cusps found in the nodule from the Blake Plateau are shown in Fig. 1. Examples are shown in Figs. 3 and 5.

The globular type of colloform indicates the globular growth of nodule materials. Globules usually consist of either one homogeneous phase or parallel bands.

From Fig. 1, it can be recognized that the fundamental colloform textural units in manganese nodules are: banded, cuspate and globular, and that important combined textures are: cuspate banded, banded cuspate, globular cuspate, and banded globular. It can be expected that there are wide gradations among these major textural types.

The above new textural classification can be used to describe the textures of manganese nodules systematically. The textural order of growth of nodule materials can be mentioned using the symbol (shown in Fig. 1) for each texture. The manganese nodule from the Blake Plateau has the textural distribution from the center toward the surface in order: Gb–Cb–C–Cb–Bc–[C+B]–L–-Cg–L–C–Cb(or G)–Cb–B–Cb–L. [ ] indicates the fine alternation of types within the parenthesis.

Since the type of texture within a certain concentric layer is usually considerably uniform, the systematic tabulation of nodule textures in the order of growth as in the above example, make it easy for one to correlate environments of nodule formation between different places. The above classification of colloform textures are applicable to any nodule of any source.

Fragmental texture — Fine-grained quartz grains are enclosed in the colloform manganese oxides. Quartz grains are usually angular to subangular. They were precipitated together with manganese oxides. They were probably transported from other places by wind or sea water.

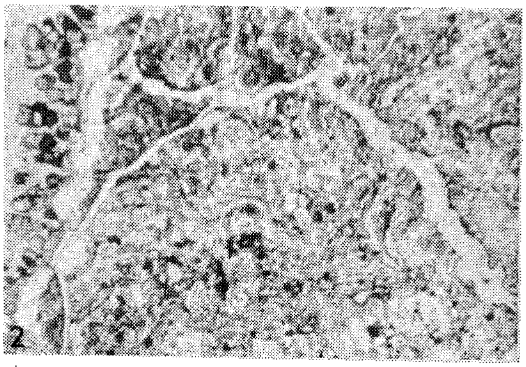
**Secondary textures — Diagenetic textures:**

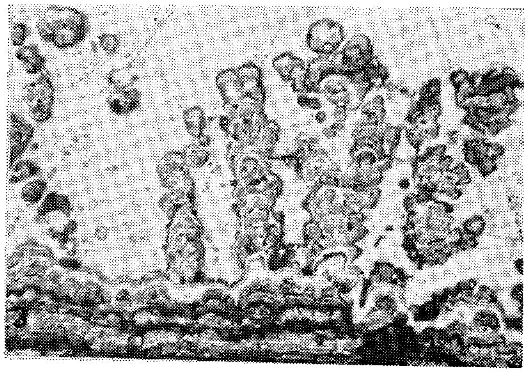
Primary growth textures have been partly changed to other textures by diagenetic processes. Diagenetic features in manganese nodules have been studied by Burns and Burns (1978). The diagenetic textures in the manganese nodule from the Blake Plateau are: replacement, solid state crystallization and recrystallization, cementation and deformation textures.

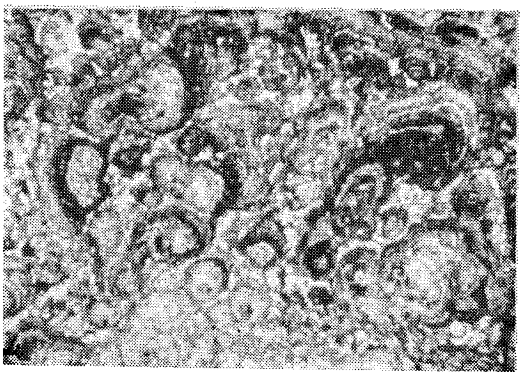
Replacement texture — Replacement took place in small scale. Quartz grains are replaced by todorokite along the margin of the grain. Microfossils are replaced by manganese oxides, leaving the relict structure.

Solid state crystallization and recrystallization texture — Almost all colloform materials which have been originally precipitated as gel ore become more or less crystalline with aging. It is uncertain whether the flaky todorokite seen under the microscope is crystallization product from the amorphous state and subsequent recrystallization, or direct crystallization product from solution. Carbonate materials and microfossils filling the fractures and open spaces within the nodule are partly recrystallized. Relict structure of microfossils are preserved in the recrystallized carbonate materials (Fig. 5).

Cementation (filling) texture — The cavities within the nodule are filled with carbonate and







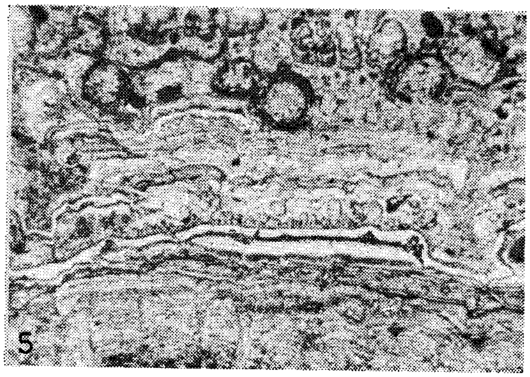


**Fig. 2.** Banded (laminated) type of colloform texture with partial banded cuspate type. Note the lining of microcrystalline todorokite (whitish) along the fracture (left side). Carbonates (grey) fill the irregular fractures which were probably formed by shrinkage with aging. x 69.

**Fig. 3.** Typical cuspate and cuspate banded types of colloform texture in the concentric fracture which was probably formed by shrinkage with aging. The columnar habit of nodule materials results from one-dimensional repetition of the cuspate growth of cryptocrystalline todorokite (grey) and the banded growth of microcrystalline todorokite (white). Note the cuspate, cuspate banded, and banded types of colloform texture in the layered banded types of colloform texture in the layered structure in the lower part. x 69.

**Fig. 4.** Banded cuspate type of colloform texture with partial globular type. x 81.

**Fig. 5.** Banded and cuspate types of colloform texture. Note the spherical relict structure of microfossils in the carbonate matrix. x 81.

clays after the formation of the nodule.

Deformation texture — Many irregular or concentric fractures have been formed by shrinkage with aging.

Shrinkage cracks are lined with manganes oxides, resulting in the banded or cuspate texture in places. Remaining open spaces are filled with carbonates and clays. Carbonates consist of calcite and aragonite. This texture is mainly developed in the older part of the nodule.

**Genetic Implication of Textures**

The main problems in the study of manganese nodules are the source of metals and the mechanism of formation.

The original source of metals are hydrogenous, hydrothermal, halmyrolytic, or diagenetic (Bonatti et al., 1972). Since the metals, whatever their source is, are precipitated through the surrounding water, it is hard to find the source of metals. The adsorption mechanism has been regarded as a dominant means of extracting Mn, Fe, and other trace metals from sea water into manganese nodules (Crerar and Barnes, 1974; Glasby, 1974).

As mentioned above, the colloform textures of manganese nodules are very complex. The complexity in textures suggests the complexity in factors acting on the formation of the nodule. Ancient environments such as historical geology and paleogeochemistry are probably the key to understanding the general problems of nodule origin as depicted by Sorem and Fewkes (1977). The fact that the complex colloform textures consist of three basic textural units, suggests that there are three different modes of accretion of nodule materials that are probably controlled by the physical and chemical environments.

Repeated alternation of these textural units in nodule indicates the repeated change of environment of formation of nodules.

Banded textures may suggest the uniform accretion of nodule materials on the older surface. Cuspate texture may suggest that the number of nuclei of growth was small but the growth rate was different from point to point. Globular texture may indicate the small number of nuclei and concentric growth around them.

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# 北大西洋上의 망간團塊의 組織, 鑛物 및 成因

金 洙 鎭

Blake Plateau 上의 망간團塊는 主로 微晶質 乃至 隱微晶質 토도로카이트와 少量의 石英, 粘土, 炭酸鹽鑛物 및 필 립사이트로 構成되어 있다. 망간團塊는 그 斷面에서 同心円層狀, 內核, 不整合, 裂隙充塡 等의 肉眼的 構造를 가지고 있고 顯微鏡下에서는 膠質狀, 碎片狀 및 다이아제네시스 構造가 觀察된다. 어떤 起源의 團塊의 組織에 對하여도 適用될 수 있는 새로운 膠質狀 組織分類 方案을 發見하여 體系化하였다. 卽 縞狀組織, 혹모양組織 및 球狀組織의 膠質狀物質의 3 가지 基本 組織單位가 存在한다는 것이 밝혀졌으며, 이의 體系的인 細分으로 모든 망간 團塊의 組織의 體系的인 記述과 硏究가 可能하게 되었다. 3 가지 基本 組織單位의 存在는 망간 團塊成長에 있어서 적어도 3 가지 主成長方式이 存在한다는 것을 指示해준다.

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**정 오 표**

1. 제13권 3, 4 호의 學會副會長 명단에 명기된 鄭寅福회원은 오류임
2. 제13권 1, 2, 3 및 4호의 學會評議員 명단에 盧海龍회원이 빠졌음
3. 제13권 3호 p. 194 추계학술답사보고서 삼보광산에서, 오른쪽 위로부터 22번째 行인 "鑛物學的인 面에서…" 부터는 金洙鎭회원의 發言임