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Preliminary Report on the Mineralogical Studies of Bottom Surface Sediments of Kagoshima Bay

Celestina U. CARRANZA*, Katsutoshi TOMITA* and Kimihiko ŌKI*

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Abstract

Results of X-ray diffraction analysis on samples from Kagoshima Bay are presented in this paper as preliminary findings on the mineralogical studies on its bottom surface. The clay mineral components detected are 10 Å-halloysite, kaolinite, smectite and illite. Feldspar, quartz, cristobalite, calcite, gypsum and halite are the non-clay minerals observed. The distributions of these minerals vary in each of the three areas, the bay-mouth, the central, and the bay-head. The common clay mineral, however is the 10 Å-halloysite observed to be present in all areas of the bay.

Introduction

Early investigations on Kagoshima Bay (Hayasaka, *et al*, 1976a; Hayasaka, *et al*, 1976b; Ōki and Hayasaka, 1978; Ōki 1989) were mainly aimed at the geological and paleontological aspects of the area. Separate studies were also made on submarine topography and bottom sediments of the three (3) different parts to which the bay is characteristically divided. In the most recent work of Ōki (1989),textural characteristics of the bottom sediments is cited indicating that clays are the principal components in the sediments. In the bottom sediment data, clay mineralogical analysis and clay mineral distribution are, however, lacking to warrant full account on the mineralogical aspect of the area.

From the materials provided from the bay samples of Ōki (1989), this present study attempts to investigate the mineralogical characteristics and the clay mineral distribution in the surface sediments of the bay. Like all other mineralogical studies on bays, the basic objective is to conduct qualitative and quantitative analysis to identify and delineate mineral distribution, respectively. In this paper however, only the XRD results of the bulk and clay sized fraction analysis are presented as preliminary findings. Results in this paper are interesting chiefly because they describe sediments of the three areas of the bay which vary in environmental conditions.

* Institute of Earth Sciences, Faculty of Science, Kagoshima Univ., 1-21-35 Korimoto, Kagoshima-shi 890 Japan.

The study area

Geographic Location

Kagoshima Bay is situated in the central part of Kagoshima Prefecture, between longitudes 130°06′ to 131°12′E and latitudes 30°59′ and 32°11′N (Fig. 1). The bay displays a sigmoidal shape with surface area measuring about 1,875km^2.

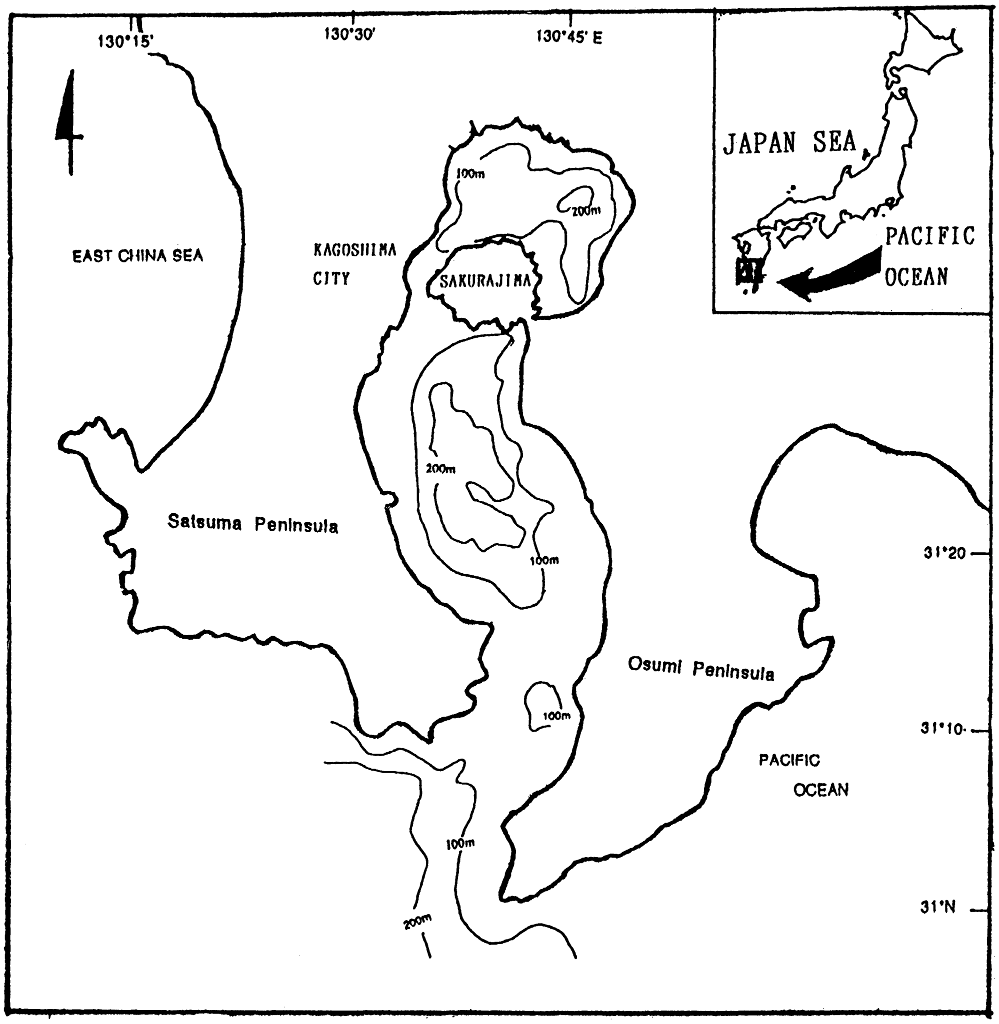

Fig. 1. Location Map of Kagoshima Bay.

The bay is bordered by Hokusatsu area in the north, Satsuma Peninsula in the southwest, and the Osumi Peninsulain the southeast. North central part of the bay lies Sakurajima, a volcanic island which is connected to the northern part of the Osumi Peninsula. This volcanic island geographically divides the central and the head area of the bay.

General Geology

Five major geological units are distributed in the South of the Kyushu Island.

The Mesozoic and Paleogene Sedimentary rocks are called the Shimanto Group and the Nichinan Group, respectively. These are composed mostly of sandstone and shale which consist the basement of the area.

Granitic rocks that intruded into the basement rocks.

The Neogene and Quaternary volcanic rocks and pyroclastic flow deposits.

Several late Quaternay pyroclastic flow deposite which resulted to the formation of caldera and the interbedded marine strata.

The volcanic and pyroclastic flow rocks erupted from the volcanoes of Kirishima, Sakurajima and Ibusuki. Activities of which volcanoes started in the late Pleistocene and continues up to the Recent period.

Local Geology

Kagoshima Bay is generally underlain by volcanic and pyroclastic flow deposits.

It was proposed by Matumoto (1943), based on his detailed studies on topographic features and pyroclastic flow deposits around the bay, that there exist two gigantic calderas, namely: Ata Caldera at the bay mouth area and Aira Caldera at the bay head area. This proposal has led further to the assumption that the bay is genetically related to the caldera formation. Another proposal of Hayasaka and Ōki (1977) and Hayasaka (1987) and Ōki *et al* . (1990) attributed the formation of the bay to a graben which runs from the bay mouth towards the north of about 110 km distance.

Several volcanoes (Kirishima, Sakurajima, Kaimondake) and calderas (Kakuto, Aira, Ata, Kikai) are aligned along this so called "Kagoshima Graben".

The present topography of the bay is assumed to have been formed after the subsidence of the bay mouth-Ata Caldera and the bay head-Aira Caldera areas. The volcanic island Sakurajima is situated in the south rim of Aira Caldera that divides the bay into the central and head areas. North of bay head arealies the Wakamiko Proto-Caldera wherein many fumaroles are sporadically distributed at the bottom.

Characteristic Features of Kagoshima Bay

Several reports by Hayasaka *et al.* (1974, 1976a, 1976b) and Ōki and Hayasaka (1983) have considered 3 portions of Kagoshima Bay which were divided based on its bathymetric features. It is divided into the following: the bay-head, the central and the bay-mouth areas (Fig.2).

a) The Bay-Head Area. The bay-head area is located north of Sakurajima island. This area is further divided into the following two portions: the western half which has a rather flat bottom topography, while the eastern half shows a rather complex features. The sea water in this area rapidly decreases in PH value as the depth increases from 100m depth, and this suggests the occurrence of an acidic water mass below the 100m depth. The genesis of the acidic water can be explained by the component of the carbon dioxide of the gases collected directly from fumaroles by submersible (Kagoshima Prefectural Government, 1978). Perfect dissolving of carbon dioxide in water on the way from the fumaroles must have

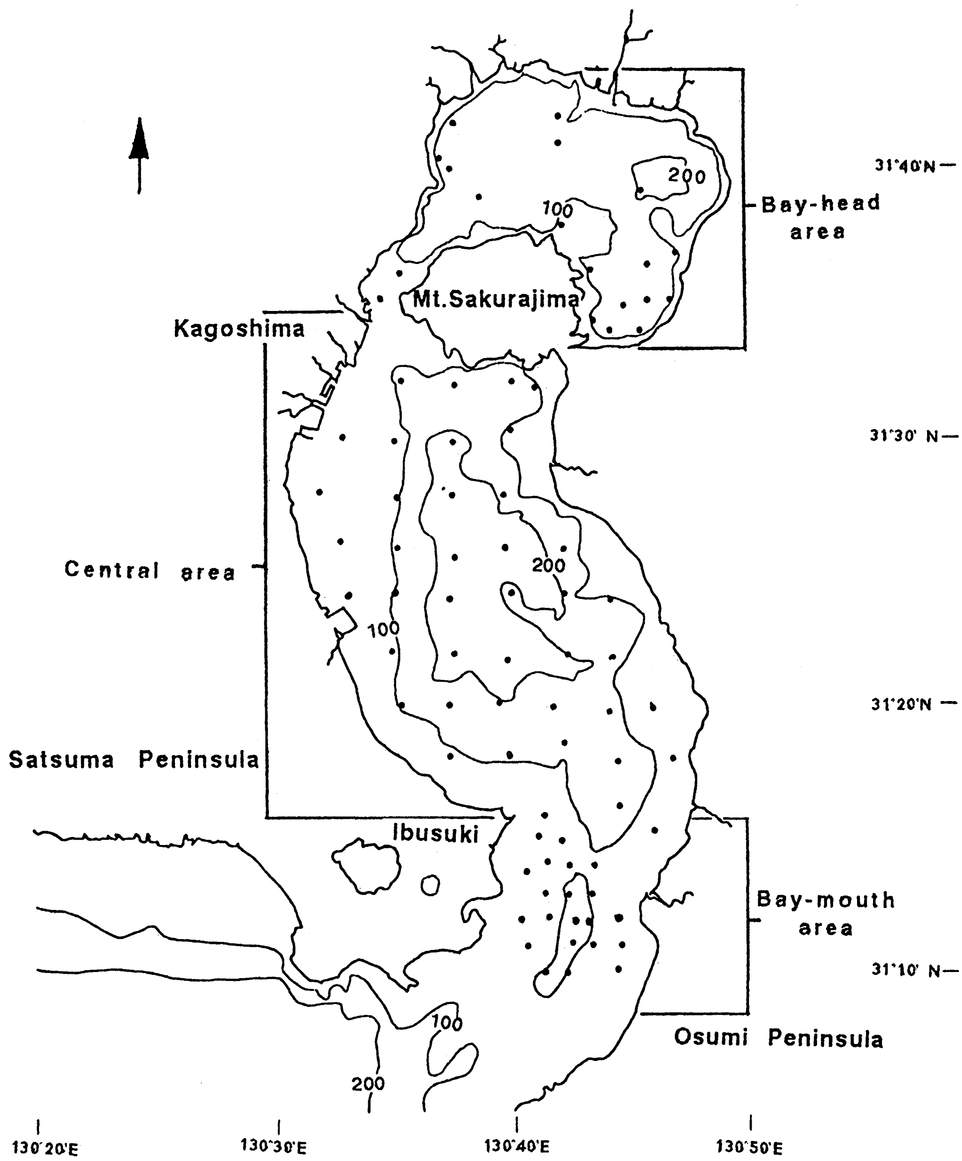

Fig. 2. Map showing the sampling locations and the three divisions of Kagoshima Bay.
• - sampling locations

occured since no carbon dioxide was detected from gases collected from bubbles at the sea surface. Current movements in the bay-head area are generally weak. The salinity of the surface layer in the area is strikingly low, particularly in summertime at which the rainy season permits considerably large volume of water to flow into the bay-head area from the rivers (Ōki, 1989). Lowering of salinity in the west Sakurajima passage and the bay-head area is thought to be the dilution of surface water by the fresh water supplied as rain and from rivers flowing into this area.

(b). The Central Area. The central portion of the bay occupies the widest area among the three areas. It represents a basin like topography at about 230m deep (Ōki, 1989). According to Sakurai and Maeda (1980) and Nozawa and Saisho (1980), the salinity of water in this area is higher on the east side (the Osumi Peninsula side) than on the west side (the Satsuma Peninsula side), due to the effect of the Kuroshio current which increases particularly in summer.

(c). The Bay-Mouth Area. The bay-mouth represents a channel topography that connects the open sea and the central part of the bay. The east side of this channel is bounded by a steep slope representing the underwater extension of the sloping surface of a huge granite body on the Osumi Peninsula, while the west side slope of the channel goes up to the submarine terrace, about 0-20 meter in depth, developed along the coast of Ibusuki City in the southeastern end of Satsuma Peninsula (Ōki, 1987).

Data for the past five years of Sakurai and Maeda (1980) estimated the surface current in central and bay-mouth areas of the bay to be based on the distribution pattern of the surface temperature, salinity, and transparency.

Judging from the submarine topography and sediment distribution, Ōki (1989) assumed that predominant surface current flows northward along the Osumi peninsula, and flows back southward along Satsuma Peninsula. Similar current directions are suggested to occur in the central area.

Methodology

Grab samples of the upper 3 cm of the surface sediments were collected using gravity sampler. Sampling was carried out by Ōki (1989) during the study of the Ecological Analysis of Benthonic Foramineras of Kagoshima Bay.

Samples are analysed through XRD, SEM, DTA and IR methods. For X-ray diffraction analysis (XRD), the 89 samples are divided into two split sample analysis. The first sample split is airdried and powdered for bulk mineral identification. The second group is the clay fractions (<2 microns) which are separated by sedimentation technique based on settling velocities. Oriented samples are prepared for clay mineral identification. Mount of this clay fractions are prepared by pipetting about 10ml of a well dispersed sample onto a membrane through a suction. Untreated and glycolated samples are subjected to the Rigaku (GEIGERFLEX) X-ray diffractometer (30kV, 15mA) scanned at an interval 20°/min.

Results and discussions

Identification of the minerals in this report is based upon X-ray diffraction characteristics of oriented aggregates and their response to glycolation. Among the non-clay minerals identified present in the bay, feldspar is predominant in all samples, along with quartz, cristobalite, calcite and gypsum. Quartz is readily recognized by an intense reflection at 3.34Å and cristobalite which yields a strong reflections at 4.05Å. Calcite is observed present in head and central areas while gypsum is common in central area but prevails in the mouth area. The strongest and most easily identified reflections of these two minerals are 3.03Å peak for calcite and 7.61Å for gypsum. The 2.82Å peak of halite mineral is distinctively observed in the samples from the mouth area.

The clay components of the bay are 10 Å-halloysite, Kaolinite, illite and smectite. 14 Å peak observed is assigned to chlorite, but supplementary methods of identification on this minerals are yet to be employed for confirmation. The distribution of clay minerals in Kagoshima bay can be considered erratic, but dominant of which is the 10 Å-halloysite.

Most of the sediment samples contain the same mineral species, though relative proportions of the different species very from sample to sample. 10 Å-halloysite is predominantly present in most of the samples. Other clay fractions common in most of the samples are kaolinite, illite and montmorillonite. Identification of these minerals are discussed below:

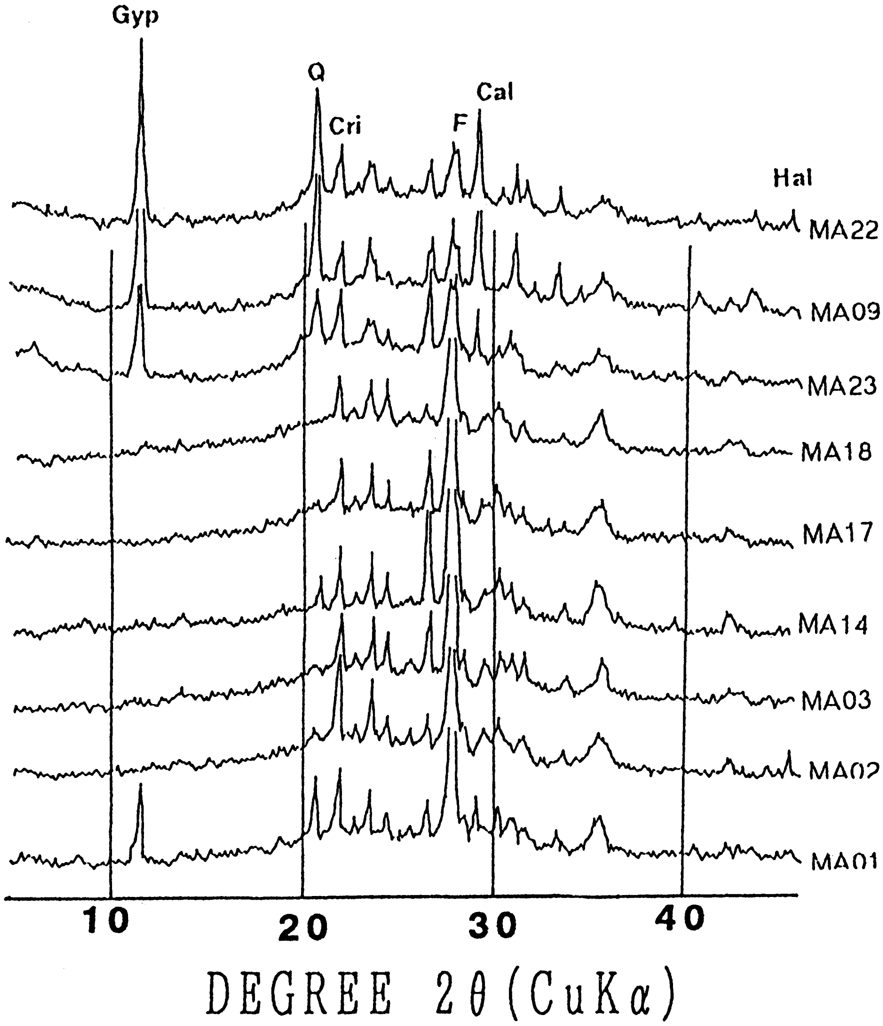

Fig. 3a. X-diffraction patterns of bulk samples from bay-mouth area. (gyp-gypsum, Q-quartz, cri-cristobalite, F-feldspar, Cal-calcite, Hal-halite)

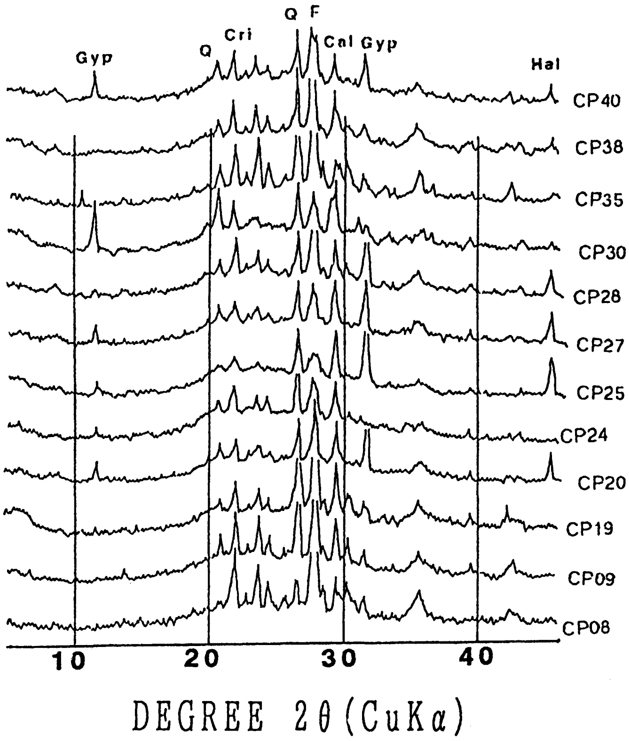

Fig. 3b. X-diffraction patterns of bulk samples from central area. (gyp-gypsum, Q-quartz, cri-cristobalite, F-feldspar, Cal-calcite, Hal-halite)

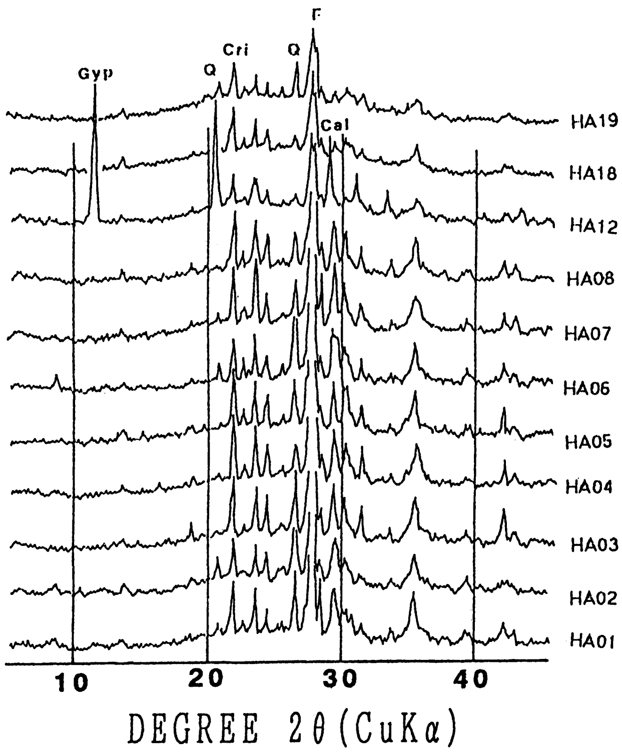

Fig. 3c. X-diffraction patterns of bulk samples from bay-head area. (gyp-gypsum, Q-quartz, cri-cristobalite, F-feldspar, Cal-calcite)

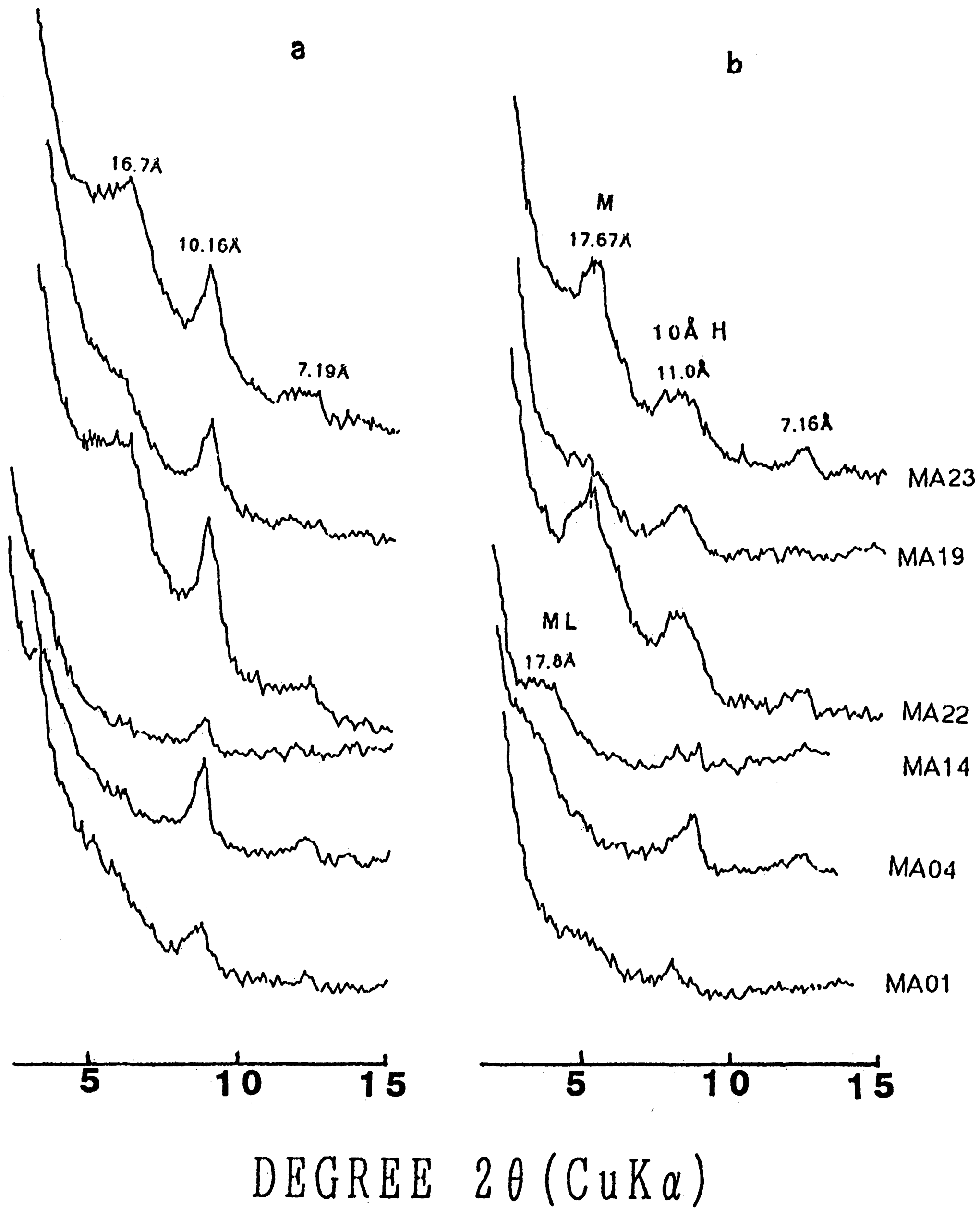

Fig. 4a. X-ray diffraction patterns of clay samples bay-mouth area.
a. oriented samples b. with ethylene glycol
(M-smectite, 10 Å H-10 Å halloysite, Kao-kaolinite, Ml-mixed layer mineral)

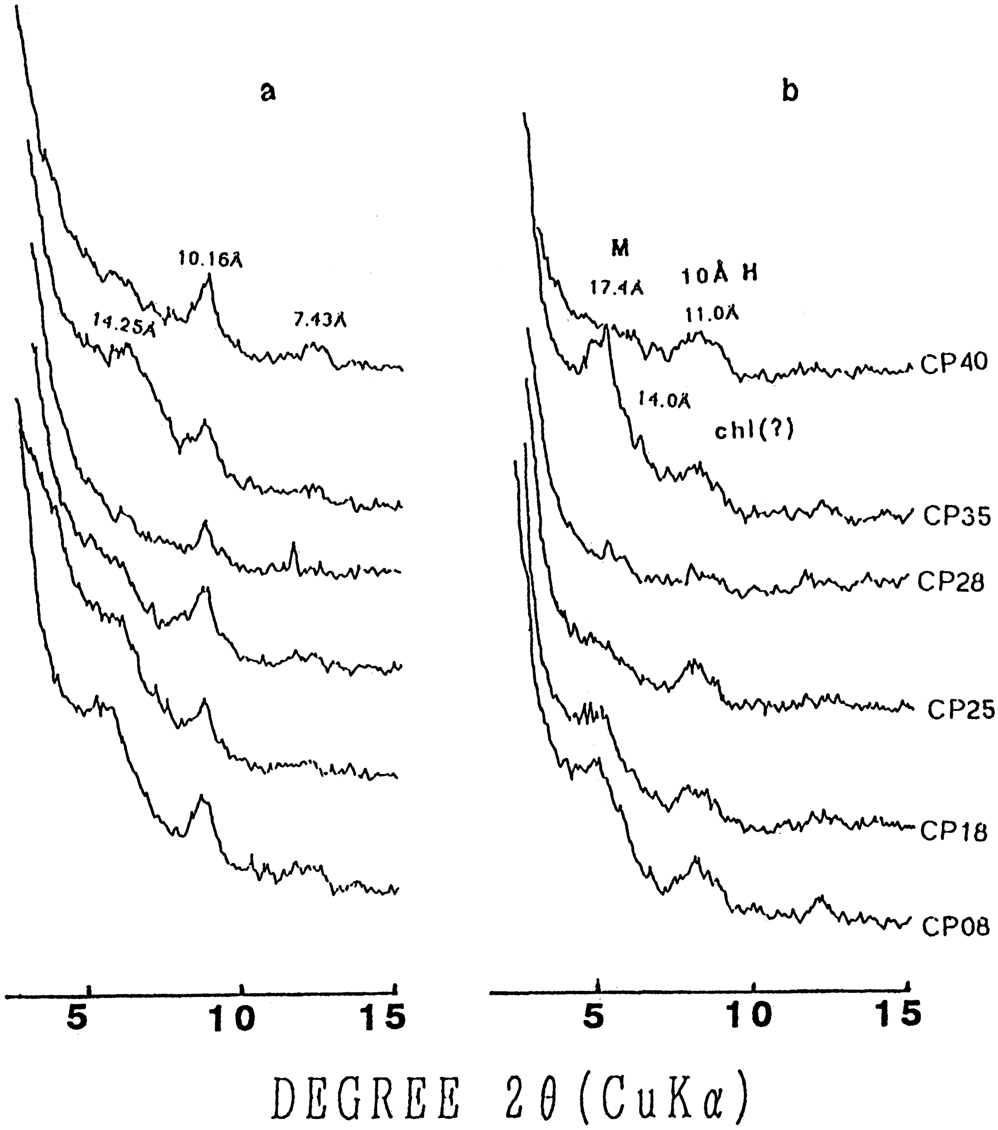

Fig. 4b. X-ray diffraction patterns of clay samples central area.
a. oriented samples b. with ethylene glycol
(M-smectite, 10ÅH-10Å halloysite)

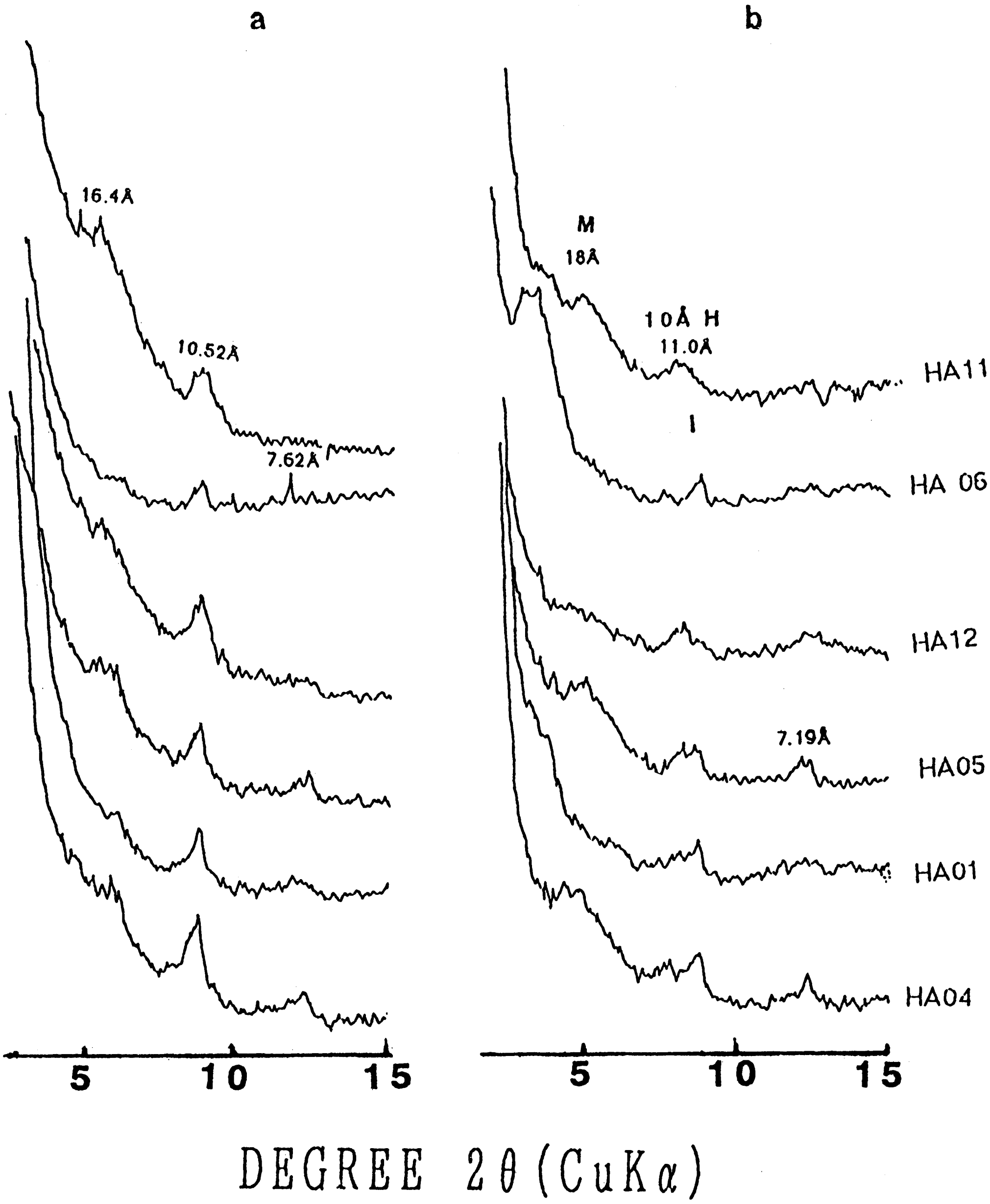

Fig. 4c. X-ray diffraction patterns of clay samples bay-head area.
a. oriented samples b. with ethylene glycol
(M-smectite, 10ÅH-10Å halloysite, Kao-kaolinite, I-illite)

Kaolinite and 10Å halloysite

10Å-halloysite mineral is identified in the untreated sample from the 10Å peak which shifted to 11Å upon glycolation (Fig. 4). 10Å is the dominant clay mineral in the Kagoshima bay sediments. It is generally observed present in all the 3 areas of the bay. The 10Å-halloysite is derived from the widely distributed weathered pyroclastic flow deposits in Kagoshima. 10Å-halloysite is a common clay observed in weathered pyroclastic flow deposits (Tomita and Onishi, 1976).

The 7Å reflection in the untreated and glycolated samples are considered to be due to kaolinite. This mineral is observed to be evident in the bay-head area. The kaolinite minerals are known to occur as constituents of sediments. In the studies of Oimuna (1969) and Aoki *et al* (1975) on recent marine sediments around Japan islands, kaolinite occurs widely as a minor constituent. In Kagoshima bay, kaolinite in bottom sediments is probably derived from altered rocks related to the young volcanic activities in the area. It has been reported (Muraoka, 1951) that kaolinite associated with quartz, cristobalite or alunite is found in Ibusuki area, southeast of Kagoshima bay.

Smectite and illite

Smectite mineral shows 15.2Å peak for untreated samples and expands to 17.4 upon glycolation (Fig. 4). Smectite and Illite are less common at bay mouth and central areas. Their predominance in the bay head area can be interpreted as a transported mineral by the inflowing rivers from which the area receives relatively large amount of run-off during summer season. These two minerals are rarely present in the central portion. Since this present study concerns only the bottom surface sediments, the subject of diagenesis is at this point, not considered. Though the occurrence of smectite with illite mineral would show some evidence that smectite might have undergone diffusion and transformation, following the fact pointed out by Dietz (1941) that the development of illite on the sea floor is carried out by the alteration of montmorillonite from source material being transported to the sea.

Calcite

Calcite is identified in the samples from the strong 3.03Å peak. Its occurrence in the bay is predominant in the central and the bay head areas. Almost all the samples throughout the central area show varying amounts of calcite from one sample to another. The widespead presence of calcite indicates that the area has been a favorable condition for its precipitation.

At the bay-head area, on the other hand, calcite appears only at the center and northeastern side. The absence of this mineral in some parts particularly the seatern section is assumed to be closely related to the acidic water caused by the fumarolic activities in the eastern half of the area. It is well known for calcium carbonates to be easily dissolved in acidic solution and this fact can be correlated to the results on the studies of Ōki and Hayasaka (1983) that the absence of calcareous foraminferas in some part of the bay-head area is assumed to be related to the development of acidic water mass caused by fumarolic activities.

The conspicuous absence of calcite in the mouth area obviously indicates environmental conditions that does not permit calcite formation or precipitation. This bay-mouth portion is characterized with strong currents, and serve as the channel between open sea and the bay's central portion. There is this occurrence of the current rip identified by Hoshino (1952) and Sakamoto (1982), that the flowing northward current on the eastern side of the bay mouth area allow quick sedimentation and flocculation of culloid materials. This active flowing conditions is not favorable for precipitation and/or concentration for calcite mineral that explains its absence in this portion.

Gypsum

Characteristic strong peak at 7.62Å is attributed to gypsum (Fig. 3a, b, c). the results of the XRD analysis show that this mineral, like halite, occur mostly in the mouth area but rarely present in the central area. Only one sample from the bay head area was found to contain this mineral in minimal amount.

The distribution of gypsum gives clue to the possible source (s) of the mineral. Gypsum is an evaporite mineral which when saturated will undergo precipitation. Although in places where gypsum occur in the bay area posses the favorable environment for its precipitation, the reported occurrence of this mineral in the southeastern section of Kagoshima (Ibusuki City) that may have been exposed to weathering to possibly supply sediment to the bay could not be neglected. In the bay head area, it was observed that acidic hydrothermal liquids are coming up from bottom, and many bubbles are observed on the sea surface. Under this conditions, gypsum is easily formed mostly in big crystals.

Halite

Halite mineral is detected at 2.82Å peak in samples from the bay mouth and central areas. These 2 areas are considered saline portions which give no doubt for the occurrence of halite. The variation of solubility of salts with temperature is called upon to explain crystallization of halite at the bottom of the brine basin (Mineral Society of America, 1979), that is evident particularly in the central portion of Kagoshima bay. There are 2 factors to consider in evaluating halite minerals' crystallization: (1) that crystallization ultimately depends upon evaporation and change of temperature that may shift the time and place of crystallization; (2) the amount of salt precipitated depends on the difference of solubility at 2 temperatures, not solubility itself. These factors are considerably important to the halite crystallization in Kagoshima bay, but the number 2 factor seems to be more evident than the first. In observations today in most temperate interior basins where there is range of summer-winter temperature, the brine saturated in summer may precipitate in the winter (Mineral Society of America, 1979).

The presence of gypsum in places where halite is present also propose an assumption that halite mineral precipitated after gypsum. Halite mineral, after sample collection may have probably crystallized in the laboratory

Table 1a. List of Minerals present in Kagoshima Bay
Bay-Mouth Area
(* * -abundant, ●- common, ○- rare, —- not present)

MINERAL CONSTITUENTS

Sample number	Quartz	Feldspar	Cristobalite	Calcite	Gypsum	Halite
MA-01	●	* *	●	—	* *	—
MA-02	—	* *	* *	—	—	—
MA-03	●	* *	●	—	—	—
MA-04	* *	* *	●	—	—	—
MA-05	●	●	—	—	—	—
MA-06	●	* *	●	○	●	—
MA-07	●	* *	●	—	●	—
MA-08	●	* *	●	—	●	—
MA-09	* *	●	●	—	* *	—
MA-10	●	* *	●	○	●	—
MA-11	—	●	●	—	—	—
MA-12	●	●	●	—	—	●
MA-13	●	●	●	—	—	●
MA-14	* *	●	●	—	—	●
MA-15	●	●	●	—	—	●
MA-16	●	●	●	—	—	—
MA-17	—	* *	●	—	—	—
MA-18	—	* *	●	—	—	—
MA-19	●	●	●	—	●	—
MA-20	●	●	●	—	○	●
MA-21	●	●	●	—	●	●
MA-22	* *	●	●	—	* *	—
MA-23	●	●	●	—	* *	—
MA-24	●	●	●	—	—	—

Table 1b. List of Minerals present in Kagoshima Bay
Central Area
(∗ ∗-abundant, ●- common, ○- rare, —- not present)

MINERAL CONSTITUENTS

Sample number	Quartz	Feldspar	Cristobalite	Calcite	Gypsum	Halite
CP01	○	●	●	—	—	—
CP02	○	∗ ∗	●	○	—	●
CP03	—	∗ ∗	●	●	—	—
CP04	●	∗ ∗	●	○	—	—
CP05	●	●	○	∗ ∗	—	—
CP06	●	∗ ∗	●	●	—	—
CP07	●	●	●	●	—	—
CP08	●	●	∗ ∗	●	—	—
CP09	∗ ∗	∗ ∗	●	●	—	—
CP10	●	●	●	●	—	—
CP11	●	●	●	●	○	—
CP12	○	●	●	○	○	—
CP13	●	●	●	●	●	—
CP14	●	∗ ∗	●	●	—	—
CP15	●	●	●	●	●	—
CP16	●	●	●	●	○	—
CP17	●	●	●	●	○	—
CP18	●	●	●	●	—	—
CP19	●	∗ ∗	●	●	—	—
CP20	●	●	—	●	○	●
CP21	●	●	●	●	○	—
CP22	●	●	●	●	○	—
CP23	●	●	●	○	—	○
CP24	∗ ∗	●	●	●	○	—
CP25	●	○	○	●	○	∗ ∗
CP26	●	●	○	●	—	—
CP27	●	●	○	●	○	●
CP28	●	●	●	●	○	●
CP29	●	●	●	●	—	●
CP30	●	●	●	●	●	○
CP31	●	●	●	∗ ∗	○	○
CP32	●	●	●	●	○	○
CP33	●	●	●	●	○	○
CP34	∗ ∗	∗ ∗	●	●	○	○
CP35	∗ ∗	∗ ∗	●	●	—	○
CP36	●	●	●	●	—	—
CP37	●	●	●	●	—	—
CP38	●	●	●	—	—	—
CP39	●	●	●	●	—	—
CP40	●	●	●	●	●	●

Table 1c. List of Minerals present in Kagoshima Bay
Bay-Head Area
(* *-abundant, ●- common, ○- rare, –- not present)
MINERAL CONSTITUENTS

Sample number	Quartz	Feldspar	Cristobalite	Calcite	Gypsum	Halite
HA01	●	* *	●	●	–	–
HA02	* *	* *	●	●	–	–
HA03	●	* *	●	●	–	–
HA04	●	* *	* *	●	–	–
HA05	●	* *	* *	●	–	–
HA06	* *	* *	●	●	–	–
HA07	●	* *	* *	●	–	–
HA08	●	* *	* *	●	–	–
HA09	○	●	○	–	–	–
HA10	○	●	●	–	–	–
HA11	●	●	●	–	–	–
HA12	* *	●	○	–	* *	–
HA13	○	●	●	–	–	–
HA14	○	●	●	–	–	–
HA15	○	●	●	–	–	–
HA16	○	* *	●	–	–	–
HA17	○	* *	●	–	–	–
HA18	○	* *	●	–	–	–
HA19	●	●	●	–	–	–

Table 2a. List of Clay Minerals Present in Kagoshima Bay.
Bay-Mouth Area
(* *-abundant, ●- common, ○- rare, –- not present)
Clay Minerals

Sample number	Illite	Kaolinite	10A Halloysite	Smectite	Remarks
MA-01	●	–	–	–	
MA-02	–	–	–	●	
MA-03					
MA-04	* *	●	–	○	
MA-05	○	–	○	○	
MA-06	●		–	–	
MA-07	–	–	●	○	
MA-08					
MA-09	–	○	* *	●	
MA-10					
MA-11	–	–	●		
MA-12					
MA-13					
MA-14	●	–	●	●	
MA-15					
MA-16					
MA-17					
MA-18					
MA-19	–	–	●	–	chl (?)
MA-20	–		●	●	
MA-21	–		●	●	
MA-22	–	●	* *	●	
MA-23	–	●	* *	●	
MA-24					

Table 2b. List of Clay Minerals Present in Kagoshima Bay.
Central Area
(∗ ∗ -abundant, ●- common, ○- rare, —- not present)

Clay Minerals

Sample number	Illite	Kaolinite	10A Halloysite	Smectite	Remarks
CP01	—	—	●	○	
CP02	●	—	—	○	
CP03	○	—	●	○	
CP04					
CP05					
CP06	—	●	●	—	chl (?)
CP07	○	—	●	○	
CP08	—	●	●	●	
CP09	—	●	●	○	
CP10	—	○	∗ ∗	○	
CP11	—	—	●	○	
CP12	○	○	●	○	
CP13	—	○	●	○	
CP14	—	—	●	○	
CP15					
CP16	—	○	●	—	
CP17	—	○	●	—	
CP18	—	○	●	○	
CP19	○	—	●	●	
CP20	—	○	●	○	
CP21	○	○	●	●	
CP22	—	○	●	○	
CP23	●	○	●	○	
CP24	●	●	∗ ∗	○	
CP25	—	—	●	○	
CP26	○	—	●	●	
CP27	—	●	●	●	
CP28	—	●	●	—	
CP29	—	—	●	●	
CP30	●	—	●	—	
CP31					
CP32	—	●	●	○	
CP33	○	—	●	○	
CP34					
CP35	—	—	●	●	chl (?)
CP36	—	○	●	—	
CP37	●	—	●	—	
CP38	—	—	●	—	
CP39	●	●	●		
CP40	●	●	●	—	chl (?)

Table 2c. List of Clay Minerals Present in Kagoshima Bay.
Bay-Head Area
(* * -abundant, ●- common, ○- rare, —- not present)

Sample number	Illite	Kaolinite	10A Halloysite	Smectite	Remarks
	Clay Minerals				
HA01	●	—	—	●	
HA02	○	—	—	—	
HA03	●	—	●	○	
HA04	●	●	●	●	
HA05	●	●	●	●	
HA06	●	—	○	●	
HA07	●	●	●	—	
HA08	●	●	○	—	chl (?)
HA09	—	○	* *	●	chl (?)
HA10	●	—	—	○	
HA11	* *	—	—	—	
HA12	○	—	●	●	
HA13	—	●	●	●	
HA14	—	●	●	●	
HA15	●	●	* *	●	
HA16	●	—	—	—	
HA17	—	—	—	—	
HA18	—	○	●	●	
HA19	—	—	—	—	

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