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AN INVESTIGATION OF THE EFFECTS OF DEPOSIT FEEDING INVERTEBRATE--ETC(U)
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Naval Ocean Research
and Development Activity
NSTL Station, Mississippi 39529

An Investigation of the Effects of Deposit Feeding Invertebrates on the Structural Properties of Clay Minerals

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EXECUTIVE SUMMARY

Controlled laboratory experiments were conducted on the effects of deposit feeding by *Heteromastus filiformis* (Polychaeta) and *Nuculana acuta* (Pelecypoda) on the structural properties of clay minerals. No evidence was found for alteration of illite after two months exposure to artificial salt water or after ingestion by *H. filiformis* and *N. acuta*. Similar changes in crystal structure and chemical composition were found in montmorillonite exposed to artificial salt water for seven months and montmorillonite ingested by *H. filiformis*. The results of the montmorillonite experiment contradict three previous studies which suggested clay mineral structure may be altered by digestive processes of marine animals.

Ltr. on file

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I. INTRODUCTION

The physical characteristics of marine sediments are profoundly affected by the activities of benthic organisms (Rhoads, 1974). This activity, termed bioturbation, includes burrowing, ingestion/digestion/defecation, tube building, biodeposition, cementation and metabolic activities. Bioturbation has been shown to alter the physical properties of sediments including porosity, grain size, density, fabric, compaction and mineralogy (Rhoads and Young, 1970; 1971; Young, 1971; Pryor, 1975; Rowe, 1974, Myers, 1977). The effects of bioturbation on sediment clay mineralogy is the subject of our experiments.

Deposit-feeding invertebrates such as bivalves, polychaetes and holothurians are common inhabitants of soft marine substrates. Studies indicate that deposit-feeding is universal in all soft surficial oxidized marine sediments and, where deposit feeders are abundant, they pass great quantities of sediment through their digestive tract (Dapples, 1942, Rhoads, 1963; Gordon, 1966; Heezen and Hollister, 1971; Cadée, 1976).

During the process of ingestion, digestion and defecation, clay minerals are subjected to trituration, mastication, attack by digestive enzymes, bacterial action, pH changes and other chemical reactions (Nicol, 1969). Experimental evidence by Anderson _et al_. (1958) and Syvitski and Lewis (1980) suggests that digestive processes of filter-feeding and deposit-feeding benthic animals can disorder the crystal structure of clay minerals and promote exchange of cations attached to or in the clay minerals crystal lattice. Pryor (1975), in a field study on the effects of filter-feeding benthic animals on suspended clay minerals, stated that ". . . their digestive tracts wreak havoc on the clay minerals". The distribution and condition of clay minerals in surficial sediments of the worlds' oceans are a result of available source material, transportation and deposition processes, and changes of clay minerals during and after transportation (Griffin _et al_., 1958). If benthic animals can alter clay minerals during or after deposition, bioturbation may be an important consideration in the interpretation of clay mineral distribution and early diagenesis of clay minerals in surfical marine sediments.

This paper reports a preliminary investigation of the effects of two common deposit-feeding invertebrates on selected structural properties and chemical composition of two dominant clay minerals, illite and montmorillonite.

II. MATERIALS AND METHODS

A. Experimental Organisms

Heteromastus filiformis (Claparede, 1864) is a small, common, capitellid polychaete found in sediments of intertidal flats, shallow bays and estuaries. Its distribution is cosmopolitan, having been reported from both coasts of North America and the Gulf of Mexico (Hartman, 1969). Although _H. filiformis_ is considered a non-selective deposit-feeder, some particle selection based upon nutritional quality (Fauchald and Jumars, 1979) and size (Cadée, 1979) is probable. Heteromastus filiformis constructs feeding and irrigation burrows up to 30 cm deep in the sediment (Cadée, 1979). The burrows provide contact with the overlying oxygenated water and allow the polychaete to feed on anoxic muds below the redox potential discontinuity (Cadée, 1979; personal observation). Small oval fecal pellets are deposited on the sediment surface. Heteromastus filiformis is classified as a conveyer-belt feeder (Rhoads, 1974) in that sediment particles at depth are moved to the surface.

Specimens of H. filiformis were collected from the intertidal zone on the southeastern side of Cat Island, Mississippi Sound. The animals were collected with a shovel and 0.5 mm mesh screen. Intact animals were removed from the screen with forceps and transported in aerated buckets to the Bioturbation Laboratory at the National Space and Technology Laboratory (NSTL), Mississippi. Specimens of H. filiformis were allowed to void their digestive tracts at least 24 hours prior to experiments.

Nuculana acuta (Conrad, 1831) is a protobranch bivalve found in subtidal muddy substrates from Cape Cod, Massachusetts to Texas and around the West Indies to Brazil (Abbott, 1974, Andrews, 1971). Nuculana acuta is more common in the southern portion of its range (Andrews, 1971). Although little has been published on the feeding behavior of N. acuta, its feeding methods can be inferred from published studies on other protobranch bivalves (Purchon, 1977) and observations made during our experiments. Nuculana acuta is a burrowing, non-selective deposit feeder which lives and feeds in the upper 2-3 cm of the sediment. Sediment particles are collected with labial palps and transferred to the palp lamellae for sorting. Particles selected for ingestion are conveyed to the mouth along an oral groove pass through the digestive system and exit as compact fecal pellets through the anus. Particles not selected for ingestion are passed to the mantle cavity where they are forcefully ejected through the excurrent siphon as uncompacted pseudofeces. This ejection of unconsolidated pseudofeces often creates turbid water conditions in aquaria holding this bivalve.

Specimens of N. acuta were collected from a muddy substrate (13-17 m depth) 5 to 15 km southeast of Dog Keys Pass, Mississippi. Samples were collected with a towed A-frame with 6 mm stretch-mesh net and by SCUBA divers. Unsorted samples were transported to the Bioturbation Laboratory in aerated buckets where N. acuta specimens were removed from the debris and held in closed-system aquaria. Specimens of N. acuta were held at least 24 hours prior to experiments to void their guts.

B. Experiments with montmorillonite

A 50% montmorillonite, 50% washed sand (125 to 250 micron diameter) mixture was used as a substrate for the experiments. This substrate, mixed with 60 mg dry weight Gerber Baby Cereal, was placed into two 75 mm deep 150 mm wide crystallizing dishes. This cereal was used as a standard food source by Tenore (1977) for deposit-feeding polychaetes. A montmorillonite/sand mixture without cereal was added to a third crystallizing dish. After the crystallizing dishes were placed in a closed-system aquaria (30 ⁰/oo salinity; 22°C water temperature), thirty specimens of Heteromastus filiformis were introduced to one of the crystallizing dishes containing cereal.

Experiments were begun on 21 December 1979, and terminated 26 July 1980. During this period, specimens of H. filiformis were fed a weekly ration of 60 mg cereal. The cereal was first ground with mortar and pestle and mixed with sea water; then pipetted onto the surface of the sediment in the dish that contained specimens of H. filiformis. At the end of the 7 month period, the control sediments and fecal pellets were removed and prepared for x-ray diffraction analysis. A 25 ml bulbed pipette was used to remove control sediment and H. filiformis fecal pellets from the dishes in the aquarium. The samples from each dish were placed in separate beakers. A Branson sonifier was used to break down the fecal pellets. All samples were passed through a 63 micron sieve and the finer montmorillonite fraction retained.

The filter-membrane peel technique (Drever, 1973) was used to prepare 25 x 75 mm glass slides of the sediment for x-ray diffraction measurements. When the clay-silt film would not transfer from the millipore filter to the glass slide, the entire filter with the sediment film was trimmed and mounted onto the slide with two-sided adhesive tape. If the sediment film separated from the filter upon drying, the filter was discarded and the film was directly mounted onto 2 glass slides with two-sided tape.

Three slides were prepared for each dish in the aquarium and analyzed on a Diano 8000 x-ray diffractometer. Diffractograms were examined for shifts and changes in shape or occurrence of peaks.

Analyses were run using a x-ray energy dispersive spectrometer (Kevex uX 7000) in conjunction with an AMR scanning electron microscope. Counts were integrated over 30 EV on either side of the major x-ray energy peak for each element potentially present in montmorillonite (i.e. Na, Mg, Al, Si, K, Ca, Ti, Mn, Fe). After the background counts were removed, all element counts were normalized to Si. This technique is not considered to yield quantitative ratios between Si and other measured elements but is used to determine if changes in those ratios occur between treatments.

Energy dispersive microprobe analysis was run on montmorillonite prior to treatment, controls with and without organics, and on H. filiformis fecal pellets. The montmorillonite used in these experiments was purchased from Georgia Kaolin Company under the product name of Gelwhite L. X-ray diffractograms for ten 100 mg samples were obtained to characterize the clay and to check the consistency of the diffraction patterns. Each of the 100 mg samples was suspended in 50 ml of distilled water. Fifteen ml of the suspension from each sample was poured into a vacuum filtration apparatus, and slides were prepared by the filter-membrane peel technique (Drever, 1973).

C. Experiment with illite

The illite experiment was set up in the same manner as the montmorillonite experiment. The first crystallizing dish contained a 50% sand/50% illite substrate. The remaining three dishes contained the illite sand substrate mixed with 60 mg Gerber Baby Cereal. Twenty-five specimens of *Heteromastus filiformis* were added to the second dish, twenty-five specimens of *Nuculana acuta* to the third dish and no animals to the fourth dish. The experiment was run from 2 July to 20 August 1980. This period of time was ample for the production of the amount of fecal pellets needed for x-ray diffraction analysis. Specimens of *H. filiformis* and *N. acuta* were fed a weekly ration of 60 mg cereal. Slides were prepared at the end of the experiment as in the montmorillonite experiments.

The illite from Silver Hill, Montana used in this experiment was obtained from the Source Clays Repository in Columbia, Missouri. It was necessary to grind the clay into smaller particles with a mortar and pestle and sieve it through a 63 micron screen to obtain finer grain sizes. Three slides of the original illite were prepared.

III. RESULTS

Fecal pellets of *Heteromastus filiformis* were ovate (Fig. 1). Mean length of the pellets was 420 um and mean width was 190 um (n = 20). Fecal pellets of *Nuculana acuta* were shaped like rectangular rods (Fig. 2). A shallow groove was present along the length of each pellet. Mean length was 220 microns and mean width was 180 um (n = 20). Fecal pellets contained an equal amount of clay and sand particles indicating the organisms were not selecting for certain grain sizes.

A. Montmorillonite x-ray diffractograms

The ten diffractogram patterns of the original montmorillonite were very similar. Figure 3 is representative of the pattern. The major peak appeared at a 2θ angle corresponding to a d-spacing of 15.37 Å. Slight variations in the height of the major peak occurred. Replicate diffractograms of the control without organics were also in close agreement with each other (Fig. 4). The main variation was in the height of the major peak. The same was true for replicates of the control with organics (Fig. 5) and the residue from the *H. filiformis* fecal pellets (Fig. 6).

The major peak in the diffractograms of the control with organics, control without organics and residue from the *H. filiformis* fecal pellets occurred at a slightly lower diffraction angle (corresponding to a d-spacing of 15.90 Å) when compared with the original sample (Figs. 4, 5 and 6).

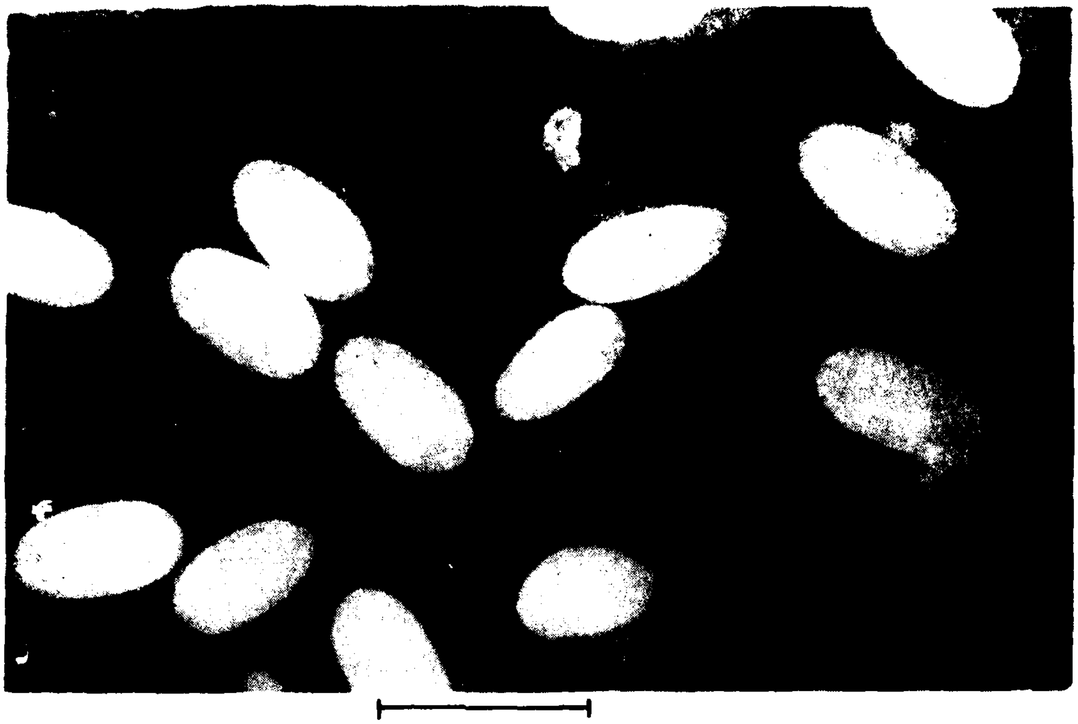

Figure 1. Fecal pellets deposited by the polychaete Heteromastus filiformis.

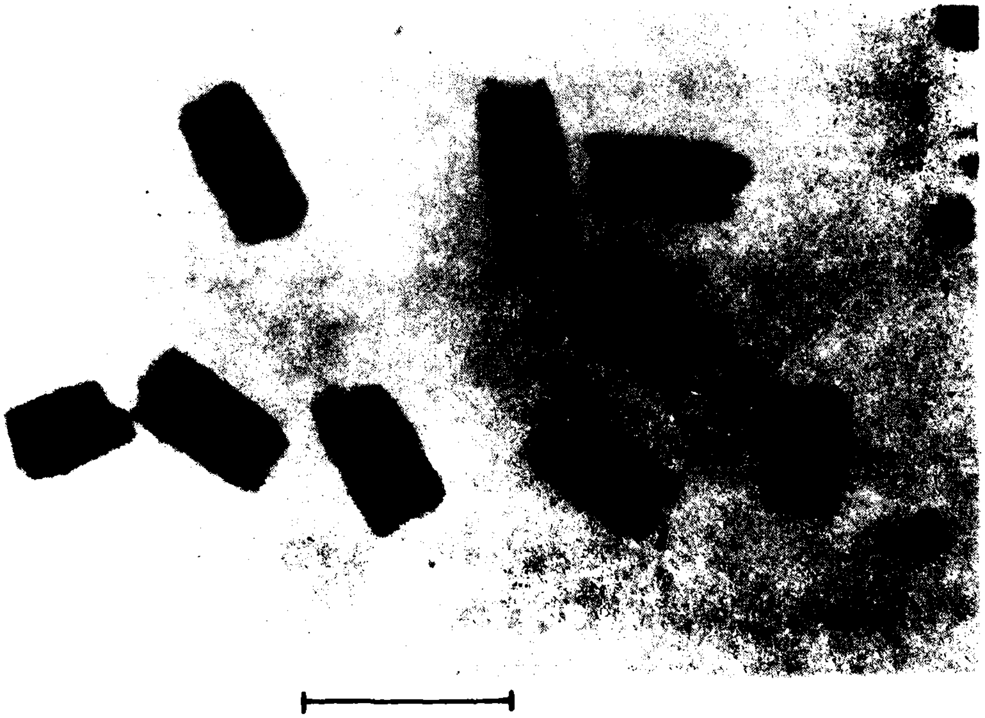

Figure 2. Fecal pellets deposited by the bivalve Nuculana acuta.

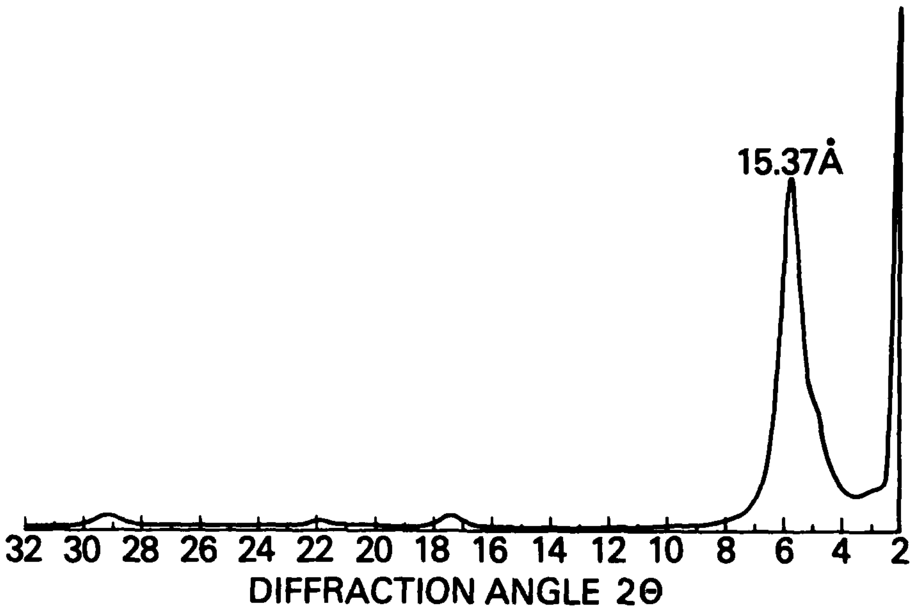

Figure 3. X-ray diffractograms of montmorillonite prior to experiment.

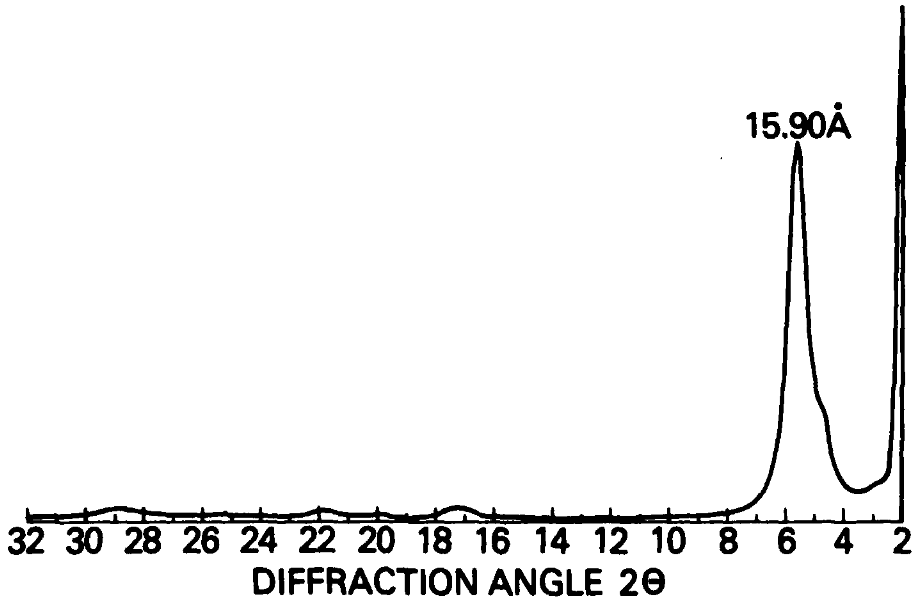

Figure 4. X-ray diffractogram of montmorillonite control without organics.

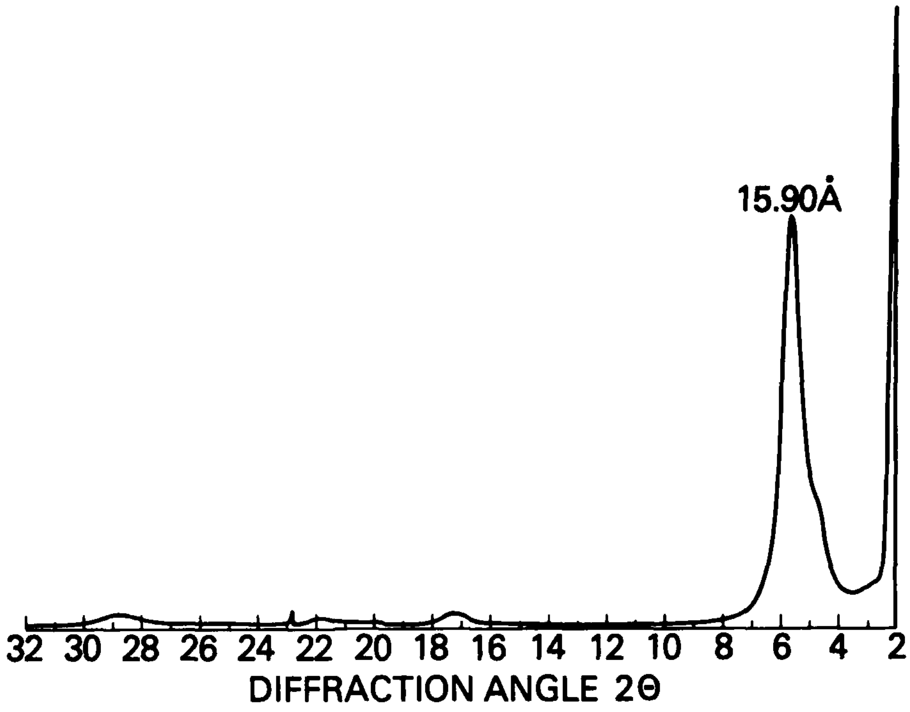

Figure 5. X-ray diffractogram of montmorillonite control with organics.

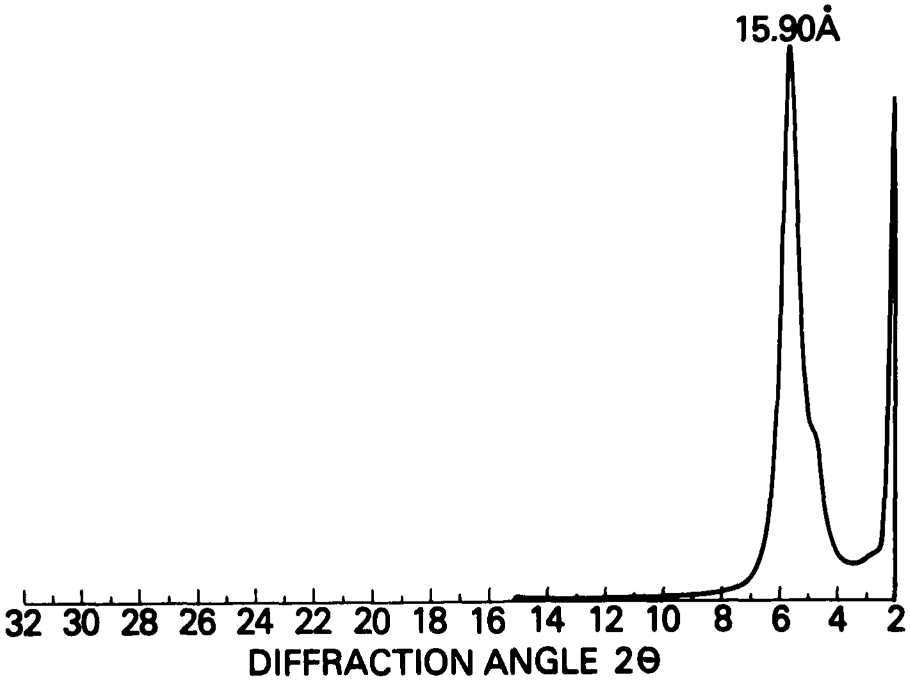

Figure 6. X-ray diffractogram of *Heteromastus filiformis* fecal pellet residue (montmorillonite experiment).

B. Illite x-ray diffractograms

No noticeable differences occurred in the diffractograms of the original illite, control without organics, control with organics and residues of *H. filiformis* and *N. acuta* fecal pellets. Peaks appeared consistently at the same 2θ angle for all samples (Figs. 7, 8, 9, 10 and 11).

C. Chemical Analysis

The original montmorillonite standard contained measurable amounts of silicon, aluminum, calcium, magnesium and iron (Table 1). The counts for titanium, potassium, sodium and manganese were not high enough above background to determine the presence of those elements. In both controls and *Heteromastus filiformis* fecal pellets the Mg/Si ratios were higher and the Ca/Si ratios were lower than the standard montmorillonite (Table 2). Changes in other element/silicon ratios were either too low for accurate determination or did not change compared to the original montmorillonite.

TABLE 1: X-ray energy dispersive spectrometer chemical analysis for montmorillonite experiments. Counts for elements after background counts were removed.

Element	Standard	Control without organics	Control with organics	*Heteromastus filiformis* fecal pellets
Na	542	934	296	810
Mg	11312	20337	23808	26141
Al	88093	112896	114879	139961
Si	386120	506751	490783	617345
K	583	1021	179	964
Ca	19494	9569	8220	12065
Ti	726	1945	1962	2847
Mn	46	199	-24	-268
Fe	2854	4786	3294	6727

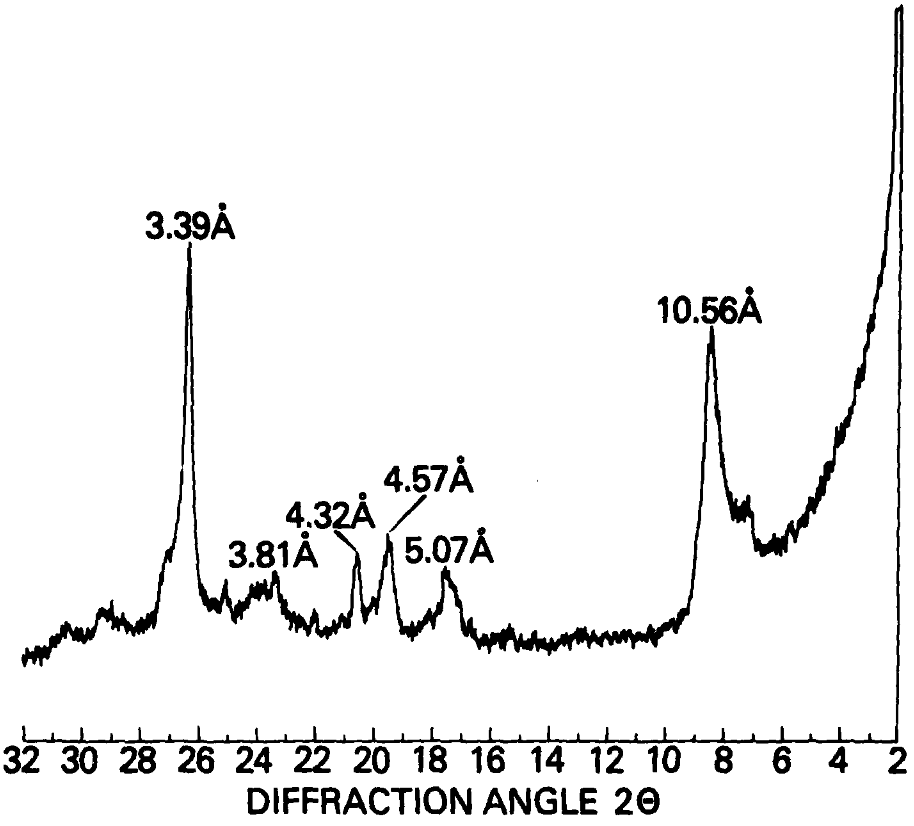

Figure 7. X-ray diffractogram of illite prior to experiment.

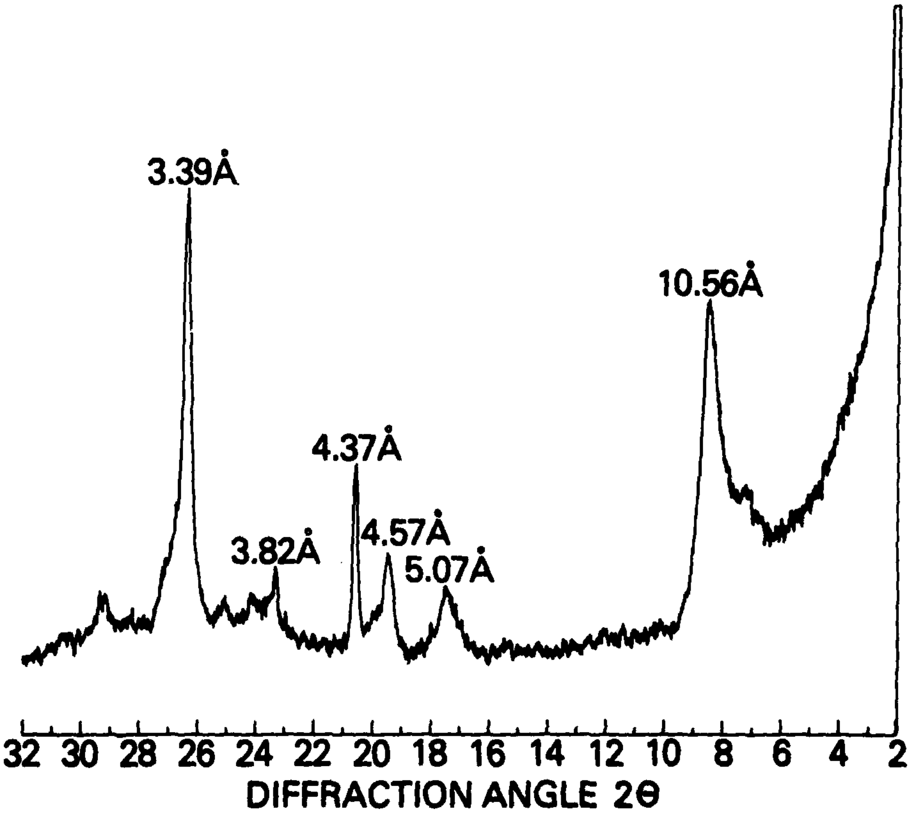

Figure 8. X-ray diffractogram of illite control without organics.

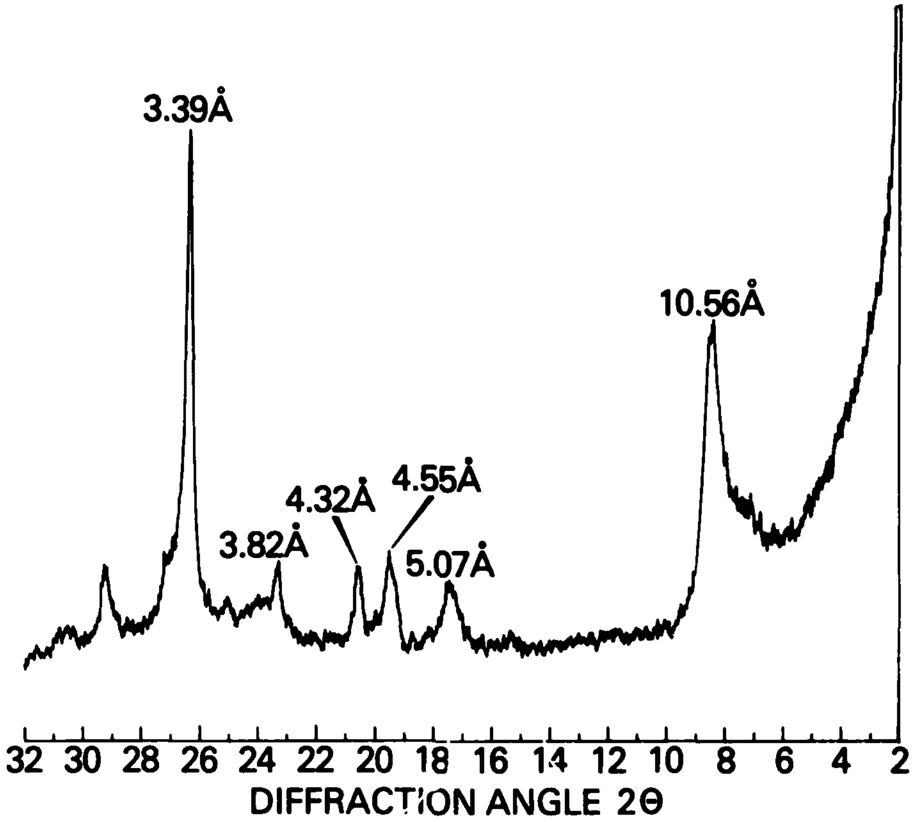

Figure 9. X-ray diffractogram of illite control with organics.

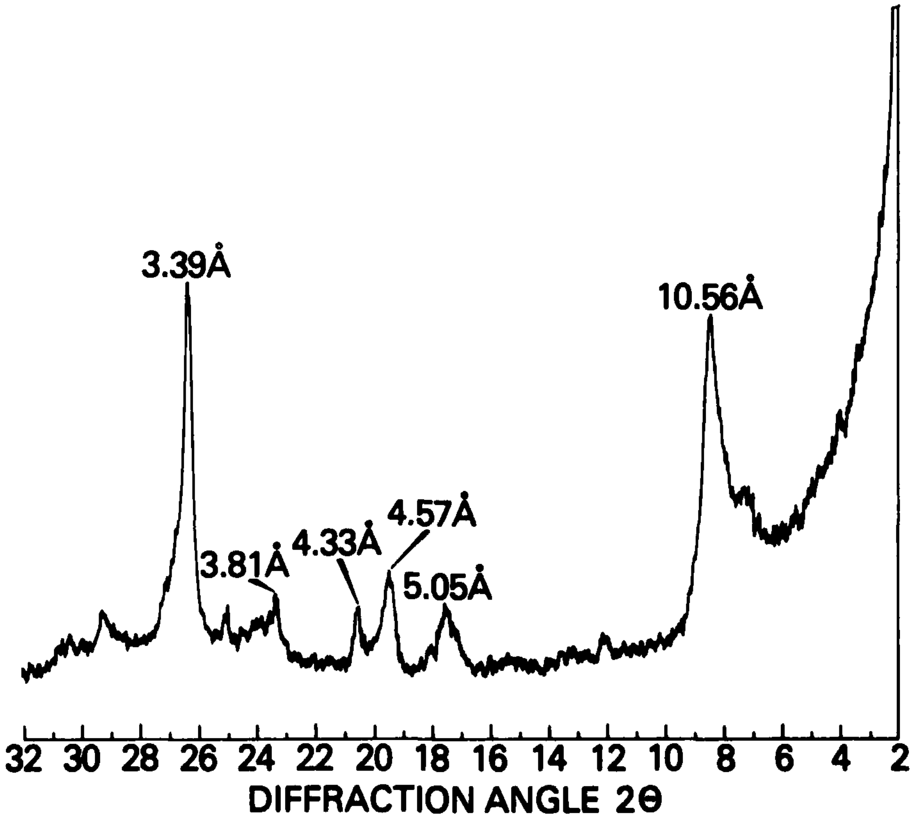

Figure 10. X-ray diffractogram of Heteromastus filiformis fecal pellet residue (illite experiment).

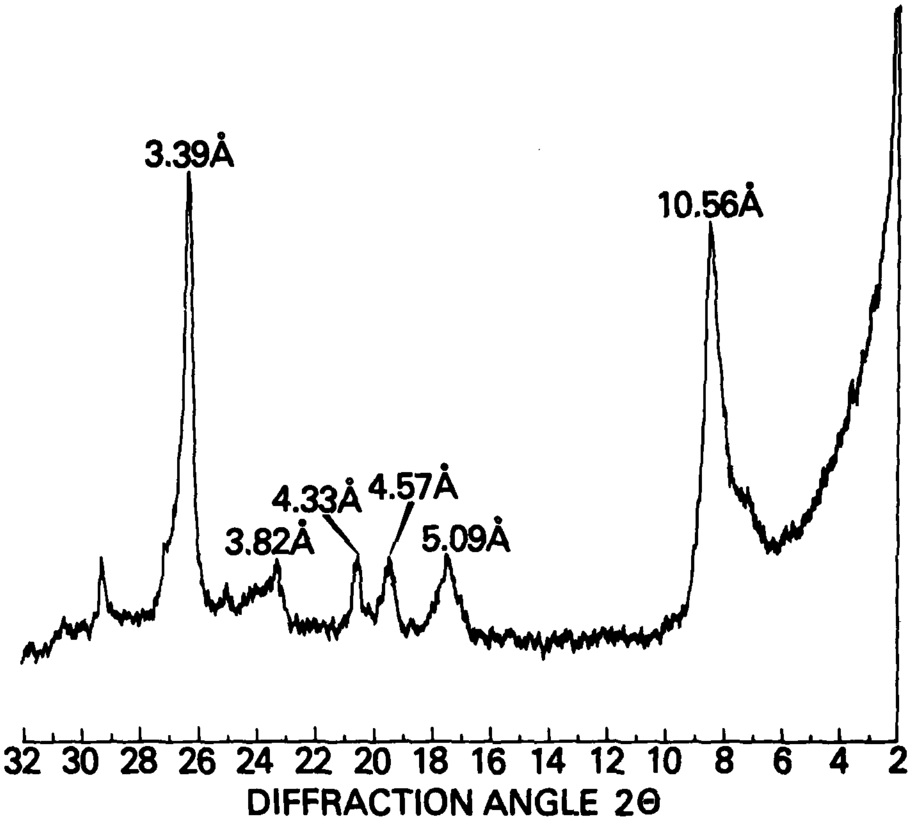

Figure 11. X-ray diffractogram of Nuculana acuta fecal pellet residue (illite experiment).

TABLE 2: X-ray energy dispersive spectrometer chemical analysis for montmorillonite experiments. Ratio of counts for elements normalized to silicon.

Element	Standard	Control without organics	Control with organics	*Heteromastus filiformis* fecal pellets
Na	0.0014	0.0018	0.0006	0.0013
Mg	0.0293	0.0401	0.0485	0.0423
Al	0.2282	0.2228	0.2341	0.2267
Si	1.0000	1.0000	1.0000	1.0000
K	0.0015	0.0020	0.0004	0.0016
Ca	0.0479	0.0188	0.0168	0.0195
Ti	0.0019	0.0038	0.0040	0.0046
Mn	0.0001	0.0004	-0.0000	-0.0004
Fe	0.0074	0.0094	0.0067	0.0109

IV. DISCUSSION

The results suggest montmorillonite may be altered by contact with artificial sea water. The shift of the montmorillonite peak from 15.37 Å to 15.90 Å indicates an increase in spacing between lattice planes (d-spacing) in the crystal structure. This increase in spacing after exposure to sea water may be the result of interlayer cation exchange or change of charge in the 2:1 layer structure due to structural alteration. Our chemical analysis indicates magnesium replaced calcium in the interlayer positions of the montmorillonite lattice. This alteration of montmorillonite in artificial sea water is consistent with the findings of Whitehouse and McCarter (1958). They found significant changes in the crystal lattice structure of montmorillonite after six months exposure to artificial seawater. Their chemical analysis showed an increase in magnesium and potassium and a decrease in sodium and calcium. Whitehouse and McCarter (1958) suggest that the alterations of montmorillonite in salt water are dominated by cation exchange for the first fifteen months exposure. After fifteen months, alterations may be the result of changes in lattice structure as montmorillonite is transformed into illite- and chlorite-like clay minerals. Anderson *et al*. (1958) also found shifts in x-ray diffraction peaks when soil montmorillonite and bentonitic montmorillonite were exposed to filtered sea water for 24 hour and 5 day periods.

X-ray diffractograms of sediment ingested by specimens of *Heteromastus filiformis* did not differ from sediment exposed to artificial sea water. These results are not consistent with the experiments conducted by Anderson *et al*. (1958) and Syvitski and Lewis (1980). Anderson *et al*. (1958) found a greater change in lattice structure of montmorillonite ingested by oysters, clams and mullet than the lattice structure of montmorillonite exposed to artificial sea water. Syvitski and Lewis (1980) found chemical and mineralogical differences in montmorillonite exposed to artificial sea water for three weeks compared to montmorillonite ingested by the marine intertidal harpacticoid copepod, Tigriopus californicus. Although not reported by Syvitski and Lewis (1980), they found little chemical or mineralogical differences between the montmorillonite standard (montmorillonite prior to salt water exposure) and montmorillonite exposed to artificial salt water (J. P. Syvitski, personal communication, 1981).

Pryor (1975) concluded the digestive tracts of Callianassa major (Decapoda) and Onuphis microcephala (Polychaeta) significantly altered the clay mineralogy of sediments these animals extracted from suspension by filter feeding. He based these conclusions on x-ray diffractograms of 11 samples of clay minerals suspended in sea water and 62 samples of fecal pellets collected near C. major burrows and O. microcephala tubes. Although these filter-feeders may alter clay minerals by their digestive processes, Pryor's conclusions are not warranted from his data. There are no data presented in Pryor's paper verifying that sediment ingested by specimens of C. major or O. microcephala is the same sediment collected in suspension. Changes in ratios of clay minerals between suspended samples and fecal pellet samples as well as changes in clay mineral crystal structure could be explained by (1) selective feeding by either species, (2) by feeding on deposited sediment (in the case of C. major), (3) by sorting of clay minerals into fecal pellets (clay minerals ingested) and pseudofeces (clay minerals not ingested) by both species, or (4) by location and time differences in sampling. From what is known about the biology of suspension feeding (see Jørgenson, 1966, for review), selective feeding is a more probable cause for differences in clay mineralogy between suspended material and fecal pellets.

The lack of significant differences between x-ray diffractogram patterns among treatments of illite exposed to sea water, with added organic matter or ingested by specimens of Heteromastus filiformis or Nuculana acuta and the control is consistent with previously reported studies. Whitehouse and McCarter (1958) found no evidence for diagenic modification of illite clays exposed to artificial sea water for 5 years. Syvitski and Lewis (personal communication, 1981) found no chemical or structural change in illite exposed to artificial seawater and ingested by specimens of Tigriopus californicus when compared to their original illite. In all cases, illite appears more resistant to chemical or structural change than montmorillonite.

V. CONCLUSIONS

The effects of digestive processes on the chemical and structural properties of clay minerals are not known. The conclusions of Pryor (1975) are discounted because of sampling problems in Pryor's field study. The results of montmorillonite experiments conducted by Anderson et al. (1958), Syvitski and Lewis (1980) and in this study are contradictory.

The diagenic changes of clay minerals when exposed to salt water of different electrolytic concentrations, different digestive processes (including pH changes, attack by digestive enzymes, physical manipulations and bacterial action) and different organic matter concentrations should be further studied by controlled experiments. These studies should specifically address interaction of these different conditions, timing of digestive processes and whether the diagenic changes are reversible. Until these studies are conducted, the role of deposit feeders in altering clay minerals will remain contradictory.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Controlled laboratory experiments were conducted on the effects of deposit feeding by Heteromastus filiformis (Polychaeta) and Nuculana acuta (Pelecypoda) on the structural properties of clay minerals. No evidence was found for alteration of illite after two months exposure to artificial salt water or after ingestion by H. filiformis and N. acuta. Similar changes in crystal structure and chemical composition were found in montmorillonite exposed to artificial salt water for seven months and montmorillonite ingested by H. (over)

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) filiformis. The results of the montmorillonite experiment contradict three previous studies which suggested clay mineral structure may be altered by digestive processes of marine animals.

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