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Minerals in the Core Sediments from the KONOD-1 Area; Northeastern Equatorial Pacific

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북동 태평양 적도대 KONOD-1지역 코아 퇴적물 중의 광물에 대한 연구

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Abstract

Sediments in the cores from the KONOD-1 area consist mainly of authigenic smectite and clinoptilolite, and terrigenous minerals of illite, chlorite, kaolinite, quartz, and plagioclase. The authigenic minerals become dominant over the terrigenous minerals with increasing depth. Clinoptilolite occurs at the deeper core depth because its formation is slower than that of smectite.

The vertical distribution of minerals indicates that the eolian influence, probably in the late Oligocene, diluted the abundance of smectite in near-surface sediments. This vertical distribution pattern may also have been affected by progressive dissolution of authigenic minerals in the near surface sediments.

요약: KONOD-1 지역의 코아 퇴적물은 자생기원의 스멕타이트와 크리놉틸로라이트, 육지기원의 일라이트, 크로라이트 및 카오린나이트로 이루어져 있다. 스멕타이트와 크리놉틸로라이트의 양은 코아깊이에 따라 증가하며, 특히 크리놉틸로라이트는 생성되는 속성기간이 길어서 스멕타이트보다 더 깊은 깊이에서 나타난다.

표층으로 갈수록 육지기원 광물의 함량이 증가하는데, 이는 올리고세 말의 강한 바람의 영향이거나 해수와 접하는 퇴적물의 용해때문인 것으로 보인다.

INTRODUCTION

Core sediments from the Korea Ocean Nodule Development (KONOD)-1 area, northeastern equatorial Pacific, consist mainly of clays with a minor amount of biogenic skeletals (Jeong et al., 1987). Mineral analysis shows that authigenic smectite and clinoptilolite are important constituents as shown in deep-sea sediments of the North Pacific (Aoki et al., 1974).

Deep-sea authigenic minerals form by the alteration of volcanic debris after sediment deposition (Petzing and Chester, 1979) and the precipitation of hydrothermal fluids in vesicles of basement rocks near the volcanic centers (Haymon and Kastner, 1986). However, chemical and oxygen-isotope analyses of smectite suggest that it forms by the low-temperature reaction of chemical element complexes in the sediment column (Aoki et al., 1974; 1979; Anderson et al., 1976; Hein et al., 1979). A large amounts of trace metals are incorporated in the authigenic minerals

(Hein et al., 1979). Formation of authigenic minerals takes place in different time stages depending upon mineral species; i.e., clinoptilolite forms after a long time later than smectite forms (Kastner, 1979).

Long DSDP cores, piston and box cores from the North Pacific show that terrigenous constituents increase toward the surface due to the prevalence of the wind (westerlies) in Quaternary time (Anderson et al., 1976; Kadko, 1985). The amount of eolian sediment decreases as the distance from the continent and the age of sediments increase (Griffin et al., 1968; Rateev et al., 1969; Johnson, 1976; Rea and Janecek, 1982). However, a detailed study of the relative abundance of eolian sediments in the long sediment cores shows that wind activity has changed with the geologic time (Janecek and Rea, 1983).

This study documents the characteristics of the vertical distribution of minerals in deep-sea core sediments from the KONOD-1 area in the northeastern Pacific. In this study, the abundance versus core depth was determined for smectite, clinoptilolite, illite, kaolinite, chlorite, plagioclase, and quartz.

GEOLOGICAL SETTING

The KONOD-1 area is located in the northeastern central equatorial Pacific, the west side of the East Pacific Rise (EPR) between the western terminations of the Clarion and Clipperton fracture zones (Fig. 1). Fracture zones dissect the sea floor in an east-west direction from the EPR to the Line Islands Ridge. These zones have been formed by transform faults in the Pacific plate from late

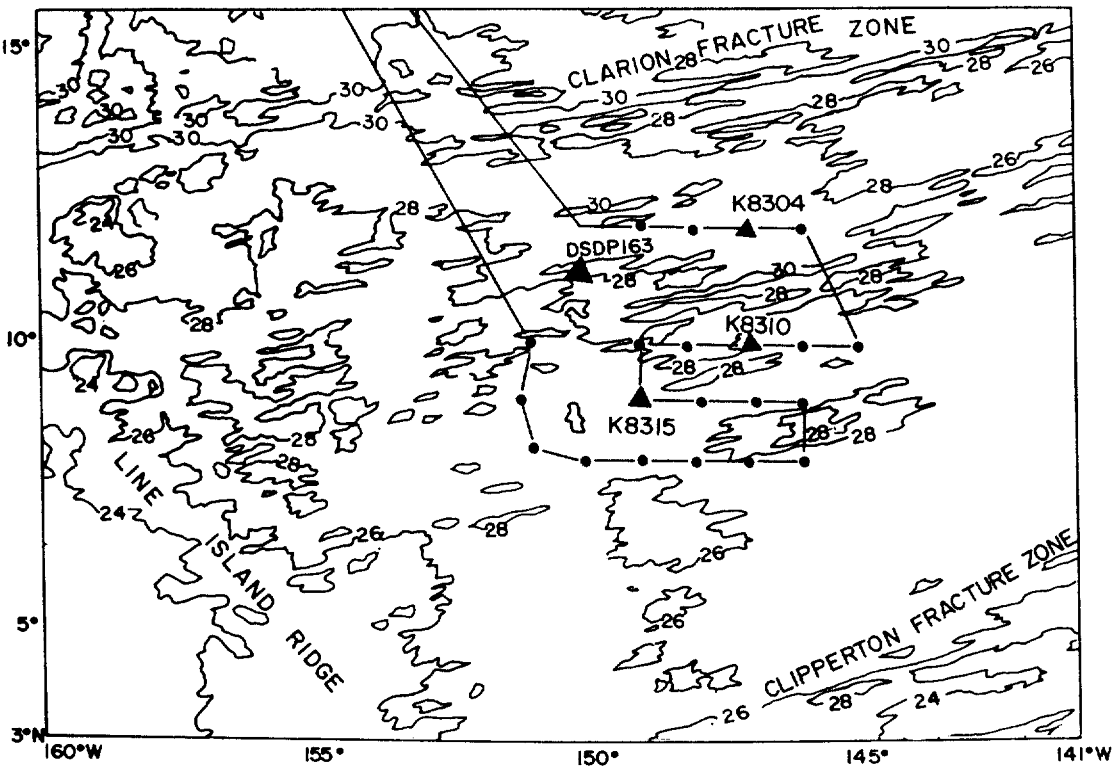

Fig. 1. Bathymetry (after Heezen and Tharp, 1978) and core sampling sites in KONOD-1 area. The depth unit is represented in 100 tau (unit tau is approximately 1.88 m). Black triangles are the core stations and the DSDP site 163. Dots and line are manganese nodule sampling stations and seismic survey tack, respectively.

Cretaceous to middle Miocene time (McKenzie and Morgan, 1969; van Andel and Heath, 1973). The Clarion fracture zone forms the deepest structural lineation in more than 5 600 m of water depth in the north. On the other hand, the Clipperton fracture zone makes a shoaling linear topography shallower than 4,700 m of the water depth in the south (Heezen and Tharp, 1978). Except for some seamounts near the Line Islands Ridge, the sea floor is relatively flat and deepens slightly to the northwest in the water depth of more than 5,000 m. According to Berger (1973), the central equatorial Pacific, excluding the topographic highs, lies below the Carbonate Compensation Depth (CCD, 4,500 to 5,000 m). Although some fluctuation of the CCD has occurred through geologic time, water conditions have been similar to those of the present time during most of the Tertiary period (Hayes et al., 1969; Lipps, 1969). Along the central equator, a thick sediment bulge formed on the sea floor because the nutrient-rich Equatorial Countercurrent upwelling resulted in high primary production in the surface water. However, the central North and South Pacific sea floor is covered with red and brown clays containing rare fossils due to barren surface water layer (Hayes et al., 1969). North from the equator, the calcareous components of the sediments decrease gradually to less than 10% in the KONOD-1 area (Huh et al., 1984). The sedimentation rate also decreases depending on the biological productivity in the surface water mass, from 17.5 mm / 1,000 yrs near the equator to 2 mm / 1,000 yrs in the siliceous ooze and to less than 1 mm / 1000 yrs (0.1 to 0.3 mm / 1000 yrs, Theyer, 1977) in the red clay area (Listitzin, 1972). Although there are some local patches of Quaternary sediments, most surface sediments are composed of the late Oligocene radiolarian ooze or red clay in the KONOD-1 area near the DSDP site 163 (Horn et al., 1973; van Andel and Heath, 1973).

In the Clarion-Clipperton fracture zones, branches of the Antarctic Bottom Water flow eastward through several passages in the Line Islands Ridge (Normark and Spiess, 1976). The mean velocity of the current is weak; less than 10 cm / sec. However, Normark and Spiess (1976) suggested that the currents were strong sufficient to erode the bottom in glacial ages. It appears that the current activity has often been strong in the past in the southern area of the KONOD-1 area (Jeong et al., in prep.).

MATERIALS AND METHODS

Three piston cores (nos. K8304, K8310, and K8315) were obtained in the KONOD-1 area in December 1983 (Fig. 1). Core lengths of K8304, K8310 and K8315 are 560 cm, 287 cm, and 265 cm, respectively. Cores were sealed, frozen and transported to the KORDI laboratory where the subsamples were taken mostly at 40 cm-depth interval.

Grain-size analysis up to 12ϕ was carried out using Sedigraph 5000D auto-size analyzer after removing organic and carbonate materials from the sediments in the solution of 30% H_2O_2 and 0.1 N HCl.

For mineral analysis, two particle fractions of less than 2 μm and between 2 and 20 μm were separated by pippetting the fractions settled in different settling time. Using procedure suggested by Brunton (1955), Hathaway (1956) and Gibbs (1965), 3 slides of non-treated, heated to 550°C, and ethylenglycol-treated samples of each sample were prepared for the identification of the minerals on the X-ray diffractograms (Biscaye, 1965). X-ray diffractograms were obtained by Nikel-filtered Cu-$K\alpha$ radiation of Phillips PW 1710 X-ray diffractometer. The relative abundances of smectite, illite, and the sum of kaolinite and chlorite were obtained by the area of 17 Å, 4 x 10 Å, and 2 x 7 Å peaks on the diffractogram of the ethyleneglycol-treated slide.

Those of kaolinite and chlorite were identified as the peak area of 3.57 Å and 3.54 Å at the same ratio of the non-treated slide, respectively. Other minerals in the powdered samples of less than $2\mu m$ and of between $2\mu m$ and $20\mu m$ were analyzed by peak heights. The peaks of 4.26 Å, 4.03 Å, and 8.9 Å were respectively assigned to quartz, plagioclase, and clinoptilolite.

SEDIMENT CHARACTERISTICS

The sediments consist mostly of very fine clays. According to Munsell soil color chart (1975), the upper parts (K8304, 460 cm; K8310, 140 cm; K8315, 240 cm depth) of the core sediments are generally reddish brown (10YR8/4~4/3), and the lower parts are gray or deep gray color (10YR3/1~4/2, 2.5YR5/1~5YR4/1) (Fig. 2).

The brown color in the upper and gray color in the lower parts of the cores are due to oxidation of ferric oxide and reduction states of ferrous oxide in the sediments (Lynn and Bonatti, 1965). The oxidized sediment zone is thick, more than 1 m, in the central Pacific (Lyle, 1983).

The sediments are highly saturated with sea water (water content, 135~240%, Huh et al., 1984) and bioturbated with various shapes of halo and simple burrows that are typical burrows in the Pacific deep-sea sediments (Donahue, 1971; Piper and Blueford, 1982). The bioturbated parts are characterized by the lighter color (light or pale brown). K8304 core contained a small manganese nodule (less than 2 cm) at 220 cm core depth (Fig. 2). Some of dissolved diatom and radiolarian fragments and spicules were found on the smear slides.

The core sediments are similar to those described in the Pacific manganese nodule fields adjacent to the KONOD-1 area such DOMES Sites A, B and C (Bischoff et al., 1979) and Valdivia Site VA-13/2 (von Stackelberg, 1979).

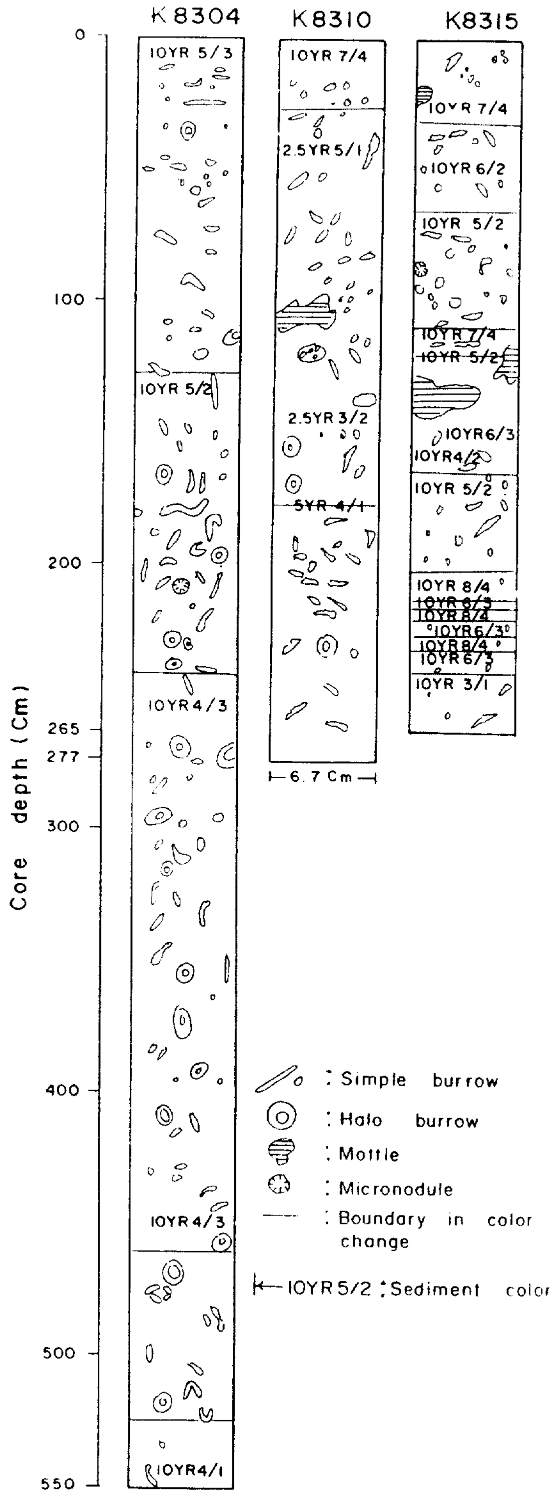

Fig. 2. Characteristics of KONOD-1 area sediment cores. Color changes and burrows are presented (see text).

VERTICAL DISTRIBUTIONS OF MINERALS

Smectite

The relative abundance of smectite is 27 to 76% in K8304, 34 to 82% in K8310, 29 to 80% in K8315. According to Aoki et al. (1974; 1979) and Hein et al. (1979), smectite in the Pacific originates from an authigenic reaction in the sediments and is rich in Fe. Smectite in the KONOD-1 area increases downwards at expense of illite, chlorite and kaolinite (Fig. 3). Core K8304 shows that the smectite abundance increases gradually to a depth of 250 cm and is nearly constant below that. Smectite abundance in K8310 increases abruptly at a depth of 50 cm and then rather constant with minor deviation to the bottom. This may be due to sediment mixing by the biological ac-

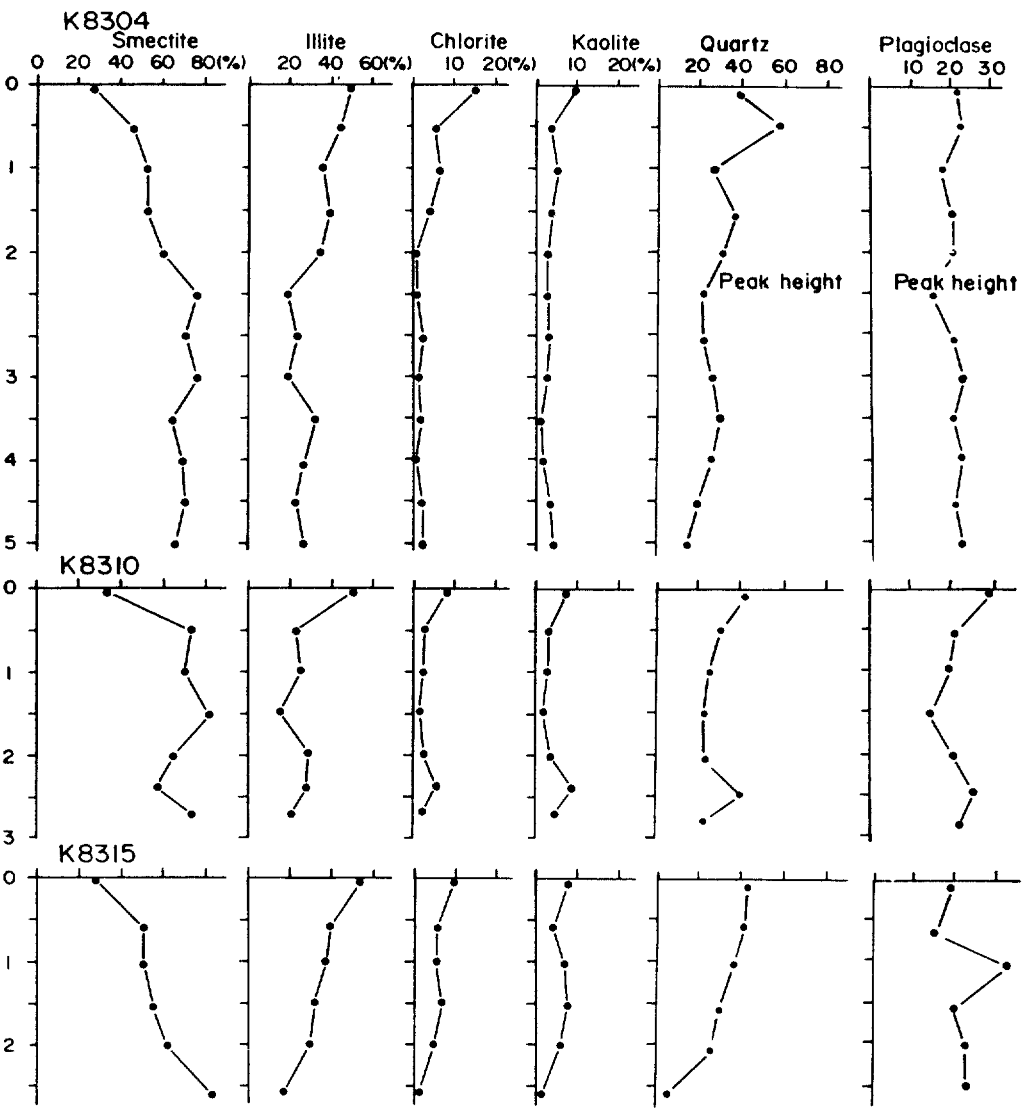

Fig. 3. Vertical distributions of minerals in the core sediments of K8304, K8310 and K8315.

tivity and by bottom current activity as described by Craig (1979) in DOMES Site A.

Illite

Illite makes up the surface sediment in the cores from 48 to 54 % (Fig. 3). This abundance is similar to the general concentration in the North Pacific where the content of illite decreases as the distance increases from the American continent (Griffin et al., 1968). Illite decreases inversely with smectite to the core bottom. Griffin et al. (1968) pointed out that illite in the tropical zone of the North Pacific becomes abundant in the surface sediments because of the westerly wind prevailing in Quaternary time (Griffin et al., 1968).

Kaolinite and Chlorite

The abundance of chlorite in the surface sediment of K8304 is about 15% and decreases gradually to less than 3% below a depth of 200 cm. Kaolinite and chlorite in cores K8310 and K8315 are less than 10% (Fig. 3). Their vertical distributions are reversed to that of illite in each core.

Quartz and Plagioclase

In the KONOD-1 area cores, vertical distri-

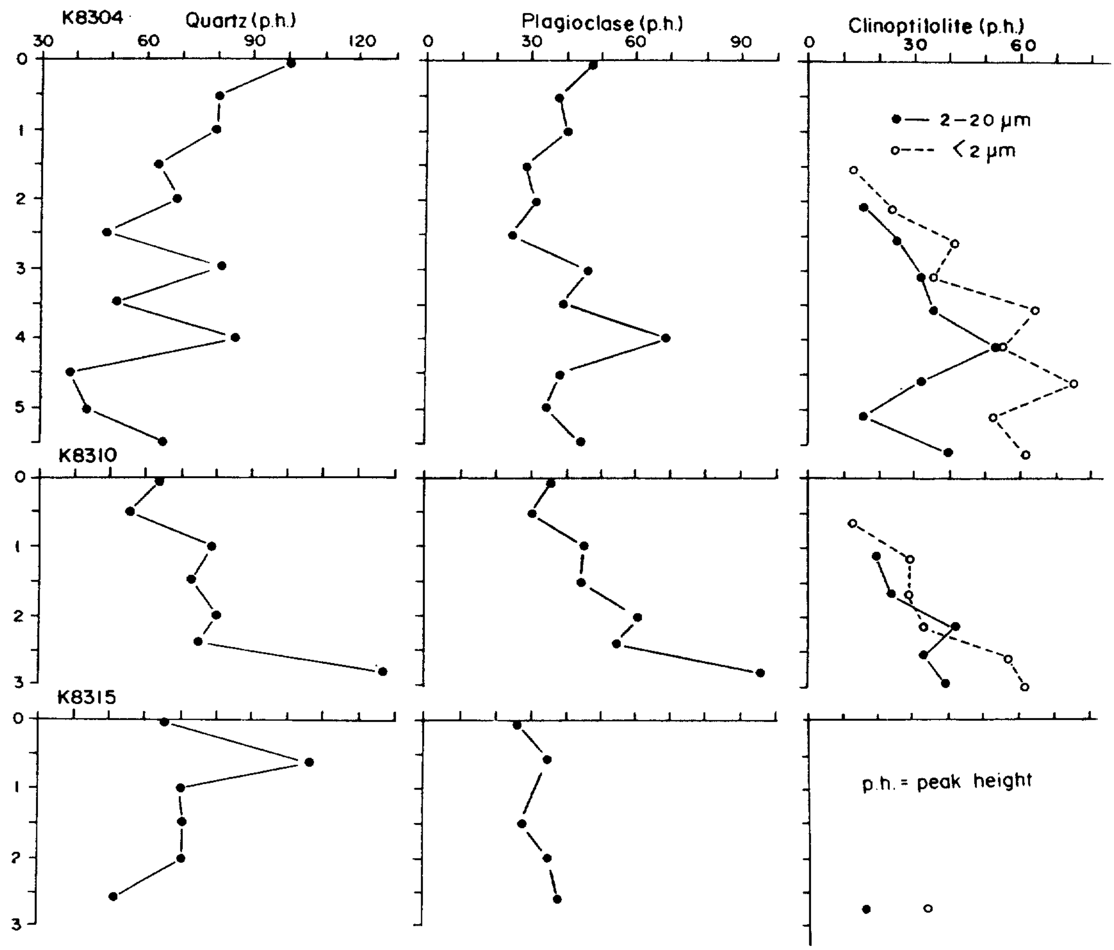

Fig. 4. Vertical distributions of silt-sized minerals of plagioclase and quartz. Clinoptilolite is presented both in clay- and silt-size fractions. The abundances of minerals are identified by the peak intensities.

bution patterns of quartz and plagioclase were determined by examining the X-ray peak heights of clay- and silt-sized sediment fractions. In K8304 core sediment, the peak height of clay-sized plagioclase is relatively constant through the depth (Fig. 3). However, the peak height of quartz increases toward the top of the core. Quartz and plagioclase of silt size are variable in their peak intensities below 250 cm but they increase upward (Fig. 4).

Core K8310 shows that the peak heights of quartz and plagioclase are variable in the clay fraction, however those of silt decrease to the surface (Fig. 4). Clay- and silt-sized plagioclases in core K8315 show rather uniform peak heights with some variations with depth. Quartz in both fractions increases toward the top (Fig. 3 and 4).

Clinoptilolite

The diffraction peak of clinoptilolite in the clay size fraction was found at depth greater than 140 cm in K8304, and 60 cm in K8310 (Fig. 4). The peak intensities in silt size are weaker than those in clay and detected only in the lower core depth below the depth of 220 cm in K8304 and 120 cm in K8310. The abundances of both clay- and silt-sized clinoptilolite generally become higher toward the bottoms of the cores. In K8315, the clinoptilolite peak is identified only at a depth of 260 cm. Generally, the peaks of silt-sized clinoptilolite are weaker than those in clay size.

DISCUSSION

In the DSDP site 163 core from the northwest of the KONOD-1 area, sediments are of the late Oligocene in age (van Andel and Heath, 1973) and the hiatuses are ubiquitous for the last 50 m.y. (van Andel et al., 1976). Horn et al. (1973) and Piper and Blueford (1982) dated the ages of the sediments in the DOMES Site A, included in the KONOD-1 area, as late Oligocene. The KONOD-1 area sediments are thus postulated to be late Oligocene in their ages.

In the KONOD-1 area cores, clay constituents are defined by increasing relative abundance of smectite and decreasing illite, kaolinite and chlorite with depths (Fig. 3). According to Aoki et al. (1974); 1979) and Hein et al. (1979), smectite in the Pacific deep-sea sediments are generally Fe-rich montmorillonite. Chemical and oxygen-isotope analyses on smectite indicate that its formation occurred at low temperature by chemical combination of Fe-hydroxide, silica and aluminum during diagenesis. Pacific authigenic smectite shows high Si/Al ratios (2.8 to 6.9) and high Fe_2O_3 (up to 18.4 %) in the DOMES Sites and the North Pacific. In core sediments from the KONOD-1 area, the high Si/Al ratio (3.0 to 3.6) and high Fe_2O_3 content (mean, 7.2 %, Jeong et al., 1987) also suggest that smectite occurring in the KONOD-1 area is the product of authigenesis. Piper and Blueford (1982) found abundant smectite in Tertiary sediments in DOMES Site A. Hein et al. (1979) suggested that Fe-oxihydroxide originates from the EPR, and silica and aluminum, from the dissolution of siliceous biogenic remains. However, the Fe-oxihydroxide seems to be transported from the west side or from the intraplate volcanisms near or in the KONOD-1 area. Bischoff and Rosenbauer (1977) attributed the metalliferous sediments with high iron content in the central Pacific Mn-nodule field to submarine volcanic activity in the Line Islands Ridge and in the central Pacific intraplate. It appears that the eastward-flowing branch of the Antarctic Bottom Water (AABW) played a role in transporting Fe-oxihydroxide (Jeong et al., 1987).

As the core depths increase, clinoptilolite appears and its abundance gradually increases downcore (Fig. 4). Clinoptilolite is also an authigenically formed deep-sea mineral of zeolite group (Aoki, 1974; Kastner, 1979).

The occurrence of clinoptilolite in deeper sediments than that of smectite suggests that the diagenetic period to or clinoptilolite is longer than to form smectite (Venkatarathnam and Biscaye, 1971). Also clinoptilolite is distinguished from other zeolite by the high Si/Al ratio (larger than 4, Petzing and Chester, 1979). Kastner (1979) showed that clinoptilolite increases in older sediments and then is most abundant in late Cretaceous sediments. In the DOMES areas, clinoptilolite was rare or not found in box core sediments with a penetration depth less than 50 cm (Hein et al., 1979). This gives additional evidence to the above facts. According to the chemical study of the core sediments of the KONOD-1 area (Jeong et al., 1987), most chemical elements are depleted in the upper parts of the cores due to the high oxidization state in upper core sediments. KONOD-1 cores show that the oxidized sediment zones are more than 1 m deep (Fig. 2). This suggests that the chemically-formed authigenic minerals may be deteriorated due to dissolution of the siliceous biogenic materials and metal oxides in an environment of non-depostion or extremely low sedimentation such as in the KONOD-1 area. The above effects as well as the increase of terrigenous detritus may cause the relatively low abundance of smectite in the near-surface sediments.

In the North Pacific, the amount and grain size of quartz were both larger in the Eocene to early Oligocene, late Oligocene, mid-Miocene and Pliocene to Pleistocene times as global aridities and glaciations enhanced (Janecek and Rea, 1983). The age-depth backstripping of the Pacific plate beneath the DSDP 163 core shows that the plate passed the equator and has been in the north equatorial zone by the late oligocene (van Andel et al., 1976). The relative abundance of smectite and peak heights of quartz are in an apparent inverse relationship (Fig. 5a). Several studies (Windom, 1968; Theide, 1979; Janecek and

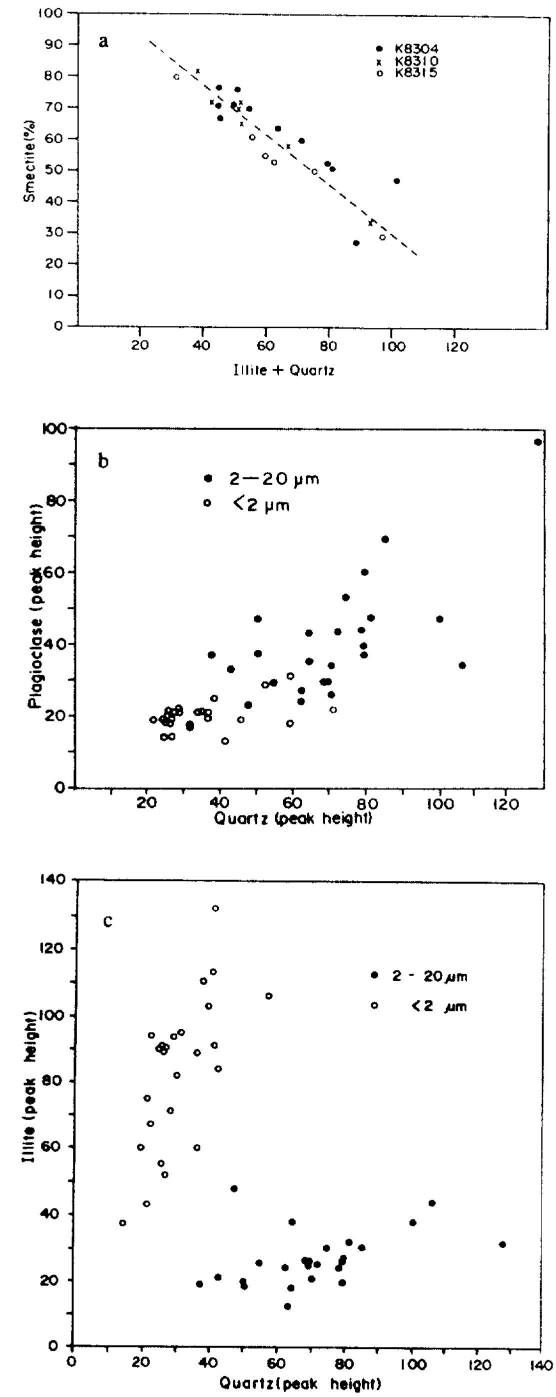

Fig. 5. Relationships between relative abundances of smectite and sum of illite and quartz in clay size fraction (a), peak intensities of plagioclase and quartz both in clay- and silt-size fractions (b), and peak intensities of illite and quartz both in clay- and silt-size fractions (c).

Rea, 1983) showed that quartz grains were derived from the America continent desertic areas and transported into the Pacific Ocean by the westerlies. The relationships between the peak heights of quartz and plagioclase, quartz and illite in this study suggest that they are evidently of continental in origin (Fig. 5b and c). A sediment-trap study in the Pacific shows that illite, kaolinite, chlorite, quartz and plagioclase originated from the America continent (Honjo et al., 1982).

The vertical variations of plagioclase mostly correspond to those of quartz (Fig. 4). Compared with quartz grain sizes, plagioclases both in clay and in silt fractions are less in amount than quartz (Fig. 5b). Clay-sized plaglioclase is mostly in the peak height less than 40. This suggests that the resistence of plagioclase to alteration is weaker than that of quartz grains and that plagioclase particles are subsequent to quartz in the eolian constituent (Heath, 1969; Johnson, 1976). However, illite is mostly clay size with less than 40 relative peak heights, whereas quartz is silt size (Fig. 5c). It may be that quartz has been transported in silt grains during occasional wind storms as in other Pacific areas (Bonatti and Arrhenius, 1965; Gillette and Walker, 1977). Gillette and Walker (1977) found that the particles between 1 to 10 micron are dominantly transported to the Pacific Ocean by the wind.

CONCLUSIONS

The core sediments of the KONOD-1 area show that the minerals of sediments consist of authigenic and eolian constituents. The authigenic minerals dominate the eolian as the core depths increase. The occurrence of clinoptilolite in the deeper sediment depth provides evidence that the formation of clinoptilolite takes longer time than the smectite formation. The sediment characteristics are preferable to form smectite and clinoptilolite because of the dissolution of siliceous biogenic remains in the sediments.

The high abundance of eolian components in the near-surface sediments of the cores may be due to the wind activity in the late Oligocene time in the equatorial Pacific. The segregation pattern of illite and quartz grains suggests that illite has been transported by the normal westerlies of the wind, whereas the quartz grains, often by the wind storms in addition to the westerlies. It also suggests that the active release of chemical elements to the ambient seawater through the dissolution of the near-surface biogenic sediments and metal oxides may be responsible for the low relative abundance of smectite in the tops of the cores.

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