19. DISTRIBUTION OF CLAY FRACTION MINERALS IN MIOCENE THROUGH PLEISTOCENE TERRIGENOUS DEPOSITS OFF SOUTHERN CALIFORNIA AND BAJA CALIFORNIA, DEEP SEA DRILLING PROJECT LEG 63[1]

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This paper discusses the distribution of clay minerals and identification of their assemblages in relation to sedimentary facies encountered during DSDP Leg 63 drilling off southern California and Baja California. We also consider how these assemblages are determined by source areas and changes in general paleogeographic environments during different periods of sedimentation.

The minerals in the clay fraction (<1 μm) were studied from cores recovered in the eastern Pacific along Southern California and Baja California. Sites 467 and 468 are located near the western edge of the southern California Continental Borderland. Sites 469, 470, 471, and 472 are located near the foot of the continental slope between 32°37.00′N and 23°00.35′N. Site 473 is on the Rivera plate in the mouth of the Gulf of California, near the northern end of the Middle America trench (Fig. 1).

SOME PECULIARITIES OF ENVIRONMENTS DURING FORMATION OF CLAY DEPOSITS

The composition and structure of Miocene through Quaternary deposits recovered along the eastern marginal Pacific reflect a combination of three main inputs: biogenic (silicate and carbonate) accumulation, terrigenous sedimentation, and accumulation of pyroclastic material. The main types of sediments are represented by nannofossil and diatom oozes, clays, aleuritic clays, carbonate-silicate clays, sandy, aleurolite deposits, and rare volcanogenic sediments.

Proximity to the land and abundance of sandy-clay terrigenous material determined the predominance of terrigenous accumulation. These factors sometimes account for the high rates of sedimentation, particularly for the lower parts of the sequences at a majority of the holes (except Sites 470 and 472). Middle Miocene or upper Miocene deposits at Site 473 are represented by sandy–aleuritic–clay turbidites. Land-derived clay mineral assemblages include relatively stable varieties such as illite, chlorite, minor kaolinite, and mixed-layered montmorillonite-illite (M-I), as well as abundant smectites. The predominance of smectites in the composition of terrigenous clay mineral assemblages is rather typical for Miocene through Quaternary deposits along the California margin. The abundance of smectite is probably related to a broad distribution of volcanogenic and volcanogenic–sedimentary formations that contain predominantly clay-size components.

Changes related to tectonic movements within the source province should affect the composition of assemblages of heavy-fraction minerals and detrital clay minerals. The middle Miocene sediments include only terrigenous, multiple redeposited material with monotonous assemblages of most stable heavy minerals: zircon, garnet, chromic spinel, and ore minerals. Near the end of the middle Miocene and the beginning of the late Miocene, volcanogenic deposits are more common. Pliocene deposits contain considerable proportions of debris weathered from metamorphic rocks exposed in seafloor outcrops in the southern California Continental Borderland. Common heavy minerals in this detritus include glauconite and minerals of the epidote–zoisite group.

Pyroclastic material also served as an important source for formation of authigenic clay minerals in the deposits studied. A considerable admixture of pyroclastic material (predominantly volcanic glass)—probably the products of subareal andesite volcanism—were found in many Miocene through Quaternary deposits. Fine interlayers of vitric ashes and tuffs with andesite-dacite composition were also found. The volcanogenic material is an important component only in middle to upper Miocene (Hole 467) or middle Miocene (Holes 468 and 469) deposits of the southern California Continental Borderland. The upper part of the sedimentary sections (down to the depth of about 200 m) belongs to the zone of unaltered volcanic glass (Grechin et al., this volume). It is characterized by ashes not altered by secondary processes. Below this zone, all volcanic interlayers are diagenetically altered. Clay minerals and zeolites are formed by alteration of volcanic material. Authigenic clay minerals in the tuffs are represented by different structural varieties of smectites or mixed-layered components with a predominance of smectite layers in their structure. The same minerals are also developed in scattered pyroclastics and can be identified by X-ray diffraction analyses. However, the estimation of quantitative ratios between authigenic and terrigenous smectites is rather difficult.

[1] *Initial Reports of the Deep Sea Drilling Project*, Volume 63.

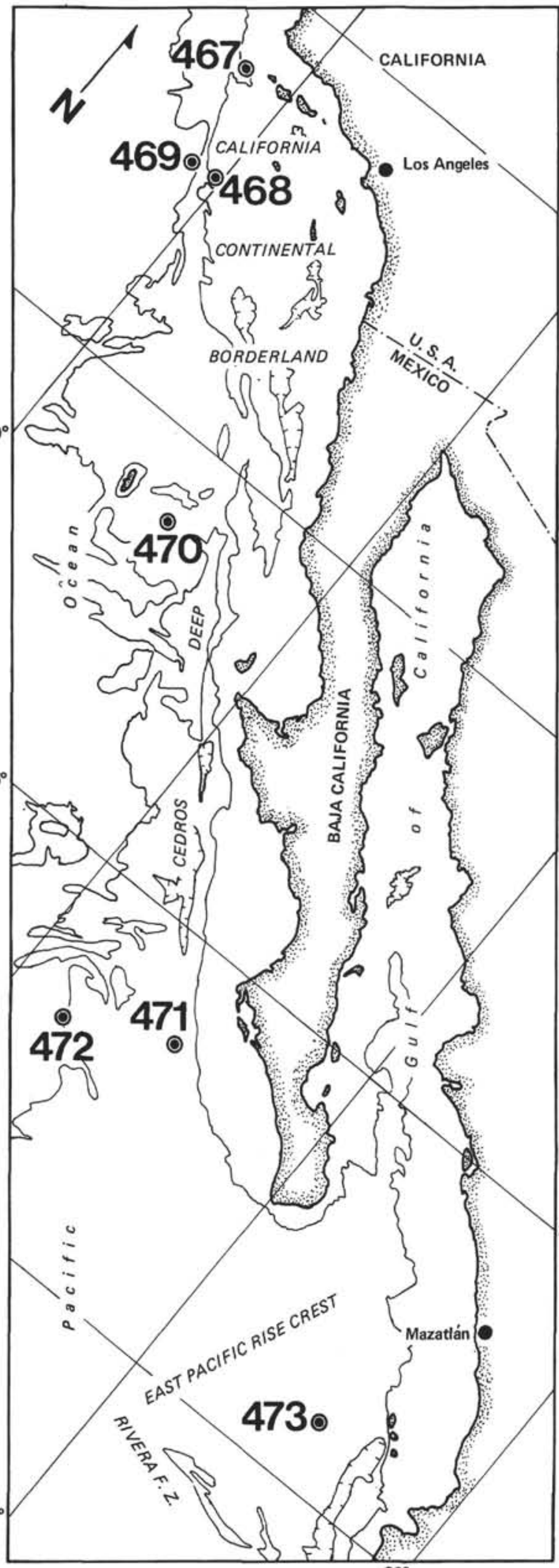

Figure 1. Location map of Leg 63 sites.

X-RAY DIFFRACTION ANALYSES OF CLAY MINERALS

The clay minerals were mainly studied by the standard X-ray diffraction method for the fraction < 1 μm. The diffractograms were obtained by the diffractometer "DRON-1" (USSR) using CuK_α radiation generated at 34 kV and 20 mA. Scanning rates were $2°2\theta$/min. All samples were X-rayed in three states: (1) natural or air dry, (2) saturated by glycerine, and (3) heated at 550°C. Besides illite, chlorite, and kaolinite, we described mixed-layered phases and structural varieties of minerals from the smectite group. We identified structural varieties of smectites on the basis of the correlation between intensities of basal peaks d_{001}, d_{002}, d_{003} as well as the degree of resistance of these minerals to a 10% solution of HCL heated at 80°C for one hour. The volcanogenic rocks revealed the following varieties of smectites: dioctahedral Al- and Al, Fe-and Ca-montmorillonites, K, Fe-montmorillonite, and trioctahedral Mg-montmorillonite. Al- and Fe-montmorillonites and more frequently montmorillonite with K in the interlayers in the form of a green glauconitelike mineral (Holes 468 and 468B) were identified in clay mineral products of scattered vitroclastics in the rocks with mixed composition. The latter mineral has d = 13.4 Å to 13.7 Å in an air-dry state, d = 16 Å to 17 Å after saturation with glycerine, and d = 9.93 to 10.07 Å after heating at 550°C.

In those cases in which a mineral was identified as montmorillonite without indicating its structural varieties, it is synonomous with the group name smectite. Besides common ones we found iron varieties of illites. So-called "defect" chlorite, with d = 13.1 Å to 13.8 Å after heating at 550°C (or undergoing disintegration at the same temperature [Drits and Sakharov, 1976]), is frequently found among Mg-Fe trioctahedral chlorites with d = 7.08 Å, 4.70 Å, and 3.53 Å. Among mixed-layered minerals we identified two types; an intensively swelling montmorillonite-illite (M-I) close to smectite and an illite-montmorillonite (I-M) close to illite. Identification of mixed-layered minerals was made on the basis of well-known works by Reynolds (1968), Drits and Sakharov (1976), and Gradusov (1976).

An intensively swelling type of mixed-layered mineral (M-I) with disordered alternation of montmorillonitic layers was identified by diffraction maxima of 12.74 Å up to 14.9 Å in an untreated specimen, 18.3 Å in a specimen saturated with glycerine, and 9.92 Å in a specimen heated at 550°C, with distinct assymetry of the peak towards small angles (Fig. 2). The second type of weakly swelling mixed-layered mineral (I-M) with disordered alternation between illite and montmorillonite layers revealed the following diffraction peaks: 10 Å in an untreated specimen, 9.8 Å to 9.89 Å in a specimen saturated with glycerine, and 9.8 Å after heating (Drits and Sakharov, 1976).

DISTRIBUTION OF CLAY MINERALS AND THEIR ASSEMBLAGES IN SEDIMENTARY SEQUENCES OF LEG 63 SITES

The distribution of clay minerals in sedimentary sequences is described from the bottom upward. All as-

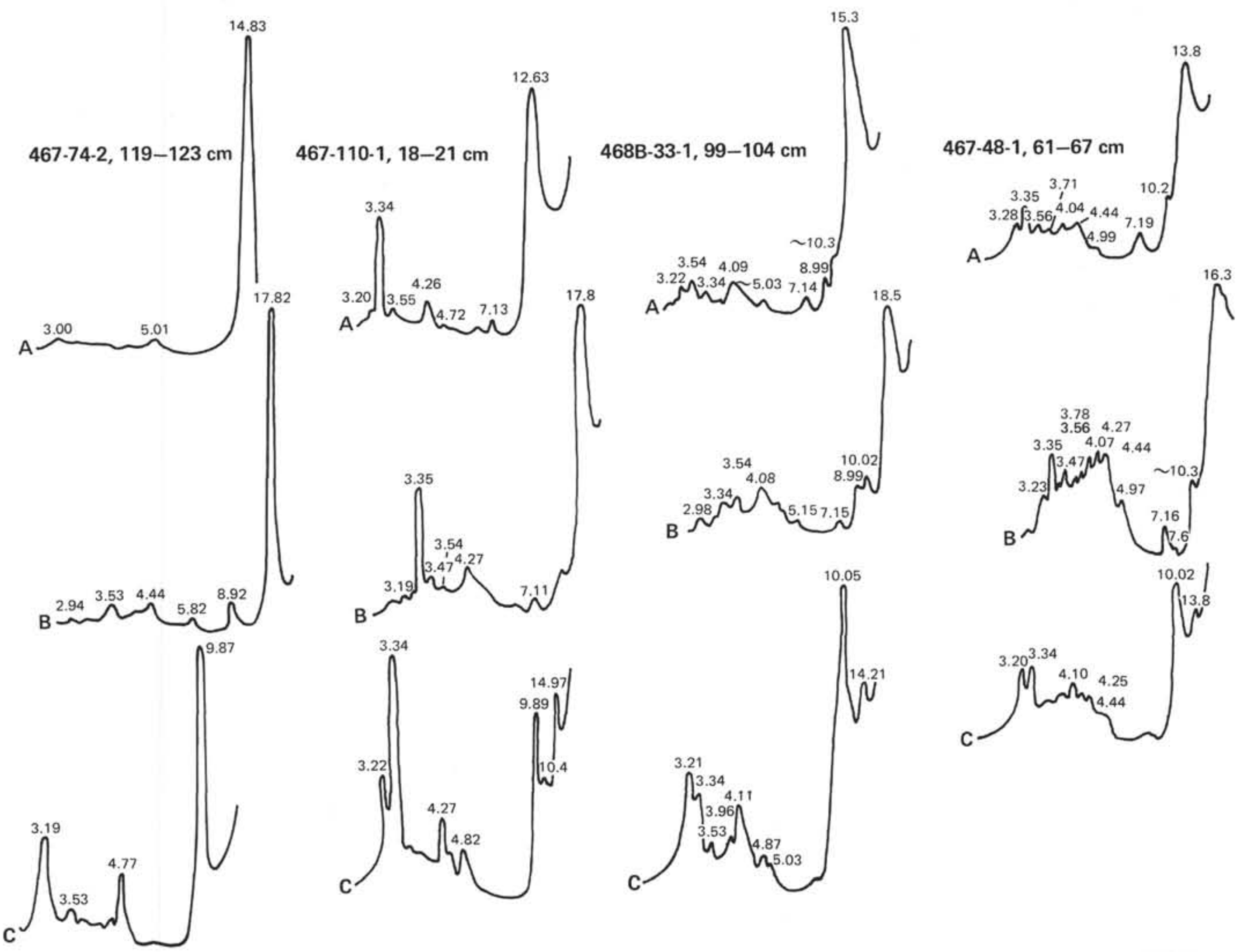

Figure 2. X-ray diffractograms of typical clay minerals—A. air dry; B. saturated with glycerine; and C. after heating at 550°C. (Sample 467-74-2, 119–123 cm is a clay fraction composed of Al-montmorillonite, developed after tuffaceous material; Sample 467-110-1, 18–21 cm is composed of Al,Fe-montmorillonite with an admixture of illite and chlorite; Sample 467-48-1, 61–67 cm is K,Fe-montmorillonite with an admixture of illite and chlorite. Sample 468B-33-1, 99–104 cm is composed of montmorillonite, illite, and an admixture of chlorite and kaolinite.)

semblages of clay minerals are shown in Figure 3 by corresponding signs.

Southern-California Continental Borderland

Hole 467

The distribution of clay minerals in Hole 467 has the following features (Table 1).

Series 6 (Cores 86–110) is composed of middle to upper Miocene, poorly sorted sandy-silty-clay deposits frequently with carbonate cement (sometimes dolomitic) and minor authigenic barite and gypsum. The clay fraction in this series is represented by common montmorillonite and in single interlayers by unstable Fe-montmorillonite. These minerals are accompanied by a rather persistent admixture of chlorite and illite, more abundant in the lower part of the series.

Series 5 (Cores 74–84) comprises middle to upper Miocene, altered hyalotuffs with basaltic composition and nannofossil claystones. Assemblages of clay minerals from the tuffs are composed of an authigenic complex of minerals frequently without distinct admixture of detrital clay components. It shows a peculiar mixture of Al-octahedral smectites and Mg-trioctahedral smectites, partly chloritized. The authigenic smectites in tuff interlayers are often accompanied by mixed-layered minerals of chlorite-montmorillonite type (Ch-M).

Series 4 (Core 55–73) is made up of upper Miocene, calcareous claystones with single interlayers of silicate and nannofossil claystones. The clay fractions in this series contain montmorillonite, admixture of weakly swelling mixed-layered mineral of an illite-montmorillonite type (I-M), and traces of chlorite and opal C-T.

Series 3 (Cores 40–55) upper Miocene through lower Plicoene, poorly consolidated calcareous claystones, alternating with thinner interlayers of nannofossil and siliceous oozes. The series shows predominance of unstable montmorillonite with admixture of detrital minerals in the clay fraction: illite, chlorite, quartz, and feldspar.

Series 2 (Cores 10–40) is Pliocene nannofossil clay with interlayers of calcareous-clay and siliceous ooze.

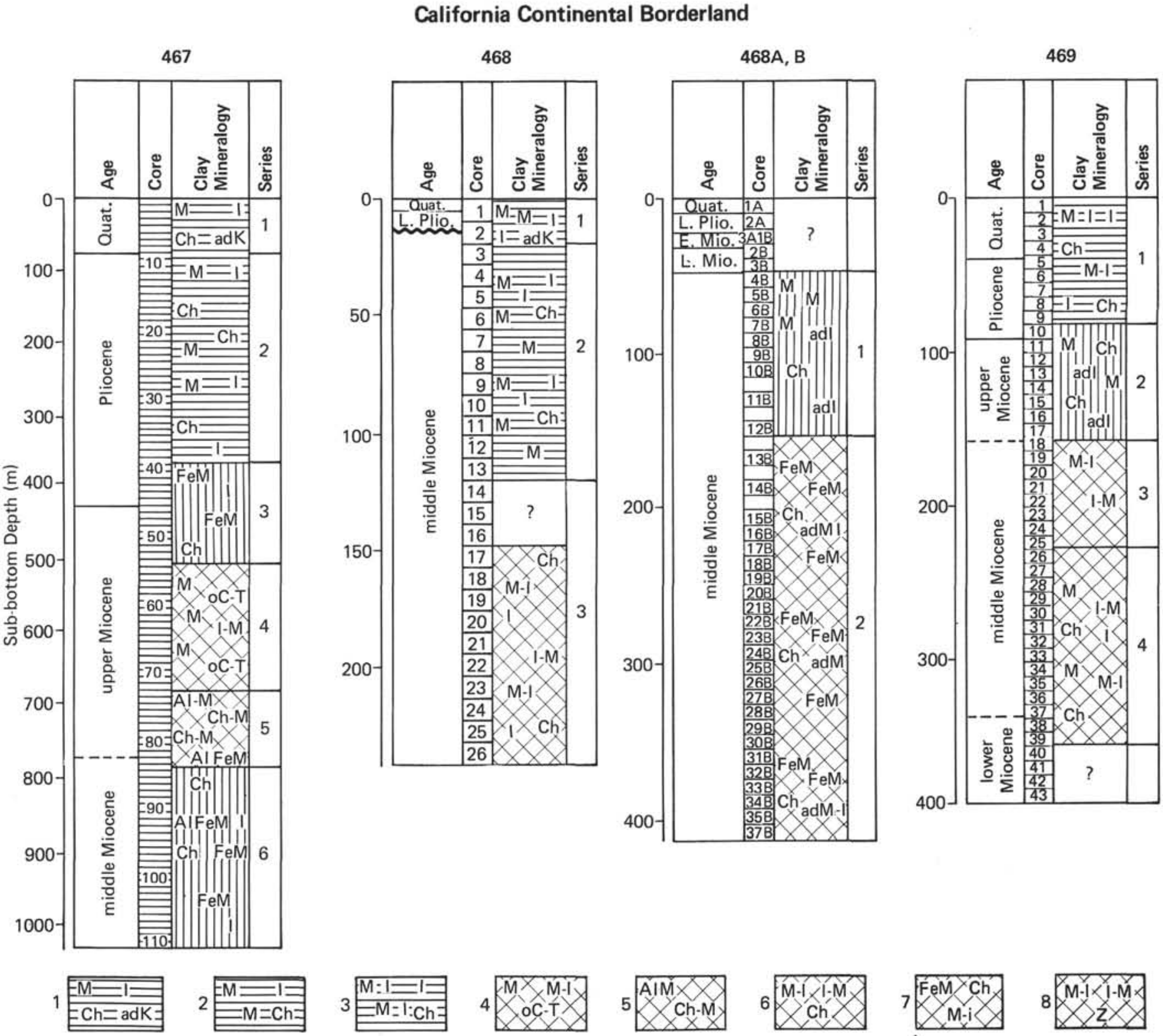

Figure 3. Scheme of distribution of clay mineral assemblages throughout the Leg 63 holes. (In the key to clay mineralogy, 1 = polymineral montmorillonite (M) with illite (I), chlorite (Ch), and a small admixture of kaolinite (ad K); 2 = polymineral montmorillonite with illite and chlorite; 3 = polymineral with mixed-layered mineral (M-I), illite, and chlorite; 4 = montmorillonite, mixed-layered (I-M), with opal C-T (o C-T); 5 = Al-montmorillonite (Al-M) with mixed-layered mineral of a chlorite-montmorillonitic type (Ch-M); 6 = mixed-layered with two types of minerals (M-I) and (I-M); 7 = Fe-montmorillonite (Fe-M) with chlorite and intensely swelling mixed-layered mineral (M-I) and opal C-T; 8 = mixed-layered with two types of minerals (M-I) and (I-M) and zeolite; 9 = montmorillonite with an admixture of chlorite, illite, and mixed-layered mineral (M-I); 10 = montmorillonite with an admixture of illite, chlorite, and mixed-layered weakly swelling mineral (I-M); 11 = montmorillonite with illite, chlorite, two types of mixed-layered minerals (M-I and I-M), and a small admixture of kaolinite; 12 = Fe-montmorillonite with an admixture of chlorite and illite; 13 = montmorillonite with chlorite and small admixture of illite and zeolite; and 14 = montmorillonite with chlorite and a small admixture of illite.)

The clay fraction of the series is predominantly composed of a polymineralic montmorillonitic assemblage with persistent admixture of detrital illites, chlorites, quartz, and feldspar.

Series 1 (Cores 1–11) is composed of Pleistocene greenish gray clay, and foraminifer-coccolith-spicular-diatomaceous oozes. The clay fraction of Series 1 is composed of montmorillonite with more considerable admixture of detrital illites, chlorite, kaolinite, and quartz than in underlying Series 2.

Hole 468

Clay minerals encountered at Hole 468 were divided into three series (Table 2).

Series 3 (Cores 17–26) is lower or middle Miocene diatom-nannofossil claystones, aleuritic or sandy claystones, and tuffs. The clay fraction of Series 3 is represented by montmorillonite (with potassium in interlayers), weakly swelling mixed-layered illite-montmorillonite (I-M), and admixture of chlorite.

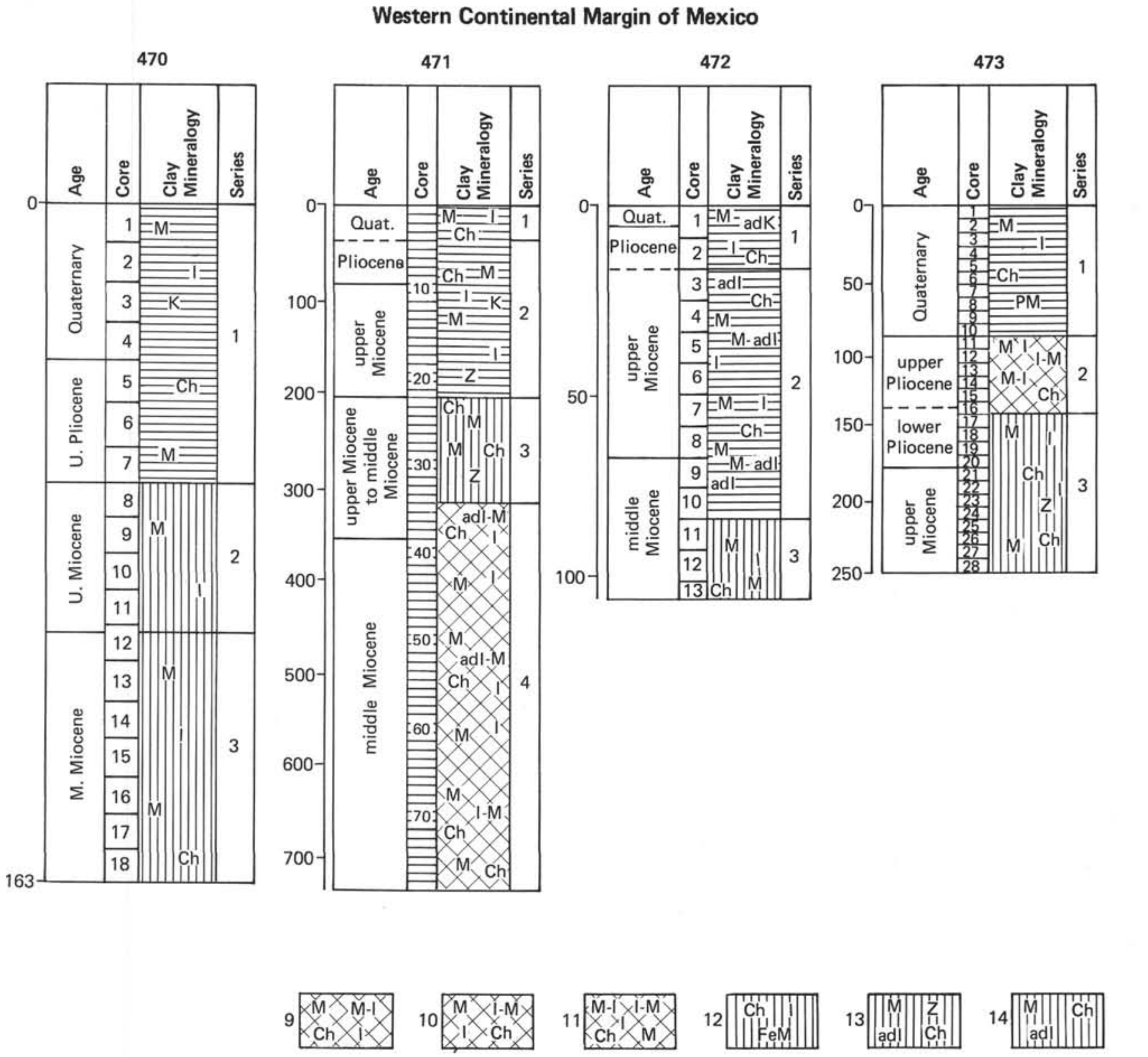

Figure 3. (Continued).

Series 2 (Cores 3–13) comprises middle Miocene nannofossil–diatom oozes with interlayers of sand, siltstone, and clay. The clay fraction (< 1 μm) has a polymineral composition with a predominance of montmorillonite and small admixtures of detrital minerals: illites, chlorite, quartz, and feldspar. More sandy interlayers contain K, Fe-montmorillonite in places.

Series 1 (Cores 1–2) is composed of Pliocene through Pleistocene foraminiferal and nannofossil oozes. The clay fraction is also predominantly composed of montmorillonite, however, the detrital admixture contains illite and chlorite and small amounts of kaolinite, quartz, and feldspar. Some interlayers have traces of K,Fe-montmorillonite.

Hole 468B

Clay minerals of Hole 468B were divided into two series (Table 2).

Series 2 (Cores 13–37) comprises middle Miocene, calcareous siltstones, claystones with interlayers of andesite-dacitic breccia, pumiceous lithoclastic tuffs, and volcaniclastic sandstones. The clay fraction has a predominance of Fe-montmorillonite with admixture of chlorite and intensely swelling, mixed-layered mineral (M-I).

Series 1 (Cores 4–12) is middle Miocene, alternating nannofossil oozes and diatom–nannofossil oozes with interlayers of detrital sands and aleuritic clayey sedi-

Table 1. Clay minerals and their assemblages in Miocene through Quaternary sediments from Hole 467.

Age	Sample (interval in cm)	Lithologic Type of Sediments	Mineralogical Composition of Clay Fraction (< 1 μm)	Assemblages of Clay and Accessory Minerals
Quaternary	2-3, 37–38	Aleuritic clay	Fe-montmorillonite, illite, admixture of chlorite, kaolinite, quartz, and feldspar	Polymineral with Fe-montmorillonite, illite, chlorite, and small admixture of kaolinite
	8-5, 45–50	Nannofossil diatomic clays	Fe-montmorillonite, illite, admixture of chlorite, kaolinite, quartz, and feldspar	
Pliocene	19-5, 110–115	Diatom clays	Montmorillonite, illite, small admixture of kaolinite, quartz, and feldspar	Polymineral montmorillonite with admixture of illite, chlorite, traces of kaolinite (with Fe-montmorillonite in some interlayers)
	30-2, 110–114	Clays	Fe-montmorillonite, illite, chlorite, admixture of quartz and feldspar	
	40-1, 16–20	Nannofossil, aleuritic clays	Montmorillonite, illite, small admixture of kaolinite, quartz, and feldspar	
	40-3, 16–20	Nannofossil, aleuritic clays	Montmorillonite, illite, small admixture of kaolinite, quartz, and feldspar	
	48-1, 61–67	Clays	Fe-montmorillonite, illite, chlorite, admixture of quartz and feldspar	Fe-montmorillonite with small admixture of illite and chlorite
late Miocene	52-1, 32–34	Clays	Fe-montmorillonite, illite, chlorite, admixture of quartz and feldspar	
	57-1, 104–108	Calcareous aleuritic claystones	Al, Fe-montmorillonite, small admixture of illite and opal C-T	Minerals of silica with montmorillonite and admixture of mixed-layered minerals (M-I)
	71-1, 35–38	Calcareous claystones	Opal C-T, small admixture of montmorillonite and mixed-layered mineral (M-I), traces of chlorite	
	74-2, 98–100	Intensively altered hyalotuff	Al-montmorillonite (beidellite-montmorillonite)	Authigenic Mg, Fe-montmorillonite at the initial stage of chloritization, Al-montmorillonite
	74-2, 119–123	Intensively altered hyalotuff	Al-montmorillonite (beidellite-montmorillonite)	
	80-2, 16–20	Altered hyalotuff	Mg, Fe-montmorillonite, Al-montmorillonite, small admixture of chlorite-montmorillonite	
	82-1, 114–118	Altered hyalotuff	Mg, Fe-montmorillonite, Al-montmorillonite, small admixture of chlorite-montmorillonite	
	82-1, 118–120	Altered hyalotuff	Mg, Fe-montmorillonite, Al-montmorillonite, small admixture of chlorite-montmorillonite	
	83-3, 83–85	Tuff	Mg, Fe-mixed-layered mineral (M-I), Al-montmorillonite, chlorite-montmorillonite	
	84-1, 31–35	Tuff	Mg, Fe-mixed-layered mineral (M-I), Al-montmorillonite, chlorite-montmorillonite	
middle Miocene	86-3, 146–150	Calcareous nannofossil claystones	Montmorillonitic, mixed-layered mineral (M-I), small admixture of chlorite	Al and Al, Fe-montmorillonite with Fe-montmorillonite in some interlayers (the lower part has a more distinct admixture of detrital minerals: illite, chlorite, and quartz)
	90-1, 32–37	Nannofossil claystones	Montmorillonitic, mixed-layered mineral (M-I), small admixture of chlorite	
	92-1, 67–71	Clay chalk	Quartz, small admixture of montmorillonite and illite	
	96-1, 95–98	Clay, nannofossil claystone	Al, Fe-montmorillonite, admixture of quartz	
	101-1, 123–127	Calcareous, nannofossil claystone	Al, Fe-montmorillonite, admixture of quartz	
	104-2, 25–28	Calcareous, aleuritic claystone	Fe-montmorillonite, illite, chlorite, and quartz	
	107-1, 1–4	Aleuritic claystone	Montmorillonite, illite, chlorite, and quartz	
	110-1, 18–21	Calcareous, aleuritic claystone	Al, Fe-montmorillonite, small admixture of illite, chlorite, and quartz	

ments in the lower part of the sequence. Its clay fraction is predominantly represented by montmorillonite (sometimes including K,Fe-montmorillonite) with admixture of chlorite and illite.

Off the Continental Slope (between 32° and 23°N)

The sediments of this region have interlayers of vitric ashes and scattered volcaniclastics with andesitic and andesitic-dacitic compositions. Postdepositional alteration of this volcaniclastic material leads to formation of dioctahedral, stable, common Al-montmorillonites (with admixture of Mg^{2+} in octahedral positions).

Hole 469

Clay minerals in Hole 469 were divided into four series (Table 2).

Series 4 (Cores 26–38) is lower middle Miocene aleuritic claystones with subordinate interlayers of pumiceous lithoclastic tuffs, volcanic sandstones, porcellanites, nannofossil claystones, chalk, and siliceous limestones. The clay fraction is mainly composed of montmorillonite with admixture of illite, chlorite, and mixed-layered intensely swelling mineral (M-I) in some interlayers.

Series 3 (Cores 18–25) is middle Miocene nannofossil oozes and diatom–nannofossil oozes. The clay fraction is represented by two types of mixed-layered minerals (M-I and I-M) with admixture of zeolite.

Series 2 (Cores 10–17) is upper Miocene clayey nannofossil oozes with interlayers of diatom–nannofossil oozes. The clay fraction is predominantly composed of montmorillonite (partially with potassium in interlayers) with chlorite and small admixture of illite.

Series 1 (Cores 1–9) is composed of Pliocene through Pleistocene foraminifer–nannofossil clays (Cores 5–9) enriched by ash material upsection (Cores 1–4). The clay fraction is composed of a polymineral assemblage with predominance of intensely swelling mixed-layered mineral (M-I) close to smectite with admixture of illite and chlorite.

Table 2. Clay minerals and their assemblages in Miocene through Pliocene sediments, DSDP Leg 63.

Age	Sample (interval in cm)	Lithologic Type of Sediments	Mineralogal Composition of Clay Fraction (<1 μm)	Assemblages of Clay Minerals
			Hole 468	
Pliocene	101, 110–112	Foraminifer–nannofossil oozes	Montmorillonite (with potassium in interlayers) illite, chlorite, admixture of feldspars and quartz	Polymineral montmorillonite with illite and small admixture of kaolinite
	2-1, 25–27	Diatom-nannofossil oozes	Montmorillonite (with potassium in interlayers) illite, chlorite, admixture of feldspars and quartz	
middle Miocene	6-6, 29–34	Nannofossil–diatom oozes	Montmorillonite, admixture of illite and chlorite	Polymineralic morillonite with admixture of illite and chlorite
	9-5, 70–74	Diatom aleuritic clays	Montmorillonite, admixture of illite and chlorite	
	10-1, 55–59	Nannofossil–diatom aleuritic clays	Montmorillonite (with potassium in interlayers), traces of chlorite	
	11-1, 30–35	Zeolitic aleuritic sand	Montmorillonite, traces of illite and admixture of zeolite	
	17-1, 70–75	Aleuritic claystone	Montmorillonite (with potassium in interlayers), admixture of weakly swelling mixed-layered mineral (I-M) and chlorite	Montmorillite with admixture of mixed-layered weakly swelling mineral (I-M) and chlorite
	18-1, 72–78	Diatom–nannofossil aleuritic claystone	Montmorillonite (with potassium in interlayers) (I-M) and chlorite	
			Hole 468B	
middle Miocene	6-1, 70–72	Nannofossil oozes	Montmorillonite, montmorillonite (with potassium in interlayers), small admixture of illite and chlorite	Montmorillonite with chlorite, small admixture of illite and zeolite
	6-6, 29–34	Nannofossil oozes		
	8-4, 35–37	Diatom–nannofossil oozes	Abundant amorphous silica with admixture of weakly swelling (defective) chlorite	
	11-1, 30–35	Diatom–nannofossil oozes	Montmorillonite, traces of illite, zeolite (clinoptilolite)	
	13-2, 62–66	Calcareous, aleuritic claystone	Amorphous silica, small admixture of montmorillonite	Montmorillonite with chlorite mixed-layered minerai (M-I) and opal C-T (in the lower part of the sequence)
	15-1, 30–36	Calcareous, aleuritic claystone	Abundant amorphous silica, intensely swelling mixed-layered mineral (M-I), traces of illite and chlorite	
	17-1, 70–75	Aleuritic claystone	Mixed-layered minerals with variable relation of layers (M-I and I-M), admixture of chlorite and illite	
	25-2, 29–33	Calcareous, aleuritic claystone	Montmorillonite, admixture of chlorite, illite and zeolite	
	26-1, 42–46	Zeolite, volcanic sandstone	Intensely swelling mixed-layered mineral (M-I), admixture of chlorite and zeolite (from the group of heulandite)	
	26-1, 72–76	Zeolitic, lapilli tuff	Intensely swelling mixed-layered mineral (M-I), admixture of chlorite and zeolite (from the group of heulandite)	
	33-1, 99–104	Calcareous, aleuritic claystone	Montmorillonite, illite, chlorite, admixture of zeolite and opal C-T	
	34-1, 60–63	Redeposited pumice, lithic lapilli tuff	Intensely swelling, mixed-layered mineral (M-I), gypsum, calcite	
	35-1, 107–110	Calcareous aleuritic claystone	Intensively swelling mixed-layered mineral (M-I), illite, chlorite, opal C-T	
	37-2, 19–26	Redeposited pumice, lithic lapilli tuff	Intensively swelling mixed-layered mineral (M-I), traces of weakly swelling (defective) chlorite, admixture of zeolite (from the heulandite group)	
			Hole 469	
Quaternary	1-1, 110–114	Clays and nannofossil foraminiferal oozes	Intensely swelling mixed-layered mineral (M-I), close to smectite, admixture of illite, chlorite, quartz, and feldspar	Polymineral with montmorillonite, illite, chlorite, and intensely swelling mixed-layered mineral (M-I) (in some interlayers)
	2-1, 70–74	Clays	Intensely swelling mixed-layered mineral (M-I), close to smectite, admixture of illite, chlorite, quartz, and feldspar	
Pliocene	6-3, 102–106	Foraminifer–nannofossil clays	Montmorillonite (with potassium in interlayers), illite, chlorite, admixture of quartz and feldspar	
	10-1, 42–48	Nannofossil, aleuritic clays	Montmorillonite (with potassium in interlayers), illite, chlorite, admixture of quartz and feldspar	
middle Miocene	20-1, 128–130	Nannofossil oozes	Two types of mixed-layered minerals (M-I and I-M) with zeolite	Mixed-layered with two types of minerals (M-I) and (I-M) and zeolite
	25,CC	Calcareous porcellanites	Montmorillonite, illite, chlorite	Montmorillonite with admixture of mixed-layered mineral (M-I), illite, and chlorite
	29,CC	Volcaniclastic sandstones	Montmorillonite, illite, chlorite admixture of mixed-layered mineral (M-I)	
	31,CC	Calcareous claystones	Montmorillonite, illite, chlorite, small admixture of opal C-T	
	34-1, 6–9	Aleuritic claystones	Fe-montmorillonite, admixture of ferrum illite, chlorite, and opal C-T	
	35-1, 49–52	Redeposited pumice tuff	Montmorillonite, admixture of mixed-layered mineral (M-I), chlorite and hydromica, traces of zeolite	
	36-1, 77–78	Pumice tuff	Montmorillonite, traces of zeolite	

Hole 470

Clay minerals in Hole 470 were divided into three series (Table 3).

Series 3 (Cores 12-15) is middle Miocene diatomaceous, aleuritic clays and nannofossil oozes. The clay fraction is predominantly composed of montmorillonite (with K and Na in interlayers), with admixture of illite, chlorite, feldspar, and quartz.

Series 2 (Cores 8-11) consists of upper Miocene diatomaceous, aleuritic clays. The clay fraction is predominantly composed of montmorillonite with admixture of illite, chlorite, quartz, and feldspar in some interlayers.

Series 1 (Cores 1-7) comprises upper Pliocene through Pleistocene aleuritic and nannofossil clays. The clay fraction is predominantly composed of montmorillonite (with K and Na in interlayers) with small admixture of illite and chlorite and rarely kaolinite, quartz, and feldspar.

Hole 471

Clay minerals in Hole 471 were divided into four series (Table 4).

Series 4 (Cores 35-78) consists of middle Miocene bioturbated claystones with thin interlayers of calcareous sandstones (less abundant in the base) and several interlayers of clayey limestones and altered vitritic tuffs. The clay fraction is composed of montmorillonite (frequently with K in interlayers) with admixture of illite, chlorite, and mixed-layered weakly swelling mineral (I-M), quartz, and feldspar.

Series 3 (Cores 22-34) is upper Miocene porcellanites and porcelaneous, aleuritic claystones with cherts and several interlayers of clayey limestones. The clay fraction is predominantly composed of montmorillonite (partially with K in interlayers) with admixture of illite, chlorite, zeolite, and opal C-T.

Series 2 (Cores 4-22) is composed of upper Miocene through Pliocene diatomaceous aleuritic clays and clayey-diatomaceous oozes. The clay fraction is composed of a polymineral assemblage with montmorillonite, illite, and chlorite, with some admixture of kaolinite, quartz, and feldspar.

Series 1 (Cores 1-3) is Pleistocene nannofossil clays. The clay fraction has polymineral composition with montmorillonite, illite, and chlorite.

Hole 472

Clay minerals in Hole 472 were divided into three series (Table 5).

Series 3 (Cores 11-13) is middle Miocene diatomaceous oozes and nannofossil clays. The clay fraction is composed of montmorillonite with small admixture of illite and chlorite.

Series 2 (Cores 3-10) is middle upper Miocene, clayey-diatomaceous oozes and siliceous pelagic clays. The clay fraction has a polymineral composition with montmorillonite, admixture of illite, chlorite, quartz, and feldspar.

Series 1 (Cores 1-2) is Pliocene through Pleistocene, brown pelagic clays with subordinate amount of greenish gray pelagic clays. The clay fraction has a polymineral composition with montmorillonite, illite, admixture of kaolinite, small admixture of chlorite, quartz, and feldspar. Montmorillonite in all series frequently contains K in interlayers.

The Mouth of the Gulf of California

Hole 473

Distribution of Hole 473 clay minerals has the following succession (Table 5).

Series 3 (Cores 17-28) is upper Miocene through lower Pliocene claystones and interbedded aleuritic quartz sandstones. The clay fraction is composed of montmorillonite with small admixture of chlorite, illite, and opal C-T. The montmorillonite frequently contains K in interlayers.

Series 2 (Cores 11-16) contains upper Pliocene, terrigenous clays with a subordinate amount of aleuritic and nannofossil clays. The clay fraction is composed of montmorillonite, illite, and chlorite in places with small admixture of mixed-layered (M-I) and (I-M) minerals or kaolinite.

Series 1 (Cores 1-10) is Pleistocene clays with small admixture of ash material. The clay fraction has a polymineral composition. It is composed of montmoril-

Table 3. Clay minerals and their assemblages in Miocene through Quaternary sediments, Hole 470.

Age	Sample (interval in cm)	Lithological Type of Sediments	Mineralogical Composition of Clay Fractions (< 1 μm)	Assemblages of Clay and Accessory Minerals
Quaternary	1-3, 92-96	Aleuritic clay	Montmorillonite (with K and Na in interlayers), considerable admixture of illite and chlorite	Polymineral montmorillonite with admixture of illite, chlorite, traces of kaolinite, quartz, and feldspar
	2-3, 77-82	Aleuritic clay	Montmorillonite (with K and Na in interlayers), small admixture of illite and chlorite	
Pliocene	5-1, 108-113	Nannofossil clays	Montmorillonite (with K and Na in interlayers), considerable admixture of illite, chlorite, quartz, and feldspars	
late Miocene	8-2, 90-91	Diatom aleuritic clays	Montmorillonite (with considerable amount of K in interlayers)	Montmorillonite with small admixture of illite, quartz, and feldspar in some interlayers
	10-2, 21-25	Diatom aleuritic clays	Montmorillonite finely dispersed, with small admixture of illite, quartz, and feldspars	
middle Miocene	12-3, 120-125	Diatom aleuritic clays	Montmorillonite (with K and Na in interlayers), admixture of hydromica, chlorite, quartz, and feldspars	Montmorillonite with admixture of illite, chlorite, feldspar, and quartz
	15-1, 80-85	Diatom nannofossil oozes	Montmorillonite (with K and Na in interlayers), small admixture of chlorite, illite, and feldspars	

Table 4. Clay minerals and their assemblages in Miocene through Pliocene sediments, Hole 471.

Age	Sample (interval in cm)	Lithologic Type of Sediments	Mineralogical Composition of Clay Fraction (< 1 μm)	Assemblages of Clay and Accessory Minerals
Quaternary	1-3, 90–95	Nannofossil, aleuritic clay	Montmorillonite (partially with exchange potassium in interlayers), illite, chlorite (defective) and admixture of feldspar	Polymineral montmorillonite with illite and chlorite
	3-2, 20–24	Aleuritic clay	Montmorillonite (with potassium in interlayers), illite, chlorite (defective), small admixture of zeolite	
Pliocene	7-4, 135–140	Diatom clay	Fe-montmorillonite, illite, chlorite, admixture of kaolinite, quartz, and feldspar	Polymineral montmorillonite with illite, chlorite, and small admixture of kaolinite in some interlayers
late Miocene	13-3, 120–125	Clay, diatom ooze	Illite, montmorillonite, small admixture of chlorite	
	16-3, 60–65	Diatom clay	Montmorillonite (with potassium in interlayers), traces of illite	
	21-1, 16–20	Clayey limestone	Montmorillonite, admixture of illite, chlorite, quartz, and feldspar	
From middle to late Miocene	23-1, 33–36	Clay porcellanite	Montmorillonite, admixture of iron illite, small admixture of chlorite, opal C-T and feldspar	Montmorillonite with chlorite, small admixture of illite, zeolite, and opal C-T; Fe-illite in interlayers
	26-1, 1–4	Clay porcellanite	Montmorillonite (with potassium in interlayers) illite, chlorite, zeolite, and opal C-T	
	32-1, 77–81	Porcellanite claystone	Montmorillonite with admixture of illite, chlorite, and opal C-T	
	35-3, 9–12	Aleuritic claystone	Montmorillonite, admixture of illite, chlorite, small admixture of kaolinite, essential amount of quartz	Montmorillonite with admixture of illite, chlorite and quartz
	36-1, 91–93	Altered vitric tuff	Montmorillonite finely dispersed, traces of chlorite and zeolite	
middle Miocene	39-1, 41–45	Aleuritic claystone	Montmorillonite, admixture of chlorite, illite, quartz, and feldspar	
	41-4, 50–52	Aleuritic claystone	Montmorillonite (with potassium in interlayers), admixture of illite, chlorite, and quartz	
	42-1, 12–15	Altered claystone	Montmorillonite (with potassium in interlayers), admixture of illite, chlorite, and quartz	
	44-3, 40–42	Altered vitric tuff	Al-montmorillonite, finely dispersed	
	47-2, 54–57	Aleuritic claystone	Montmorillonite, admixture of illite, chlorite, and quartz	
	52-1, 24–28	Aleuritic claystone	Montmorillonite, admixture of illite and quartz	
	65-1, 6–9	Aleuritic claystone	Montmorillonite, illite, chlorite, admixture of quartz and feldspar	
	71-1, 136–140	Aleuritic sandstone	Montmorillonite, admixture of illite, chlorite, feldspars, and quartz	
	75-3, 112–114	Aleuritic claystone	Montmorillonite, admixture of illite, chlorite, feldspars, and quartz	
	78-2, 29–32	Aleuritic claystone	Montmorillonite, chlorite, small admixture of weakly swelling mixed-layered mineral (I-M), quartz, and feldspar	

lonite with admixture of illite, chlorite, quartz, and feldspar.

CONCLUSION

Middle Miocene through Quaternary sediments encountered in southern California Continental Borderland and the western continental margin of Mexico are principally composed of siliceous and calcareous biogenic material, clay, and admixtures of aleuritic and fine, sandy, terrigenous, or tuffaceous material. Thicknesses of sedimentary sequences vary in the studied region from 150 up to 1000 meters.

The upper parts of sedimentary sections, approximately to the depth of 200 meters (and in Hole 467, up to 500 m), are represented predominantly by unconsolidated or poorly consolidated oozes. The interlayers of volcanic ashes here do not show any features of secondary alteration such as the formation of authigenous clay minerals.

The clay fraction of these deposits is terrigenous and polymineralic. These minerals include a complex association of redeposited detrital minerals from the montmorillonite (smectite) group, and to a lesser extent, illite (with a different degree of degradation), chlorites (Fe-Mg trioctahedral type), and rarely kaolinite. All clay minerals may have been derived from land.

The predominance of the smectitic component is a mineralogical peculiarity of these deposits; illites and chlorites are found as an admixture. Smectites occur in practically all sequences penetrated by Leg 63 holes, as in Pliocene sediments of the Panama basin (Rateev et al., in press), and can be considered as a background terrigenous component against which the Leg 63 deposits were formed. The presence of such smectitic background may indicate persistent subaerial and submarine volcanic sources.

In lower parts of the sedimentary sequences, below 200 meters on the average (in Hole 467, below 500 m), the tuffaceous material (including both separate tuff interlayers and scattered volcaniclastics) is partially or completely transformed into clay or zeolitic mineral. Smectite here is the main authigenic mineral. However, its structural features vary depending on petrographic composition of the source rocks. For example, the basaltic hyalotuffs are altered to smectites with high Fe and Mg content in association with a small amount of chlorite in the form of a mixed-layered chlorite-montmorillonitic (Ch-M) mineral. Only in one case (Sample 467-74-2, 96–100 cm) was almost monominerallic smectite of the beidellitic type formed (with replacement of Si atoms in tetrahedral layers), possibly after the basaltic tuff.

Pumiceous and vitroclastic tuffs of more acid andesitic and dacitic composition also have altered to montmorillonites or intensely swelling, mixed-layered montmorillonite-illite (M-I) minerals of the type with a small

Table 5. Clay minerals and their assemblages in Miocene through Pliocene sediments, DSDP Leg 63.

Age	Sample (interval in cm)	Lithologic Type of Sediments	Mineralogical Composition of Clay Fraction (< 1 μm)	Assemblages of Clay and Accessory Minerals
			Hole 472	
Quaternary	1-2, 120–125	Clay	Montmorillonite, illite, admixture of kaolinite chlorite, quartz, and feldspar	Polymineralic montmorillonite with illite, chlorite, and small admixture of kaolinite
late Miocene	3-1, 35–39	Clay	Montmorillonite admixture of illite and chlorite	Polymineralic montmorillonite with illite and chlorite
	5-2, 90–95	Clay diatom ooze	Montmorillonite admixture of illite, chlorite, quartz, and feldspar	
	8-2, 40–45	Clay diatom ooze	Montmorillonite (with potassium in interlayers), small admixture of illite, chlorite, quartz, and feldspar	
middle Miocene	11-3, 136–140	Diatom, nannofossil ooze	Montmorillonite (with potassium in interlayers), traces of illite and chlorite	Montmorillonite with small admixture of illite and chlorite
			Hole 473	
Quaternary	2-2, 10–15	Clay	Montmorillonite (with exchange potassium in interlayers), traces of illite and chlorite, cristobalite, quartz, and feldspar	Polymineralic montmorillonite with illite, chlorite, quartz, and feldspar
	7-1, 30–34	Clay	Montmorillonite (with potassium in interlayers), admixture of illite, chlorite, and quartz; traces of feldspar	
	10-2, 60–64	Clay	Montmorillonite (with potassium in interlayers), admixture of illite, chlorite, feldspar, and quartz	
late Pliocene	13-3, 90–95	Clay	Montmorillonite (with potassium in interlayers), admixture of intensely swelling mixed-layered mineral (M-I), illite, chlorite, kaolinite, and zeolite (from heulandite group)	Montmorillonite with illite, chlorite, and two types of mixed-layered minerals (M-I and I-M) and small admixture of kaolinite
	14-2, 70–75	Clay	Montmorillonite (with potassium in interlayers), admixture of illite, chlorite, and zeolite	
	16-3, 40–42	Vitric tuff	Montmorillonite, finely dispersed, small admixture of weakly swelling mineral (I-M) with 15%–20% of swelling layers, zeolite, and feldspar	
early Pliocene	19-2, 40–44	Clay	Montmorillonite, illite, chlorite, zeolite (from heulandite group)	Montmorillonite with chlorite, illite, zeolite, and opal C-T
late Miocene	21-1, 70–74	Aleuritic claystone	Montmorillonite, illite, chlorite, traces of quartz and feldspar	
	23-3, 20–24	Clay	Montmorillonite (with potassium in interlayers), illite, chlorite, admixture of opal C-T and feldspar	
	25-1, 11–115	Aleuritic claystone	Montmorillonite, illite, chlorite, admixture of zeolite	
	26-2, 32–36	Vitric tuff	Montmorillonite finely dispersed, small admixture of illite, chlorite, traces of zeolite	
	27-1, 120–124	Aleurolite claystone	Montmorillonite, illite, chlorite, small admixture of kaolinite, quartz, and feldspar	

proportion of mica layers. We relate the small admixture of illite and chlorite in the clay fraction of these rocks with some portion of terrigenous material.

Besides clay material formed at the expense of subaerial pyroclastics, a considerable proportion of alteration products might be derived from submarine volcanic rocks. The clay products resulting from secondary alteration of igneous rocks in the Leg 63 area are described by Grechin et al. (this volume). They show that secondary alterations of abyssal tholeiitic hyalobasalts and dolerites predominantly led to formation of smectites (Fe and Mg-Fe types) and intensely swelling mixed-layered minerals of montmorillonite-illite type (M-I), frequently with a ratio of about 85:15. Sometimes they are mixed with so-called "defective" chlorites and mixed-layered chlorite-montmorillonitic type minerals (Ch-M). All these minerals could enter the clay constituent of the Miocene through Pliocene sedimentary deposits. The absence of illite in the secondary minerals of basalts confirmed our conclusion that this clay mineral is probably land-derived and not authigenic.

In the lower part of the middle to upper Miocene sequences, clays derived from the land or from subaerial and underwater volcanism also occur with a constituent of authigenic smectites, formed *in situ* by diagenetic transformations of ash-tuffaceous material. However, the similarity between a number of clay mineral assemblages, abundant both in the lower and upper parts of the sequences, shows that the proportion of authigenic smectites in the terrigenous deposits as a whole is not considerable.

The minor alteration of the studied terrigenous rocks and small volume of authigenic smectite formation after tuffaceous material here result from relatively shallow burial (maximum up to 1000 m) of sedimentary matter. Burial diagenesis may also account for all variations in diagenetic clay mineral assemblages in a variety of lithofacies encountered during Leg 63 drilling.

These conclusions are in good agreement with the results of Hein et al. (1979) on distribution of clay minerals throughout the sequence of Test Well-OCS CAL 78164, No. 1 in the external part of the continental shelf off Southern California (19 km to the west of Point Conception). In this test well, the authors revealed considerable alterations of clay minerals at a depth of about 8600 feet (2866 m). These alterations affected mixed-layered smectite-illite mineral, which showed a decrease in swelling smectitic layers and corresponding increase in illitic structural packets, below this depth. The K required for illite formation may have been derived from K-feldspars. Perry and Hower (1970; 1972) show that the decrease of swelling layers down to 30% to 40% takes place under a temperature range of 95°C to 100°C and is accompanied by an increase of order in the mixed-layered phase.

We think that alteration in the zone of relatively deeper burial (Müller, 1967) occurs in already partially consolidated ("ready") rock under the effect of gravitation (i.e., consolidation, partial increase of temperature, recrystallization, solid-state reactions [Kossovskaya, and Shutov, 1963]). In contrast to this, diagenetic alteration in the zone of "shallow burial" takes place in poorly consolidated oozes in concert with abundant interstitial waters (Strachov, 1960).

Above the depth of 2866 meters, Hein et al. (1979) identified a number of intervals by a change in percentage of separate clay minerals, relating them to a change of source areas. Small changes include some increase of kaolinite within the interval of 6100 to 8800 feet (1859–2682 m) together with an increase of quartz and feldspar, as well as pronounced increase of illite (within the interval of 6700–7400 feet—2042–2255 m). Hein et al. think that the intervals of greater quantitative variations of clay minerals, which have stratigraphic significance, can also reflect the change in physical-geographical environments of source areas. Thus, in their opinion, considerable decrease or increase in the depth of sedimentation can determine the scale of mineralogical alterations.

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