PRELIMINARY REPORT ON THE MINERALOGY AND PETROLOGY OF SOME MARINE BOTTOM SAMPLES OFF THE COAST OF PERU AND CHILE[1]

E-AN ZEN, *Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.*

ABSTRACT

Marine bottom core samples from the coast of Peru and Chile were studied by x-ray and optical methods. For the fourteen cores included in this report, the following minerals are definitely identified: quartz, plagioclase, illite, chlorite, kaolinite, montmorillonite, calcite, aragonite, pyroxene, amphibole (both exclusively detrital), and an oxide of iron. The distribution of the minerals in a given core, as well as their textural relations, tends to remain constant, although considerable differences exist among the cores.

Volcanic glass is a common phase in many samples. Much of the glass is partially or completely devitrified; the products of devitrification include the clay minerals and calcite and demonstrate the exchange of material between the glass and the surroundings. Detailed study of such mineral assemblages should shed light on the equilibrium relations among these minerals in sediments.

INTRODUCTION

During the last months of 1955, the research vessel *Atlantis* of the Woods Hole Oceanographic Institution, under the leadership of B. Kummel and the late H. C. Stetson, undertook a cruise (no. 221) off the Pacific coast of Peru and northern Chile, to collect hydrographic data and bottom sediment samples from this part of the continental margin of South America. A free-running, Stetson-type coring tube was used, and eighty-four cores were recovered. The mineralogy and petrology of these cores have been studied since the autumn of 1956; this paper is a preliminary report of the investigations to date.

The west central coast of South America had been chosen for the investigation for various reasons. Study of the modern sediments from this area have been confined to reconnaissances (Revelle, 1944). The area, however, possesses a combination of both shallow and deep bottoms close to land, strong subaerial relief, and extensive Tertiary and modern volcanism. Sedimentological studies here thus might yield information useful in the interpretation of ancient sediments. Bottom profiles along the coring traverses are being prepared by J. M. Zeigler of the Woods Hole Oceanographic Institution. In addition, broad surveys of the coastal geology may be found in the works of Jenks (1946; 1956), Cristi (*in* Jenks, 1956), and Rüegg (1957); of the bottom topography by Schweigger (1947); and of the surface hydrography by Gunther (1936).

---

[1] Contribution No. 384 from the Department of Mineralogy and Petrography, Harvard University; No. 913 from the Woods Hole Oceanographic Institution.

LABORATORY PROCEDURE

Identification of the minerals in the core samples was principally by means of the Norelco recording Geiger-counter diffractometer, aided by the petrographic microscope with oil-immersion lens. As results using the diffractometer are highly sensitive to experimental methods, a description of the procedure follows.

Samples were taken from a given core at intervals of about 10 centimeters, or wherever visible variations of lithology occur such as color, grain size, and reactivity with HCl. The sample was dried, ground fine, and divided into several portions. One part was saved for heat-treatment and another part used directly for x-ray study. Copper radiation with nickel filter was used at 45 KV and 20 ma. A typical instrumental setting was as follows: goniometer speed, $1°$ 2θ per minute; chart speed, $\frac{1}{2}''$ per minute; scale factor, 4; multiplier, 1; time constant, 4 or 8 seconds; and divergent, scatter, and receiving slits, $1°$, $1°$, and $0.003''$, respectively.

The diffraction patterns were compared with standards for identification. For samples suspected of kaolinite and/or chlorite, a second portion was heated in a muffle furnace to between 550 and 600° C. for $\frac{1}{2}$ hour and x-rayed under identical conditions (Brindley and Robinson, *in* Brindley, 1951, p. 188); for samples suspected of montmorillonite, an additional portion was saturated with glycerin and x-rayed (MacEwan, *in* Brindley, 1951, p. 115).

Samples were mounted for x-ray work using a small hand press. Although this method of sample preparation is liable to uncontrolled orientation effects for some minerals, for routine identification work this effect is an advantage, since commonly the platy minerals occur only in small amounts and without preferred orientation their presence in a crude sample might be undetected.

IDENTIFICATION OF MINERALS

To avoid any possible confusion, the nomenclature used for the various platy minerals is set out below. It should be emphasized that the names do not necessarily correspond to distinct mineral phases, many of which cannot be differentiated by the adopted techniques.

Illite

This name is used in the sense of Grim (1953, p. 35), and applies to all platy minerals in the samples with a strong reflection at about 10 Å. Although much of this is probably related to muscovite, phases such as glauconite and biotite, with 10 Å basal spacings, are possibly present and not distinguished. Nagelschmidt (1937, p. 519) suggests the use of the

(060) line to distinguish the dioctahedral from the trioctahedral micas, a criterion which Grim, Bradley, and Brown (*in* Brindley, 1951, p. 159) point out does not apply to glauconite. Moreover, the criterion is unsuitable for samples with minerals such as kaolinite and quartz with interfering diffraction lines (see, e.g., Brindley and MacEwan, *in* Brindley, 1951, Table XIV, 1, II). Nagelschmidt also suggests (1937, p. 519) that the relative weakness or absence of the 5 Å basal reflection is suggestive of trioctahedral micas. Most of the 10 Å micas from the cores show this relationship. However, this does not seem to be a reliable criterion, as prolonged grinding of natural, coarsely crystalline muscovite has resulted in the complete obliteration of the 5 Å line while the 10 Å line remains strong.

The possibility exists that the 10 Å "illite" in some samples represents intergrowth of muscovite and montmorillonite. Such interlayering may be detected by the angular displacement of the basal reflection spacings of the untreated samples (Brown and MacEwan, *in* Brindley, 1951, p. 277), and by additional displacements upon thermal and organic complexation treatments (MacEwan, *op. cit.*, pp. 118–121; Yoder and Eugster, 1955, p. 249). Detailed studies on a few cores (cores nos. 70 and 74) so far have failed to show the existence of such interlayering.

Kaolinite

This is applied to platy minerals with a ca. 7 Å line, that becomes destroyed by heating to 550–600° C. for $\frac{1}{2}$ hour (Brindley and Robinson, *op. cit.*, p. 188).[2] Although probably predominantly kaolinite, other phases with the same structure cannot be distinguished.

Chlorite

This name applies to a non-swelling platy mineral with a 14 Å line, or, in those cases where this is too weak to be resolved, a 7 Å line which is not destroyed by heating. This criterion is subject to the reservations already discussed in the previous paragraph.

Montmorillonite

This is defined by the presence of a diffraction line between 10 and 14 Å, which swells to ca. 17 Å upon saturation with glycerin (MacEwan, *op. cit.*, p. 115), and collapses to 10 Å upon heating to 550–600° C. Mont-

---

[2] Johns, Grim, and Bradley (1954, p. 243) suggest that the loss of diffraction lines after heating to 450° C. is attributable to chlorite, whereas their retention is due to kaolinite. Bradley's suggestion (1954, p. 328) of partial replacement of brucite-layers by "hydrous layers" in some sedimentary chlorites may eventually explain the apparently contradictory observations. The applicability of Brindley and Robinson's criterion to the Peruvian samples is being studied.

morillonite is found in several cores as an important clay-mineral phase; however, as remarked earlier, there is no conclusive evidence for the existence of its intergrowth with muscovite-type layers.

Many of the samples have been examined microscopically. Such optical studies yield information on the textural relations in the samples, as well as the presence of fossils and material amorphous to the x-ray, such as certain siliceous microfossils and volcanic glass. They also conveniently check the x-ray results on mineral identification.

DESCRIPTION OF THE CORES

The course of cruise 221 of the *Atlantis* was so arranged that seven coring traverses were made roughly normal to the shore line, and one long traverse parallel thereto. The traverses span the region between the coastline and the Peru-Chile trench, a submarine deep running roughly parallel to the west coast of South America (Schweigger, 1947). Not all the cores are yet studied; instead two or three cores from each transverse cruise, one from each end and one from the middle, were taken for the reconnaissance work. The locations of the fourteen cores reported here are given in Fig. 1; in Table 1 the results are summarized in terms of the megascopic lithology (somewhat generalized) and x-ray and microscopic mineralogy of the corresponding intervals.
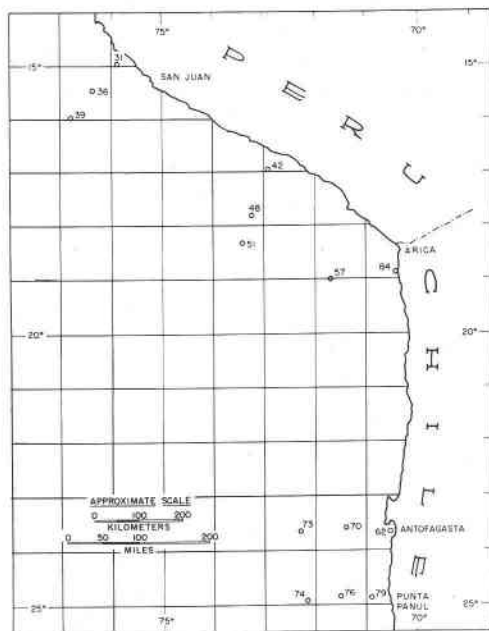

FIG. 1. Map showing locations of the fourteen cores.

TABLE 1. DATA ON THE CORES

Depth interval from top of core, cm.	Megascopic description	Mineralogy
	Core no. 31–3. Depth of water: 225 meters	
0–12	Empty	
12–17	Dark olive-brown, homogeneous clayey mud. Weak HCl reaction	Quartz: present but subsidiary Plagioclase: local, subsidiary Illite: trace to absent Kaolinite: rare trace Samples are largely microfossils showing no *x*-ray pattern and optically isotropic
17–23	Grades down from above through light brown silt to white, friable, sandy layer (2 cm.). No HCl reaction	Same as above
23–42	Sharp contact above; fine brown clayey mud. No HCl reaction	Same as above
42–48	Grading down into yellowish white sandy layer (2 cm.) with irregular bodies of brown mud. No HCl reaction	Same as above
48–62	Sharp upper contact; brown mud with light-coloured sandy layers 1 mm. thick, locally crossbedded. No HCl reaction	Same as above
62–77	Brown clayey mud. No HCl reaction	Same as above
77–90	Alternation of 1 mm. layers of brown clayey and pale sandy layers, with planar beddings. No HCl reaction	Same as above
90–107	Brown clayey mud with occasional shell remains. Weak HCl reaction	Abundant quartz at 97 cm., otherwise same as above
107–115	Like 77–90, but strongly crossbedded. Weak HCl reaction	Same as above
115–174	Brown mud, with thin white layers at irregular intervals. The latter type becoming rarer towards the bottom. No HCl reaction except locally	Same as top of core, with rare calcite. (124–162 cm. levels: abundant quartz, variable amount of plagioclase)
174–183	Like 77–90. Weak to no HCl reaction	Same as top of core
	Core no. 36–3. Depth of water: 4,435 meters	
0–199	Deep olive brown, clayey mud. Uniform textured, without visible grains. Occasional irregular patches varying in colour from pale brown to dark brown. Rare white ovoids scattered throughout the core. No reaction with HCl except in depth intervals between 45 and 120 cms	Quartz and plagioclase: predominant Kaolinite Illite Pyroxene and amphibole: detrital Calcite: an added phase between 45 and 120 cm. levels Glass: fairly common, mostly devitrified Fossils: abundant throughout the core

TABLE 1. (*continued*)

Depth interval from top of core, cm.	Megascopic description	Mineralogy
	Core no. 39–3. Depth of water: 2,600 meters	
0–30	Brown, friable silt with scattered white and black spots. Vigorous HCl reaction	Calcite: predominant, mostly organic remains Quartz and plagioclase: subsidiary; partly detrital Illite Kaolinite or chlorite Glass: abundant
30–36	Grades down to white silty loam, with sharp contact at the bottom. Moderate to weak HCl reaction	Plagioclase: predominant Quartz: trace Illite (possibly biotite) Glass: abundant No calcite
36–63	Brown silt with interspersed layers of white chalky silt in the upper part; otherwise same as 0–30 cm. Sharp contact at the bottom, changing to	Calcite: predominant, organic remains Quartz and plagioclase: abundant Illite Kaolinite: local Pyroxene and amphibole: rare, detrital Glass: abundant
63–90	Pale, chalky silt, with vigorous HCl reaction, grading down to	Calcite: predominant, organic remains Quartz and plagioclase: trace Illite: trace Glass: abundant
90–185	Pure white chalk, without stratification. Vigorous HCl reaction	Calcite: nearly pure sample; organic remains Quartz: very rare
	Core no. 42–4. Depth of water: 1,152 meters	
0–40	Unconsolidated, medium sand. Massive and homogeneous, dark olive-green in colour. Rare 1 mm. laminae of white sand. Vigorous HCl reaction except for the top 10 cm.	Quartz and plagioclase: predominant. Mostly as angular (detrital?) grains but partly probably as devitrification product Illite Kaolinite: above 30 cm. level Chlorite: below 30 cm. level Calcite: present except in the top 10 cm; as large rhombs and as devitrification product Pyroxene and amphibole: angular, detrital Glass: abundant, in various stages of devitrification
40–80	Gradationally changes from above downward into olive-yellow colour with local brown stain; otherwise no change in lithology. Vigorous HCl reaction	Same as above, with chlorite Aragonite: between 40 and 60 cm. levels; probably shell fragments
80–86	Gradationally changes from above into light gray, fine silt with dark green partings. Vigorous HCl reaction	Same as 0–40 cm., with chlorite

TABLE 1. *(continued)*

Depth interval from top of core, cm.	Megascopic description	Mineralogy
	Core no. 48–4. Depth of water: 6,146 meters	
0–14	Sticky, fine clayey mud, mostly olive to brown, with local black layers. No HCl reaction	Quartz and plagioclase: predominant; at least partly detrital Illite Kaolinite Pyroxene and amphibole: detrital Biotite: rare, detrital (?) Iron oxide (hydrous?) Glass: abundant Microfossils
14–16	Light brown, friable layer with oölitic texture. No HCl reaction	Quartz and plagioclase: predominant Illite and kaolinite: subsidiary Glass Microfossils
16–80	Same as 0–14 cm.; below 32 cm. level largely olive brown with faint, irregular layering due to colour variation. No HCl reaction	Quartz and plagioclase Illite Chlorite down to 56 cm. Kaolinite below 56 cm. Pyroxene and amphibole: detrital Glass Microfossils: very abundant
80–82	Yellowish-olive, silty clay. No HCl reaction	Same as above, with kaolinite
82–151	Same as 16–80 cm. No HCl reaction	Same as above
	Core no. 51–4. Depth of water: 4,456 meters	
0–18	Empty	
18–80	Deep brown, plastic clayey mud, uniform and homogeneous, nonstratified, with rare white, tiny ovoids. Gradually becomes brownish-gray towards the bottom. No HCl reaction	Quartz: very abundant Plagioclase: abundant Illite Kaolinite Montmorillonite (?) Pyroxene and amphibole: detrital Glass: rare Microfossils: present, but not abundant
80–91	Same as above, except that the mud is hard and non-plastic	Same as above
91–254	Brown plastic mud as above, gradually becoming olive-brown below 200 cm. level. Very local HCl reaction	Same as above
	Core no. 57–5. Depth of water: 4,106 meters	
0–60	Dull whitish green-gray mud, fine, compact, hard, with irregular, thin films of a green colour criss-crossing the sample at intervals of a few mms. No HCl reaction	Quartz: predominant Plagioclase: important Illite and kaolinite: in appreciable amounts Pyroxene and amphibole: scattered Glass: abundant, partly devitrified Microfossils: abundant

TABLE 1. (*continued*)

Depth interval from top of core, cm.	Megascopic description	Mineralogy
60–62	Angular fragments of fine white silty matter in green argillaceous matrix. No HCl reaction	Same as above
62–118	Same as 0–60 cm. levels	Same as above
118–138	Olive brown, unconsolidated, well sorted sand with pale, argillaceous cement; sharp contacts. No HCl reaction	Plagioclase: predominant Quartz: important Illite and kaolinite: absent to barely detectable Glass: abundant Microfossils: abundant
138–175	Same as 62–118 cm. levels	Same as above 118 cm. level

Core no. 62–6. Depth of water: 79 meters

0–30	Massive, olive coloured, well sorted, unconsolidated sand, grains about 0.5 mm. across. Scattered shells of complete or fragmentary gastropods and pelecypods; locally concentrating into layers. Vigorous HCl reaction	Calcite: predominant Plagioclase: important Quartz: variable in amount, generally subsidiary Illite: only between 60 and 90 cm. levels Kaolinite and/or chlorite: in small amounts, not differentiated Aragonite: probably shell fragments, locally important Amphibole and pyroxene Glass: present in small amounts Fossils: very abundant, including considerable foraminifera
30–90	Same as above but with dark brown argillaceous layers interspersed, up to 2 cm. thick, at irregular intervals	Same as above
90–122	Same as above, but the sand becomes finer-grained approaching silt; core well stratified by colour variation (coarser, olive-colour vs. finer, brown colour)	Same as above

Core no. 70–6. Depth of water: 6,999 meters

0–70	Fine, sticky, dark brown, homogeneous clayey mud with only occasional colour variations to suggest layering. No HCl reaction	Quartz and plagioclase: predominant. Most of these are large, angular, probably detrital grains Chlorite and illite Kaolinite: local Montmorillonite: local only. With illite, chlorite, and possibly kaolinite Pyroxene and amphibole: detrital, subsidiary Biotite: rare, may be detrital Iron oxide (hydrous?) Glass: moderate in amount, in various stages of devitrification Microfossils: rare

TABLE 1. *(continued)*

Depth interval from top of core, cm.	Megascopic description	Mineralogy
70–131	Gradual change from above; slowly becomes a clay-mud of steel gray colour but with the same texture. No HCl reaction	Same as above; no evidence for montmorillonite
131–134	Gray, friable, fine silt with gradational upper and sharp lower contacts. No HCl reaction	Same as above; grains well sorted Glass: abundant
134–138	Steel gray fine clayey mud as before. No HCl reaction	Same as 0–131 cm. levels
138–141	Same as 131–134 cm., with gradational upper and sharp lower contacts. No HCl reaction	Same as above; much volcanic glass. Grains well sorted
141–145	Olive gray-green clayey mud. No HCl reaction	Same as 0–131 cm. levels

Core no. 73–6. Depth of water: 4,279 meters

0–31	Empty	
31–107	Deep chocolate brown, sticky, clayey mud. Uniform and homogeneous, without stratification. Locally (67–72 cm.) vaguely layered due to slight colour differences, or motley-coloured (78–88 cm.). Colour grades downwards into pale choc. brown. No HCl reaction	Quartz: moderately abundant Plagioclase: present, locally abundant Illite Kaolinite Chlorite: locally present Pyroxene and amphibole: detrital Glass Microfossils: present
107–110	Yellowish brown silty mud, with sharp contacts. No HCl reaction	Same as above, with abundant fresh colourless glass
110–279	Same as above 107 cm. level, except that a 2 mm. silty layer exists at 111 cm. level. Colour is predominantly chocolate brown near the top, grading downwards through yellow-brown to gray brown. No HCl reaction	Same as above 107 cm. level; kaolinite more common than chlorite Much glass, mostly devitrified

Core no. 74–7. Depth of water: 3,968 meters

0–98	Deep brown, fine, hard mud, with thin, faint layerings at 1–5 mm. intervals due to colour variations. HCl reaction: above 36 cm., none; 36–70 cm., moderate; 70–98 cm., none	Quartz and plagioclase: abundant Illite: abundant Kaolinite: in small amounts Montmorillonite: present Chlorite: in small amounts Calcite: in moderate amounts between 36 and 70 cm. levels Glass: abundant, in various stages of devitrification Microfossils: abundant
98–108	Same as above, with faint, irregular layers of buff mud. HCl reaction: moderate	Same as above, with abundant calcite

TABLE 1. *(continued)*

Depth interval from top of core, cm.	Megascopic description	Mineralogy
108–121	Same as 0–98 cm. levels. HCl reaction: moderate	Same as 0–98 cm. levels
121–141	Same as 98–108 cm. levels. HCl reaction: moderate	Same as 98–108 cm. levels, with abundant glass
141–149	Same as 108–121 cm. levels. HCl reaction: weak to none	Same as 0–98 cm. levels, with chlorite and montmorillonite
149–160	Same as 121–141 cm. levels. HCl reaction: moderate to good	Same as above, with abundant calcite
160–173	Deep brown clayey mud with numerous fine, even layers of light buff mud. HCl reaction: vigorous	Calcite: predominant Plagioclase: abundant Quartz: subsidiary Kaolinite and chlorite: subsidiary, undifferentiated Glass: abundant Microfossils

Core no. 76–7. Depth of water: 5,669 meters

0–6	Empty	
6–8	Dark brown mud, uniform and homogeneous. No HCl reaction. (type "A")	Plagioclase: predominant Quartz: in moderate amounts Microcline: possibly present locally Illite Kaolinite Pyroxene and amphibole: detrital Calcite: very rare Glass: abundant Microfossils
8–18	Same, with about equal amounts of irregular patches of fine, buff mud (type "B"); the two types in sharp contact. No HCl reaction	Same as above
18–30	Like type A, but with HCl reaction	Calcite: predominant (organic remains) Quartz and plagioclase: subsidiary Kaolinite Illite: in small amounts Pyroxene and amphibole: rare Glass: rare but present
30–35	Type B, with HCl reaction	Same as above
35–40	Type A, with HCl reaction	Same as above
40–61	A and B in about equal amounts, forming layers or with B in irregular patches. HCl reaction	Same as above
61–70	A, with HCl reaction	Same as above

TABLE 1. (*continued*)

Depth interval from top of core, cm.	Megascopic description	Mineralogy
70–78	A and B in about equal amounts, with B in irregular patches. HCl reaction	Same as above
78–103	A, with HCl reaction	Same as above

Core no. 79-7. Depth of water: 1,856 meters

0–2	Empty	
2–26	Olive green, medium-fine, massive sand, with mud matrix. Local shell fragments. Vigorous HCl reaction	Quartz, plagioclase, and calcite: predominant Kaolinite Illite Chlorite Pyroxene and amphibole: detrital Glass: abundant, some very fresh Microfossils: abundant
26–30	Same as above, with 3–5 mm. white sand layers at 3–5 mm. distance apart	Same as above
30–82	Same as 2–26 cm. levels	Same as above
82–85	Gray unconsolidated, well-sorted sand, medium-coarse, without matrix material. Gradational upper, and sharp lower contacts	Quartz, plagioclase, and calcite: predominant Platy minerals: accessory only Pyroxene and amphibole No glass Microfossils: abundant, mostly foraminifera Note: all the microscopically resolved mineral grains are angular and apparently detrital
85–118	Fine brown clayey silt, uniform but for one pale, sandier layer between 94 and 96 cm. levels. Visible quartz and mica grains rarely present	Same as between 2–26 cm. levels
118–131	Intimate interlayering of brown, muddy and white, sandy silt, grading down to uniform fine muddy silt	Same as above
131–138	Slightly coarser silt, same as above 118 cm. level	Same as above
138–140	Same as between 82–85 cm. levels; gradational upper and sharp lower contacts	Same as between 82–85 cm. levels Montmorillonite (?)
140–150	Same as above 138 cm. level, with two thin sandy layers near the upper contact	Same as between 131–138 cm. levels
150–152	Same as between 138–140 cm. levels; gradational upper and sharp lower contacts	Same as between 138–140 cm. levels
152–156	Same as above 150 cm. level	Same as between 140–150 cm. levels

TABLE 1. (*continued*)

Depth interval from top of core, cm.	Megascopic description	Mineralogy
156–158	Same as between 150–152 cm. levels; gradational upper contact	Same as between 150–152 cm. levels

Core no. 84–5. Depth of water: 933 meters

0–76	Deep olive-brown, unconsolidated, nonclayey sand. Uniform, nonstratified. Scattered calcareous shell remains throughout. HCl reaction: moderate to weak	Quartz and plagioclase: predominant, mostly detrital Illite: trace Kaolinite: subsidiary Chlorite: found at 40 cm. level only Pyroxene and amphibole: detrital Calcite: small amounts, as product of devitrification Glass: abundant Microfossils: abundant
76–156	Much like above, but with numerous small (about 2 mm. × 4 mm.) irregular light-coloured patches scattered in the core, locally concentrated to suggest layering. Moderate HCl reaction	Same as above

DISCUSSION AND INTERPRETATION

The detrital portions of the cores studied are generally well-sorted. The detrital grains consist largely of volcanic glass in various stages of devitrification, angular grains of quartz, feldspar (plagioclase), pyroxene, amphibole, and also grains comprised of exceedingly fine mineral aggregates, possibly representing fragments of pre-existing rocks. Nevertheless, for a given core at a given depth level, the grains show good sorting, suggesting current action, even though a sample may be largely volcanic glass. This point is supported by observed graded bedding, cross-bedding, and fine-scale interlamination of different lithologies in many of the cores, even one (no. 31) composed nearly exclusively of tests of microfossils.

The gross lithology as well as mineralogy of any given core tends to be constant. Although the contrast amongst cores may be great, samples from a given core, with a few exceptions, tend to have the same minerals in comparable proportions, including the micaceous portions. There seems to be little difference in the x-ray patterns between the top of a core, presumably fresh sediment, and the lower, better indurated parts, such as reported by Murray and Harrison (1956, p. 36). True enough, the cores are extremely superficial samples of the sedimentary columns, nonetheless the relative constancy remains striking.

Volcanic glass is commonly encountered. As noted previously, these

glass fragments are fairly well-sorted and at places finely interlaminated with other lithologic types—for instance calcitic layers. Quite possibly, these represent ash beds which, as far as microscopic determinations permit, are remarkably free of other types of material, except microfossils, although in this grain-size range it is admittedly difficult to detect rock fragments with any degree of certainty. The fragments of glass in a given sample show very different degrees of devitrification. Some fragments are fresh, the only crystalline phases being occasional unaltered phenocrysts, chiefly plagioclase (usually labradorite to andesine) and pyroxene or amphibole; but other fragments are partly or completely devitrified. Indices of refraction of the unaltered glass commonly yield values near or slightly greater than 1.56 and suggest basaltic composition, although rarely the index may be down to 1.51 and suggests a highly siliceous glass (Williams, Turner, and Gilbert, 1955, p. 28).

The difference in the extent of devitrification may be due to differences in the ages of the fragments, brought together through fluviatile agents. On the other hand, it may also be due to variations in the rates of devitrification, reflecting differences in the thermal history of the fragments, such as the degree of annealing and rate of chilling. Such a phenomenon is known to occur in rhyolitic flows (Boyd, 1957, p. 52); however, few laboratory data exist on this problem.

The most common, and nearly ubiquitous product of devitrification is a non-swelling mica which gives a well-defined reflection at about 10 Å. This is probably closely related to muscovite. A second common product is a 7 Å micaceous mineral, presumably kaolinite. Chlorite is relatively rare, montmorillonite is scarce; but calcite is fairly common. Quartz and an oxide of iron complete the list; whether any other phase results from devitrification is not established.

The formation of calcite and kaolinite, through hydration and carbonation of volcanic glass, is interesting in that it demonstrates the existence of interaction between the glass and its surroundings. Through the intimate association of these two minerals in a matrix of volcanic glass, as determined optically, they are probably stable together, and exclude, under the specific conditions, anorthite as a stable phase. Many samples, on the other hand, have only kaolinite and no recognizable calcite or any other diagenetic essential calcium phase; calcium may have been leached out of these samples.

Another point of interest is the role of iron and magnesium in the devitrification process. At least part of the iron goes to an "oxide" as noted. Apart from this, however, the only recognized essentially ferromagnesian phase is occasional chlorite. While it is possible that part of the magnesium goes into a 10 Å mica, a good proportion of the iron and magnesium

may have become dissolved in the surrounding water and lost to the sediment. In general, the more devitrified a volcanic glass is, the lighter its color tends to be.

Summary

Preliminary mineralogical examination of cores collected from the coast of Peru and Chile has revealed some features of mineralogical interest. Chief among these is the presence of abundant volcanic glass in many of the cores. Devitrification of the glass, in contact with sea water, results in minerals whose intimate association suggests approach towards chemical equilibrium; study of the detailed nature of these mineral associations therefore should yield data on the phase relations at the lowest end of the spectrum of diagenetic-metamorphic conditions. On the other hand, it should be emphasized that the very presence of volcanic glass indicates that the samples, as a whole, are not equilibrium systems although portions of them may locally be so.

The principal limitations in a mineralogical-petrological study of sediments lie in the fine grain size and the identification of clay minerals. While the use of modern x-ray diffractometers considerably reduces the size problem, it appears that for many sediments even x-rays are too coarse a probe, which must be supplemented by techniques such as electron microscopy and differential thermal analysis. On the other hand, conventional optical methods can also yield information valuable in the interpretation of the sediment samples.

The principles and methods of clay-mineral identification have been summarized elsewhere (Brindley, 1951; Grim, 1953; Weaver, 1956). Work is currently in progress on the detailed and specific identification of the clay-fraction of the core samples. Results to date, however, do indicate that the clay mineral phases listed in this report are essentially correct.

The geological interpretation of the mineralogical results cannot be made without a comprehensive study of the regional geology, as well as an understanding of the oceanography around the depositional site. Such an interpretation will be deferred to a later date.

agement is gratefully acknowledged. The manuscript was critically reviewed by Professors C. Frondel, B. Kummel, R. Siever, and J. B. Thompson, Jr., all of Harvard University.

REFERENCES

BOYD, F. R. (1957), Geology of the Yellowstone rhyolite plateau. Harvard University Ph.D. Thesis. 134 pp.

BRADLEY, W. F. (1954), X-ray diffraction criteria for the characterization of chloritic material in sediments. *In* Clays and clay minerals, Publ. no. 327, Nat. Acad. Sci. and Nat. Res. Council. pp. 324–334.

BRINDLEY, G. W., ed. (1951), *X*-ray identification and crystal structures of clay minerals. London: The Mineralogical society. 345 pp.

GRIM, R. E. (1953), Clay mineralogy. New York: McGraw-Hill Book Co., 384 pp.

GUNTHER, E. R. (1936), A report on oceanographical investigations in the Peru coastal current. *Discovery* Reports, **13,** pp. 107–276.

JENKS, W. F. (1946), Preliminary note on geologic studies of the Pacific slope on southern Peru. *Amer. Jour. Sci.,* **244,** 367–372.

JENKS, W. F., ed. (1956), Handbook of South American geology. *Geol. Soc. Amer., Mem.* **65,** 378 pp.

JOHNS, W. D., GRIM, R. E., AND BRADLEY, W. F. (1954), Quantitative estimations of clay minerals by diffraction methods. *Jour. Sed. Pet.,* **24,** 242–251.

MURRAY, H. H., AND HARRISON, J. L. (1956), Clay mineral composition of recent sediments from Sigsbee Deep. *Jour. Sed. Pet.,* **26,** 363–368.

NAGELSCHMIDT, G. (1937), X-ray investigation on clays, Pt. III. *Zeit. Krist.,* **97,** 514–521.

REVELLE, R. R. (1944), Marine bottom samples collected in the Pacific Ocean by the Carnegie on its seventh cruise. *Carnegie Inst. Wash. Publ.* **556,** Pt. I. pp. 1–180.

RÜEGG, W. (1957), Geologie zwischen Cañete-San Juan 13°00′–15°24′ Südperu. *Geol. Rundschau,* **45,** 775–858.

SCHWEIGGER, E. (1947), La fosa de Lima. *Bol. Soc. Geol. del Peru,* **20,** 35–50.

WEAVER, C. E. (1956), The distribution and identification of mixed-layer clays in sedimentary rocks. *Am. Mineral.,* **41,** 202–221.

WILLIAMS, H., TURNER, F. J., AND GILBERT, C. M. (1955), Petrography. San Francisco: W. H. Freeman and Co., 406 pp.

YODER, H. S., AND EUGSTER, H. P. (1955), Synthetic and natural muscovites. *Geoch. et Cosmoch. Acta,* **8,** 225–280.