

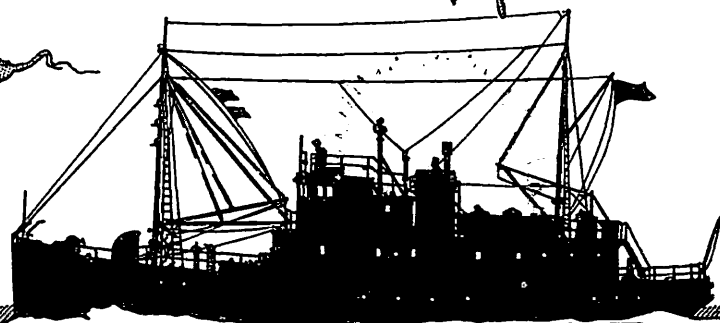
UNIVERSITY OF WASHINGTON DEPARTMENT OF OCEANOGRAPHY

Technical Reports
Nos. 174, 175, 176,
177, 178, and 179

A COMPILATION OF ARTICLES REPORTING RESEARCH
SPONSORED BY THE OFFICE OF NAVAL RESEARCH

Office of Naval Research
Contracts Nonr-477(10)
and Nonr-477(37)
Project NR 083 012

Reference M66-78
December 1966



SEATTLE, WASHINGTON 98105

UNIVERSITY OF WASHINGTON
DEPARTMENT OF OCEANOGRAPHY
Seattle, Washington 98105

Technical Reports

Nos. 174, 175, 176,
177, 178, and 179

A COMPILATION OF ARTICLES REPORTING RESEARCH SPONSORED
BY THE OFFICE OF NAVAL RESEARCH

Office of Naval Research
Contracts Nonr-477(10)
and Nonr-477(37)
Project NR 083 012

Reference M66-78
December 1966



RICHARD H. FLEMING
Chairman

Reproduction in whole or in part is permitted
for any purpose of the United States Government

ARTICLES REPORTING RESEARCH SPONSORED BY THE OFFICE OF NAVAL RESEARCH

Technical Report No. 174

IDENTIFICATION AND DETERMINATION OF ORGANIC ACIDS IN SEA WATER BY PARTITION CHROMATOGRAPHY, by Tadashiro Koyama and Thomas G. Thompson. The Journal of the Oceanographical Society of Japan, 20(5):209-220. 1964.

Technical Report No. 175

QUANTITIES OF ZOOPLANKTON AND PROPAGATION OF CALANUS FINMARCHICUS AT PERMANENT STATIONS ON THE NORWEGIAN COAST AND AT SPITSBERGEN, 1959-1962, by Ulf Lie. Fiskeridirektoratets Skrifter, Havundersøkelser, 13(8):5-19. 1965.

Technical Report No. 176

MAGNETIC AND PETROLOGIC STUDIES OF SEDIMENT FOUND ABOVE BASALT IN EXPERIMENTAL MOHOLE CORE EM7, by M. D. Fuller, C. G. A. Harrison, and Y. R. Nayudu. Bulletin, American Association of Petroleum Geologists, 50(3):566-573. 1966.

Technical Report No. 177

AN INSTRUMENT SYSTEM TO MEASURE BOUNDARY-LAYER CONDITIONS AT THE SEA FLOOR, by Richard W. Sternberg and Joe S. Creager. Marine Geology, 3(6): 475-482. 1965.

Technical Report No. 178

SOME CONSEQUENCES OF THE DECOMPOSITION OF ORGANIC MATTER IN LAKE NITINAT, AN ANOXIC FJORD, by Francis A. Richards, Joel D. Cline, William W. Broenkow, and Larry P. Atkinson. Limnology and Oceanography, 10(Suppl.): R185-R201. 1965.

Technical Report No. 179

LOW-FREQUENCY SEA LEVEL OSCILLATIONS ALONG THE PACIFIC COAST OF NORTH AMERICA, by Gunnar I. Roden. Journal of Geophysical Research, 71(20): 4755-4776. 1966.

UNIVERSITY OF WASHINGTON
DEPARTMENT OF OCEANOGRAPHY
TECHNICAL REPORT NO. 176

BULLETIN
AMERICAN ASSOCIATION
OF PETROLOGICAL GEOLOGISTS
VOL. 50, NO. 3, MARCH, 1966

MAGNETIC AND PETROLOGIC STUDIES OF SEDIMENT FOUND ABOVE
BASALT IN EXPERIMENTAL MOHOLE CORE EM7¹

M. D. FULLER,² C. G. A. HARRISON,³ AND Y. R. NAYUDU⁴
San Diego, California

INTRODUCTION

In Experimental Mohole 7 (EM7) of the Mohole test drill off the island of Guadalupe,

¹Contribution from the Scripps Institution of Oceanography, University of California, San Diego; Contribution No. 353, Department of Oceanography, University of Washington. The petrographic examinations were done by one of the writers (Y. R. N.); the other two authors did the magnetic work. Manuscript received, June 6, 1965.

²Present address: Department of Earth and Planetary Sciences, University of Pittsburgh, Pittsburgh, Pennsylvania.

³Marine Physical Laboratory, Scripps Institution of Oceanography, University of California, San Diego.

⁴Present address: Department of Oceanography, University of Washington, Seattle, Washington. Parts of this research were sponsored by the

28° 59' N., 117° 30' W., basalt was reached during run 4 of the coring operations in this hole (EM7 run 4). This run was 120 cm. long but recovered only 13.2 cm. of basalt, indicating that much of the run failed to recover core material. EM7 run 3 began 120 cm. above run 4, was 120 cm. in length, and recovered only 98 cm. of sediment, again indicating a partial failure of the run to recover core material. Because of the uncertainties in the drilling and coring operations, the depth of the basalt below the bottom of the sediment in EM7 run 3 is not known but probably was between 20-100 cm. Magnetic and petrologic investigations made on the sediment above the basalt are discussed with the objective of determining the nature of emplacement of the basalt.

GENERAL DESCRIPTION

A summary of the drilling operations during the Mohole test drill was given by Horton (1961), and a description of the sediments recovered was published by Riedel *et al.* (1961). This paper deals with the core EM7 run 3 (*i.e.*, that sediment just above the basalt), and the following description of core EM7 run 3 is from Riedel *et al.* (1961).

Centimeters from Top	Description
0-9	Dusky yellow-green sediment with many dolomite rhombs and coccolithophorids, grading by mottling to:
9-49	Greenish gray sediment with many dolomite rhombs, becoming darker downward.
63-67	Pale olive sediment with many dolomite rhombs, with patches of dusky yellowish green, changing abruptly to:
67-79 and 84-98	Dusky yellow sediment composed predominantly of dolomite rhombs with brownish black patches.

MAGNETIC RESULTS

The remanent magnetization of 13 cylindrical samples taken from EM7 run 3 were measured with an astatic magnetometer. The intensity of magnetization was low but not difficult to measure, provided that care was taken. Because the

TABLE I. SUMMARY OF MAGNETIC PROPERTIES

Sample Depth in Core (cm.)	Inclination	<i>J</i> , micro emu/cc.	<i>k</i> , micro emu/cc.	<i>Q</i>
10	Positive	0.31	6.58	.098
11	Negative	0.29	9.14	.066
15	Negative	0.14	5.14	.057
25	Negative	0.36	5.69	.132
32	Negative	0.18	5.27	.071
44	Negative	2.72	7.83	.724
47	Negative	16.30	7.98	4.255
66	Positive	0.20	16.76	.021
68	Positive	0.57	12.06	.098
76	Positive	0.48	9.69	.103
77	Positive	0.23	7.82	.061
90	Positive	0.28	11.01	.053
92	Positive	0.20	8.04	.052

azimuth of the core is not known and there is a possibility that parts of the sediment may have become twisted during the coring and retrieving operations, the writers can only compare the inclination of magnetization of the various samples. Table I lists the distance below the top of EM7 run 3 of each sample in centimeters, the sign of the inclination, the intensity of magnetization *J*, the intensity of magnetic susceptibility *k*, and the *Q* factor, where $Q = J/0.48k$. Figure 1 shows the positions of the samples relative to the top of the sediment and the basalt layer.

The samples at 47 cm. and above have negative inclinations with the exception of the sample at 10 cm. They are thus reversely magnetized with respect to the present Earth's field direction. The samples below 47 cm. have positive inclinations and are thus positively magnetized.

Four of the samples were saturated in a field of 5,500 oersteds and then demagnetized in steps. The demagnetizing curves are shown in Figures 2 and 3. Two of the samples came from above 47 cm. and two from below.

PETROLOGY

A petrographic study of the sediment shows that the upper part of the section (0-44 cm.) consists of calcareous nannoplankton, quartz, plagioclase, and aggregates of clay; dolomite rhombs are scattered throughout the sediment. From 44-47 cm. the sediment consists mainly of dolomite rhombs, yellowish green lumps, and clay aggregates. Martini and Bramlette (1963) found a few occurrences of calcareous nannoplankton in this section. There is little plagioclase, but brown-

American Chemical Society, Grant No. PRF 700A; by the Office of Naval Research, Contract Nonr 2216(05) and Contract No. 477(37), Project NR 044-04; and by the National Science Foundation, Grant GP-4056. The writers are indebted to W. R. Riedel for making the Mohole sediment available.

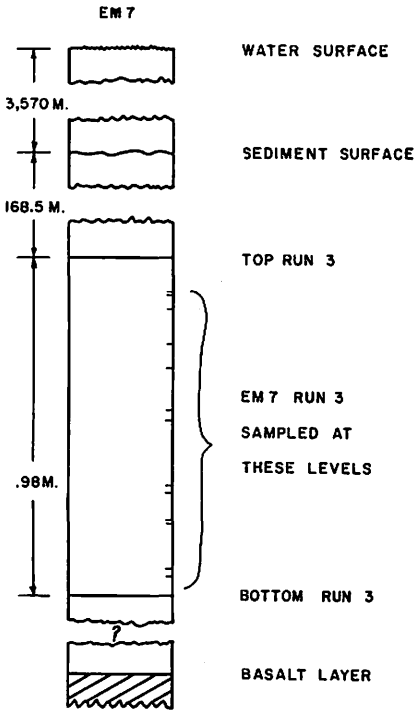


FIG. 2.—Demagnetizing curves of samples from 10 and 15 cm. previously saturated in a field of 5,500 oersteds. The intensity is plotted as that fraction of original intensity remaining after demagnetization. Both scales are logarithmic.

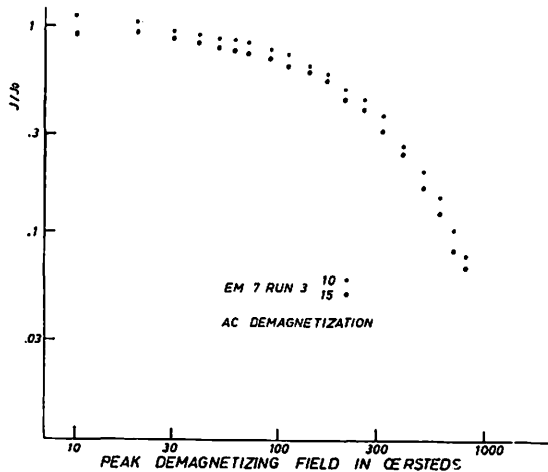


FIG. 1.—Diagram showing position of samples taken from EM7 run 3 in relation to position of basalt layer.

ish black patches are seen in a few samples. The section from 48–98 cm. is composed predominantly of dolomite rhombs, brownish black patches, and pale yellowish aggregates. Toward the lower part of this section the number of brownish black patches increases considerably. Nannoplankton are absent from this section. This study reveals that there is a definite change in the nature and composition of the sediments at about 48 cm. below the top of the core.

Detailed study of the samples of the lower section (48–98 cm.) shows that the major part of the material consists of pale yellowish green to greenish flaky and elongate fragments. Some of these fragments show the presence of "floats" or well-developed single rhombs of calcite or dolomite. In some samples, several carbonate rhombs appear to grow out of large pale yellowish or yellowish green material which occurs in lumps and aggregates (Plate I). From the color characteristics and petrographic study it is inferred that the original material was palagonite,

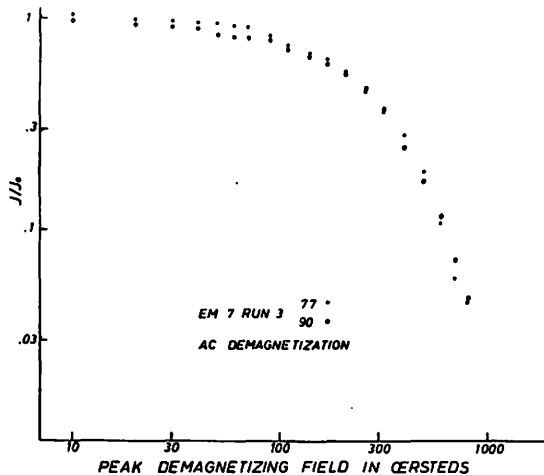


FIG. 3.—Demagnetizing curves of samples from 77 and 90 cm. previously saturated in a field of 5,500 oersteds.

as described by Nayudu (1962, 1964). In addition, dolomite rhombs are associated with the brownish black patches included in the sediment description. Some of the carbonate rhombs (dolomite and calcite) contain pale yellowish material and brownish black opaque material in the cores of the rhombs or concentrated along the margins of the crystal faces (Plate I). The yellowish green and greenish aggregates of flaky minerals probably are chlorite, saponite(?), and montmorillonitic clay; the brownish black material is ferromanganese oxide minerals. Petrologic study suggests that these minerals were formed from the alteration of palagonite tuff. The carbonate rhombs in greenish fragments occurring as "float" and brownish black opaque material probably resulted from the concentration and segregation of minerals during the alteration process.

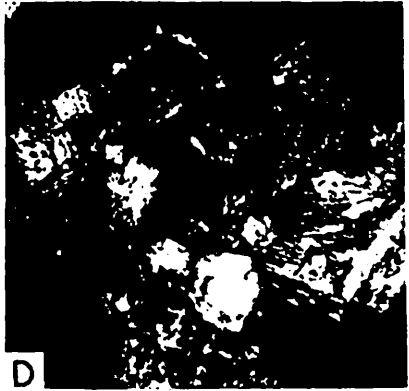
DISCUSSION

The basalt was found by Cox and Doell (1962) to be reversely magnetized with respect to the Earth's present field. The magnetic anomaly over the test drill area suggests that the body causing the anomaly is predominantly normally magnetized (Raff, 1963). The basalt drilled in hole EM7 probably was formed at a different time,

when the Earth's field was reversed, as it is unlikely that the difference in polarity is caused by a self-reversal mechanism. The Q factor (or ratio of remanent magnetization to induced magnetization in the Earth's field) of the basalt (Cox and Doell, 1962) is high, with a mean value of 40. The Q factor shows a decrease from 105 near the top of the basalt layer to values near 20 in the deepest basalt samples.

The general range of Q factors for deep oceanic sediments is between 0.04 and 2.8. Keen (1960) reported Q factors as high as 2.0 in some Atlantic sediment cores. The highest Q factor found in a Pacific sediment, other than Moho sediment, is 3.2, from a sample taken on the continental shelf close to San Diego. In general, high Q factors are found in sediments containing terrigenous material.

The natural remanent magnetization (NRM) of sediments with low Q factors may be expected to be caused by depositional remanent magnetization (DRM). Samples with higher Q factors may have become magnetized by some different mechanism. This should be especially true in the samples from 44 and 47 cm, which do not seem to differ radically in lithology from the sediment above but which have higher-than-normal Q factors.



(See legend on facing page)

Two processes can result in characteristically high Q factors. The first is chemical remanent magnetization (CRM). CRM requires that the ferromagnetic crystals grow in a magnetic field from a solution or a solid solution, with the crystals passing through the paramagnetic and superparamagnetic states and finally to the ferromagnetic state (Creer, 1957; Kobayashi, 1962). This would require that sedimentation conditions for the section above and including sample 47 differed from those of the rest of the EM7 run 3, and also from all of the sampled parts of EM8, which have Q factors between 0.04 and 0.16. CRM can produce Q factors between 1 and 100. If the magnetization of the section above 47 cm. were caused by CRM, this would not explain the upward decrease in Q factor in this section of the core.

The second process that results in high Q factors is thermo-remanent magnetization (TRM). TRM requires that the ferromagnetic crystals cool through their Curie temperature in the presence of a magnetic field. In general, high Q factors are produced when the grain size of the ferromagnetic crystals is sufficiently small that only one ferromagnetic domain is present in each crystal. TRM may produce Q factors as high as 100. The upward decrease in Q factor from 47 cm. could be explained by supposing that the temperature to which the sediment was heated decreased with increasing distance above the basalt layer, resulting in the acquisition of smaller components of TRM.

If one assumes that CRM is unlikely to be the cause of the high Q factors found in EM7 run 3, then two lines of evidence suggest that the basalt was intruded into the sediment and that, as it

was intruding, the basalt heated the ferromagnetic material to above or near its Curie temperature. The high Q factor is produced by TRM and the reversed magnetization is produced by the reversed field which probably existed during the time that the basalt cooled (Cox and Doell, 1962). The alternative explanation that the basalt and the sediment have reversed magnetization because of a self-reversal property is unlikely in view of the mineralogical and compositional differences between the two.

One factor is not explained by this hypothesis. This is the fact that the section below 47 cm. of EM7 run 3 has both normal directions of magnetization and normal Q factors, ranging from 0.024 to 0.103. It is possible that this section has undergone chemical alteration, resulting in the removal of reverse NRM and the production of normal NRM with normal Q factors, possibly by a process of viscous remanent magnetization (VRM). There is no obvious reason why such a chemical alteration should have stopped between samples 66 and 47, especially since the material at 47 cm. probably was heated.

An alternative explanation is that the material below 47 cm. was the highest layer of the original palagonite tuff-breccia formed during the emplacement of the basalt, which was later transformed either by hydrothermal and (or) normal alteration and decomposition processes which formed chlorite, saponite(?), carbonates, ferromanganese oxides, and montmorillonitic clay. It has already been noted that this section of the sediment is characterized by the presence of brownish black ferromanganese oxide minerals.

The normal magnetization of the material below 47 cm. requires that either the material

PLATE I.—I-A. Photomicrograph of rhombic outline of dolomite shown by arrow. Similar outlines are scattered throughout yellowish green matter and are optically continuous with medium. These outlines suggest initial stage of growth of dolomite rhombs from yellowish green material ($\times 60$). I-B. Photomicrograph showing concentrations of dolomite rhombs and ferromanganese oxide segregations in yellowish green material ($\times 60$). I-C. Photomicrograph of well-developed dolomite rhomb; cleavage lines extend into medium of yellowish green chlorite or saponite(?), suggesting that dolomite rhomb has grown by use of local carbonate source ($\times 120$). I-D. Photomicrograph of dolomite rhombs showing segregation of ferromanganese oxides inherited from alteration of original yellowish green chlorite or saponite(?) ($\times 60$). I-E. Photomicrograph of dolomite rhomb showing large concentration of opaque ferromanganese oxides. Also note that black opaques are scattered in rhomb ($\times 120$). I-F. Photomicrograph showing occurrence of dolomite rhombs in association with opaque brownish black ferromanganese oxides; note inclusions of opaques in dolomite rhombs ($\times 60$).

was altered long after intrusion, when the Earth's magnetic field was again normal, or that the magnetization is unstable and the normal component is caused by VRM in the present Earth's field. In either case, there should be some sign to show that the magnetic materials above and below 47 cm. are different.

The mean susceptibility of the samples at 47 cm. and above is 6.80 ± 0.59 micro-emu/cc. and that of the samples below 47 cm. is 10.90 ± 1.35 micro-emu/cc. This represents a real difference of susceptibility between the two groups at a confidence level of 1 per cent (using a normal statistical analysis). Examination of the demagnetization curves in Figures 2 and 3 reveals that the pairs of curves presented in either figure agree well with each other in shape, but not as well with either of the curves in the other figures. For example, the demagnetization curves for the samples from 77 cm. and 90 cm. show that the intensity decreases more rapidly with increasing field than it does for the samples from 10 cm. and 15 cm., indicating a lower stability for the samples from 77 and 90 cm. Statistical analysis of the curves demonstrated that there was a significant difference (at a level of 5 per cent) between the demagnetizing curves of two samples from different groups, compared with the demagnetizing curves of two samples from the same group, in seven out of eight possible cases. Thus there are two lines of evidence suggesting that the magnetic material in the section above 47 cm. is different from the magnetic material below 47 cm.

Rittenberg *et al.* (1963) stated that their sample (54-63 cm.) from the lower part of the core EM7 run 3 is different in composition from the other samples that they studied. According to them, the sediment in this sample is coarser than the other sediments, and the coarse fraction consists mainly of volcanic glass and greenish aggregates or lumps which have the appearance of montmorillonite-type clay. Part of this sample also consists of small euhedral crystals of calcite or dolomite. Quartz, plagioclase, mica, and fossils are absent. Rittenberg *et al.* (1963) considered that these sediments possibly are the weathered products of volcanic ash.

Nayudu (1964) showed that the important alteration or decomposition products of primary palagonite and basaltic glass are zeolites, mont-

morillonite clay, carbonates, and ferromanganese oxide minerals. From the petrographic study of the sediments below 47 cm. it is shown that greenish aggregates or lumps consist of chlorite or saponite(?) and montmorillonite-type clay.

Murata and Erd (1964), as a result of a study of sediments from the Mohole, concluded that their samples 33 and 34 from EM7 run 3 are different in composition from all other samples. According to them, these samples are rich in magnesium, iron oxides, manganese oxides, and phosphates. From the X-ray data they concluded that the montmorillonoid mineral (greenish lumps described in this paper as chlorite or saponite?) is of a magnesian saponite type low in aluminum. Murata and Erd (1964) suggested that the basalt may have been the source for these sediments.

Furthermore, Nayudu (in press), as a result of a study of palagonitized basalt and carbonates in contact with basaltic glass found in the experimental Mohole, suggested that there probably was extensive primary palagonite tuff developed during the emplacement of basalt; later alteration and decomposition resulted in the formation of zeolites, carbonates, silica, and black opaque segregations of ferromanganese oxides. The data presented by Rittenberg *et al.* (1963) and Murata and Erd (1964) seem to confirm the observations made by Nayudu (1964) and the results presented in this paper. Therefore, the writers believe that sediments in the lower part of core EM7 run 3 (63-98 cm.) mainly represent alteration products of primary palagonite tuff.

CONCLUSIONS

The high Q factors of the samples from 44 and 47 cm., and the reverse magnetization of samples at and above 47 cm., suggest that this part of the sediment became magnetized by a thermal process associated with the intrusion of the basalt layer, which also is reversely magnetized. Two magnetic results, the difference in susceptibility between the two sections and the difference in the demagnetizing curves, suggest that the sediment from the sections above and below 47 cm. had different origins. This is confirmed by the petrologic investigations which indicate that the material below 47 cm. resulted from the later alteration of primary palagonite tuff which was formed on the basalt layer after intrusion. The

section above 47 cm. seems to be similar to the other sediment found in the Mohole test drills off Guadalupe Island. Reasonable explanations have been given for the normal Q factors and normal magnetization of the section below 47 cm.; these are consistent with the above hypothesis, but other explanations are possible.

Because the uppermost part of the sediment on the ocean floor is much less dense than basalt and does not have sufficient mechanical strength to support a basalt column, it is probable that basalt will intrude the sediment (Kennedy, personal suggestion) rather than flow out over the surface. As a result, the overlying sediment would be altered as has been suggested in this paper. This probably has happened through much of the deep ocean and explains why no material older than Cretaceous has been found in the deep ocean (Hamilton, 1956). Older material has been covered by basalt which spread laterally when the strength of the sediment was insufficient to support the basalt column. Thus there is no need to postulate that the present ocean basins have a recent origin.

REFERENCES

- Cox, A., and R. R. Doell, 1962, Magnetic properties of the basalt in hole EM7, Mohole project: *Jour. Geophys. Research*, v. 67, no. 10, p. 3997-4004.
- Creer, K. M., 1957, The remanent magnetization of the unstable Keuper marls: *Phil. Trans. Roy. Soc. London, Ser. A*, v. 250, p. 130-143.
- Hamilton, E. L., 1956, Sunken islands of the Mid-Pacific mountains: *Geol. Soc. America Mem.* 64, 95 p.
- Horton, E. E., 1961, Preliminary drilling phase of Mohole project. I. Summary of drilling operations (La Jolla and Guadalupe sites): *Am. Assoc. Petroleum Geologists Bull.*, v. 45, no. 11, p. 1789-1792.
- Keen, M. J., 1960, Magnetization of sediment cores from the eastern Atlantic Ocean: *Nature*, v. 187, no. 4733, p. 220-222.
- Kobayashi, K., 1962, Magnetization-blocking process by volume development of ferromagnetic fine particles: *Jour. Phys. Soc. Japan*, v. 17, Suppl. B-1, p. 695-698.
- Martini, E., and M. N. Bramlette, 1963, Calcareous nannoplankton from the experimental mohole drilling: *Jour. Paleontology*, v. 37, p. 102-105.
- Murata, K. J., and R. C. Erd, 1964, Composition of sediments from the experimental Mohole project (Guadalupe site): *Jour. Sed. Petrology*, v. 34, no. 3, p. 633-655.
- Nayudu, Y. R., 1962, A new hypothesis for origin of guyots and seamount terraces, in *Crust of the Pacific basin*: *Am. Geophys. Un., Geophys. Monogr.* 6, p. 171-180.
- , 1964, Palagonite tuffs (hyaloclastites) and the products of post-eruptive processes: *Bull. Vulcanologique*, t. 27, p. 391-410.
- , in press, Petrology of the palagonite breccia and sediments from the experimental Mohole: *Bull. Vulcanologique*.
- Raff, A. D., 1963, Magnetic anomaly over Mohole Drill Hole EM7: *Jour. Geophys. Research*, v. 68, no. 3, p. 955-956.
- Riedel, W. R., H. S. Ladd, J. J. Tracey, Jr., and M. N. Bramlette, 1961, Preliminary drilling phase of Mohole project. II. Summary of coring operations (Guadalupe site): *Am. Assoc. Petroleum Geologists Bull.*, v. 45, no. 11, p. 1793-1798.
- Rittenberg, S. C., K. O. Emery, J. Hulsemann, E. T. Degans, R. C. Fay, J. H. Reuter, J. R. Grady, S. H. Richardson, and E. C. Bray, 1963, Biogeochemistry of sediments in experimental Mohole: *Jour. Sed. Petrology*, v. 33, no. 1, p. 140-172.

ORIGIN OF SHALE-PEBBLE CONGLOMERATE¹

GORDON D. WILLIAMS²
Edmonton, Alberta

Pebble-size fragments of shale in a matrix of sandstone commonly are conspicuous in parts of the stratigraphic record. The shale fragments normally are more or less rounded, and in many localities exhibit features suggesting that they were plastic at the time of incorporation into the surrounding sandstone. Most fragments are disc-

shaped, lying parallel with bedding, and commonly exhibit internal laminations which may be bent or otherwise deformed, particularly at the margins of the fragment.

The term "clay galls" has been applied to these flattened, in some cases partly curled, rounded to angular fragments, flakes, and chips of shale (Pettijohn, 1957, p. 194); the conglomerate formed by their concentration in a sand or gravel matrix is known as shale-pebble conglomerate (Pettijohn, 1957, p. 277).

Dunbar and Rodgers (1957, p. 64) have men-

¹ Manuscript received, June 25, 1965.

² Department of Geology, University of Alberta. Financial assistance provided by the General Research Fund of the University of Alberta is gratefully acknowledged.