

depending on the amount of clay-size particles. Both K-feldspars and plagioclase occur in appreciable amounts in all samples. Carbonates or evaporite minerals are totally lacking. There is a large variety of diverse minor accessory minerals, including magnetite, hematite, apatite, zircon, epidote, and several unidentified opaque minerals. Goethite was found particularly enriched in Sample 133-5-1, 142 cm. In the sand fractions, feldspars and quartz grains are very fresh in appearance and poorly rounded.

The results are consistent with the postulate that the variegated beds were deposited on a flood plain. Influxes of clastic continental sediments were derived from a varied crystalline source. The absence of evaporite minerals negated the hypothesis of detrital gypsum suggested by shipboard scientists. Poor sorting excludes the possibility that the sediments represent aeolian loess.

Glass Beads

Of special interest is the occurrence of glass beads in Sample 13-5-1, 142 cm. They are light yellow to yellowish brown, transparent to translucent, and almost perfect spheres ranging from 60 μ to 200 μ . The surface of the balls is rough, thus suggesting shrinkage cracks. From 5 grams of initial sample, 15 individual balls could be isolated. Further analysis is under way to determine if the balls are volcanic, or extraterrestrial.

REFERENCE

- Hardie, L. A. and Eugster, H. P., 1971. The depositional environment of marine evaporites: a case for shallow, clastic accumulation. *Sedimentology*. 16, 187.

25.2. MINERALOGICAL COMPOSITION OF THE NILE CONE, MEDITERRANEAN RIDGE, AND STRABO TRENCH SANDSTONES AND CLAYS

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INTRODUCTION

It had been proposed that a former Nile subsea distributary system once extended far seaward of the present day Herodotus Abyssal Plain and that clastics of Nile origin might lie beneath surficial layers of pelagic sediment on the deformed Mediterranean Ridge (Hersey, 1965). To test the validity of this hypothesis,¹ selected samples of both coarse- and fine-grained sediments from Hole 130 on the ridge and Holes 131, 131A on the Nile Cone were analyzed for a comparative mineralogical study. Detrital layers from four piston cores (*Vema* 10-53, 10-54, 10-55, and 14-128) on the lower Nile Cone and one core (*Vema* 10-57) on the Herodotus Abyssal Plain were also investigated so as to be able to establish the mineralogical composition of contemporary sediments of known Nile origin. The northern limit of the suspected Nile sedimentary province was explored by additional sampling of interbedded clastics in cores from the Mediterranean Ridge (Piston Core RC9-178), Strabo Trench (Cores 1 and 2, Hole 129B), and the Hellenic Trough (Piston Core V10-64). The locations of the drill cores and piston cores are listed in

Table 1 and are plotted in the physiographic sketch of Figure 1.

The materials investigated consist of (1) loose sand-silt-clay layers inferred to be of probable turbidity current origin, (2) dark gray to black terrigenous muds, (3) carbonate rich pelagic oozes, and (4) consolidated siltstones and sandstones.

PROCEDURES

Coarse-grained Sediment

The loosely consolidated sands and silts were initially washed and sieved into several size fractions (i.e., 62, 88, 250 and 500 microns). The heavy minerals were subsequently separated from the light minerals in the >62 μ fraction by settling in bromoform, specific gravity 2.85. The heavy minerals were mounted in Hydrax on separate glass slides for petrographic analysis.

Selected pieces of sandstones and siltstones were thin sectioned and examined under the petrographic microscope. Parts of these rock slices were disaggregated in dilute hydrochloric acid to remove the calcareous cement and then separated out and concentrated. The mineralogical data, based on counting more than 300 grains, are reported in Tables 2 and 3.

¹Discussed in some detail in Chapter 11.

TABLE 1
Station Locations

Station	Latitude N	Longitude E	Water Depth (m)	Physiographic Province
V10-53	33° 11.3'	29° 06'	2897	Western Nile Cone
V10-54	32° 48'	29° 37'	2445	Western Nile Cone
V10-55	32° 46.3'	29° 23'	2520	Western Nile Cone
V10-57	33° 21.3'	28° 25'	3115	Herodotus Abyssal Plain
V10-64	34° 23.3;	24° 06.2'	2133	Hellenic Trough
V14-128	32° 27'	29° 45'	1931	Western Nile Cone
RC9-178	33° 46'	27° 54'	2622	Mediterranean Ridge
Site 129	34° 20.96'	27° 04.92'	3042	Strabo Trench
Site 130	33° 36.31'	27° 51.99'	2979	Mediterranean Ridge
Site 131	33° 06.39'	28° 30.69'	3035	Western Nile Cone

Fine-grained Sediment

The samples of terrigenous mud and pelagic oozes were treated with sodium acetate (pH 4.5) and then washed with distilled water and dispersed in an ultrasonic bath. Oriented slides of clay components, less than 2μ in size, were made by pipetting the dispersed slurries onto glass slides and then by air-drying at room temperature. All the clays were glycolated and only some samples from widely separated areas were acid- and heat-treated. The treated as well as untreated clay specimens were analyzed on a Siemen's X-ray diffractometer with a Geiger detector using nickel-filtered copper K_{α} radiation. The clay-mineral groups observed in the present study, namely, kaolinite, chlorite, montmorillonite and illite, were identified by their characteristic basal reflection maxima (or peaks). Small quantities of mixed-layer minerals and gibbsite were also occasionally observed. Material that expanded to 17 \AA (001) peak upon glycolation was assigned to the montmorillonite group. The illite group (Grim *et al.*, 1937) was identified by diffraction maxima at 10, 5, and 3.3 \AA not affected by glycol treatment. Diffraction maxima at 14 \AA (non-expanding) and 4.7 \AA were attributed to chlorite, and those at 7 \AA and 3.5 \AA to kaolinite and chlorite. The resolution of the latter peaks was done by the method described by Biscaye

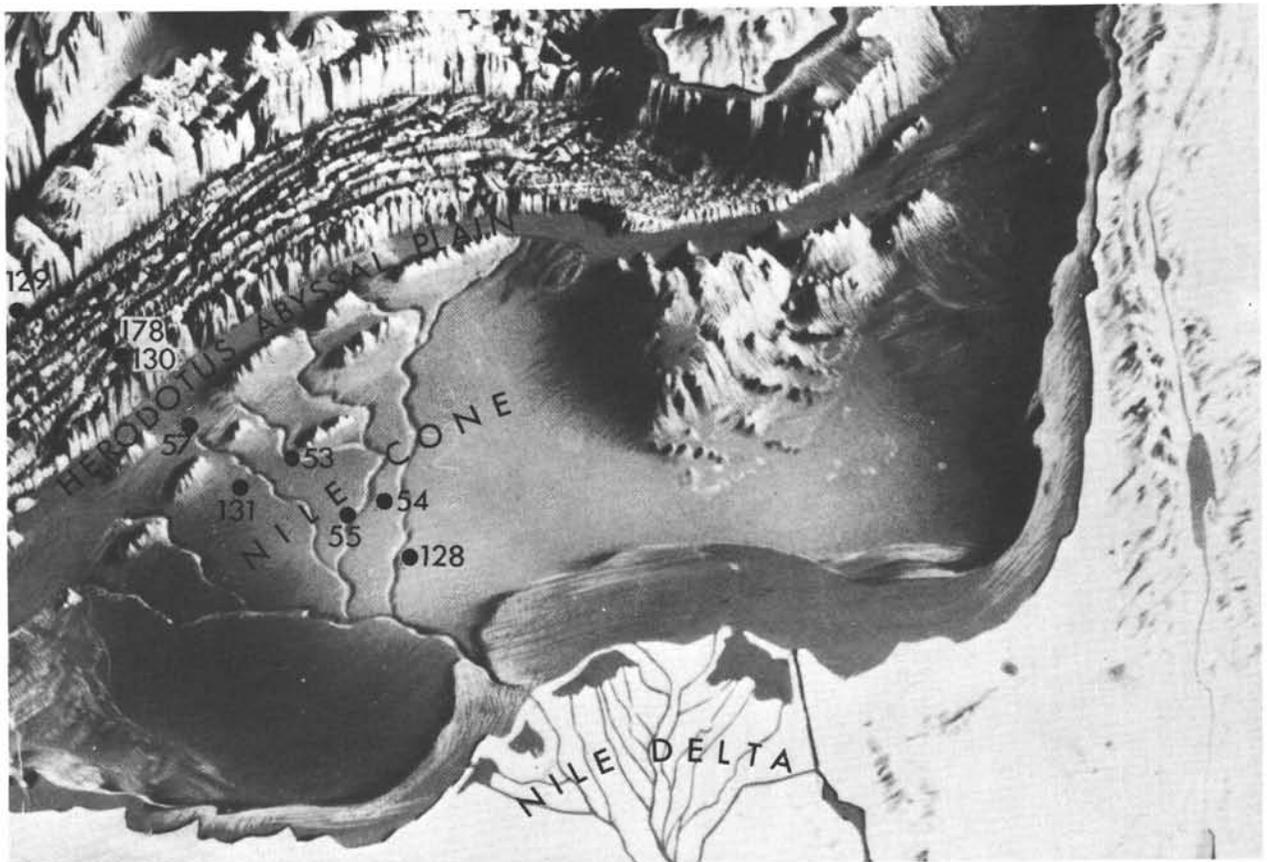


Figure 1. Location of the piston cores and drill holes on the western Nile Cone, Mediterranean Ridge and Strabo Trench.

TABLE 2
Heavy Mineral Abundances

Sample	Clinopyroxene	Hornblende	Epidote	Others	Median Size	Phi Quartile Deviation	General Remarks
V10-53 600 cm	31.0%	60.0%	8.0%	1.0%			
V10-53 208 cm	35.3%	54.7%	6.5%	3.6%			
V10-53 320 cm	39.0%	47.0%	13.0%	1.0%			
V10-54 880 cm	7.0%	90.0%	3.0%	—			
V10-55 285 cm	17.2%	78.5%	3.5%	0.9%			
V10-57 520 cm	32.9%	63.6%	3.5%	—			
V10-57 672 cm	33.1%	55.9%	5.5%	5.5%			Some olivine present.
130-4-2 36-38 cm	5.0%	76.0%	19.0%	—	2.15 ϕ	1.20 ϕ	Abundant pyrite.
130-4-2 117-118 cm	3.6%	73.0%	20.0%	3.0%	1.95 ϕ	1.05 ϕ	Fine-grained yellowish brown pyrite opaque, lots of CaCO ₃ .
130-4-2 119-120 cm	2.0%	61.4%	30.5%	6.0%			
130-7, CC Sandstone	17.0%	67.0%	12.0%	4.0%	3.15 ϕ	0.38 ϕ	Grain size measurements made after treatment with HCl.
131-1-6 40-41 cm	40.0%	37.3%	11.4%	11.4%	1.65 ϕ	0.32 ϕ	Some zircon, garnet, freshly broken clinopyroxene.
131A-1-2 68-69 cm	29.4%	57.7%	9.4%	3.5%	2.30 ϕ	0.83 ϕ	Considerable amounts of zircon, sphene and clinopyroxene.
131A-3, CC Sandstone	20.0%	59.0%	15.0%	6.0%	2.70 ϕ	0.30 ϕ	Includes also zircon.
131A-4-1 146-147 cm	32.0%	41.2%	16.6%	9.0%	1.40 ϕ	0.90 ϕ	Includes zircon, garnet; lots of freshly broken clinopyroxene.

TABLE 3
Mineralogy and Texture of the Sandstones

Sample	Quartz	Feldspar	Calcite	Rock Fragments	Matrix (cement)	General Remarks and Classification
131A-3, CC	47.0%	0.6%	—	8.0%	44.4%	Current bedding laminations present with small mud balls in an otherwise homogeneous calcite cemented sandstone. Quartz wacke
130-7, CC 1	42.0%	2.0%	0.4%	—	55.6%	Massive texture, no mud balls. Quartz wacke
130-7, CC 2	41.5%	0.4%	—	4.4%	53.6%	Massive texture, one mud ball present. Matrix mainly calcareous. Quartz wacke
129B-1, CC	76.5%	—	—	8.5%	15.0%	Laminations present with very small mud balls cement is mainly non-calcareous, probably argillaceous. Quartz arenite to Quartz wacke
129B-2, CC	12.0%	2.0%	4.2%	20.8%	61.0%	Non-laminated. Rock fragments include: chert, quartzite, volcanics, some claystone. Heavy minerals: green hornblende and epidote. Cement mostly calcareous. Lithic sandstone
V10-64	8.5%	4.0%	5.5%	22.0%	60.0%	Crossbedded and fractured with calcite filled veins. Fine-grained lithic rock fragments including volcanics (andesite) and metamorphics. Lithic sandstone

(1964), and the mineral identification was verified by acid and heat treatments. The samples with high amounts of chlorite of clay size also have high amounts of this mineral (identified microscopically) in the heavy minerals of silt size.

A semiquantitative technique (Biscaye, 1965) was used, and the weighted percentages of the different clay minerals were calculated from peak areas. The peaks and the weighting factors used are: 17 \AA glycolated peak area for

montmorillonite; 4 times the 10 \AA (glycolated) for illite; and 2 times the 7 \AA peak area (glycolated) for kaolinite and chlorite divided in proportion to the relative areas of their 002 (3.58 \AA) and 004 (3.54 \AA) peaks (Biscaye, 1964) respectively. The process of measurement of the peak areas was carried by numerical integration using Simpson's method from digitized tracings of the original diffractograms with a pencil following table-top digitizer. The calculation of the weighted percentages was performed

from the digitized input data by computer, and is listed in Table 4.

Carbonate Content and Grain Size Analyses

Additional samples from Holes 130, 131 and 131A were analyzed at the Scripps Institution of Oceanography to determine the amount of acid-soluble and insoluble carbon. The procedure is standard for DSDP samples and is discussed by Boyce and Bode (1972). The results are reported in Table 5 in terms of "calcium carbonate" (acid soluble) content and "organic" (acid insoluble) carbon. The grain size distribution was determined by sieving and pipette analysis of another set of samples from the same drill holes. The granulometric data are listed on the core summaries in this volume, in terms of percentages of the sand, silt, and clay fractions (i.e. -1.0 to 4.0 phi=sand; 4.0 to 8.0 phi=silt; finer than 8.0 phi=clay).

HEAVY MINERAL RESULTS

Nile Cone Sands

The heavy mineral determinations of sand layers in the piston cores from the western Nile Cone contain a considerable amount of clinopyroxene (augite and diopside) (mean=28.0%, σ =9%), green hornblende (mean=58.5%, σ =12.3%) and epidote (mean=6%, σ =2.6%) which are clearly characteristic of detrital materials derived from the Nile distributary system (Shukri, 1950 and 1951; Emel'yanov, 1968; Chumakov, 1967). The Site 131 sands recovered from the same region of the Nile Cone (Figure 1) are directly comparable in their clinopyroxene (mean=30.5%, σ =5.8%) and hornblende (mean=48.4%, σ =9.5%) contents, and have slightly greater amounts of epidote (mean=13.1%, σ =2.7%). The higher epidote content in the Site 131 samples may reflect a slightly different mineral supply in the past since the drill core samples are of an appreciably older Pleistocene age than the surface piston cores. An increase in epidote from 8 per cent (σ =2%) in youngest Nile River valley deposits (Q₄ formation of

TABLE 4
Clay Mineralogy

Quantitative Clay Mineral Measurements	Pelagic Oozes		Terrigenous Muds				
	130-4-2, 93-94 cm	131A-4-1, 114-115 cm	130-4-2, 101-102 cm	131A-4-1, 121-123 cm	RC9-178, 670 cm	V10-57, 355 cm	V14-128, 500 cm
Weighted Peak Area Percentage Montmorillonite	38	64	78	85	58	57	52
Weighted Peak Area Percentage Illite	37	17	6	5	15	14	28
Weighted Peak Area Percentage Kaolinite	20	15	16	9	26	26	16
Weighted Peak Area Percentage Chlorite	4	2	0	0	0	1	3
Ratio Kaolinite/Illite	1.11	1.69	2.60	3.29	1.73	3.64	1.62
Ratio Kaolinite/Montmorillonite	0.27	0.12	0.05	0.05	0.11	0.23	0.16
v/p Ratio for Montmorillonite	0.38	0.52	0.68	0.74	0.65	0.34	0.51

TABLE 5
Carbon and Carbonate Contents

Core Section Interval	Percentage of Total Carbon	Percentage of Organic Carbon	Percentage Calcium Carbonate	Sediment Type
Hole 130				
1-1, 112 cm	6.1	0.7	44.8	Sapropel
1-1, 140 cm	4.7	0.3	36.5	Pelagic
1-1, 140 cm	9.0	0.1	73.5	Pelagic
1-2, 80 cm	1.2	1.0	1.9	Terrigenous
1-2, 105 cm	9.7	3.0	55.5	Sapropel
1-3, 30 cm	6.3	0.2	50.3	Pelagic
1-3, 90 cm	3.3	0.3	24.7	Drilling mixture of pelagic and terrigenous
1-4, 35 cm	1.3	1.0	2.4	Terrigenous
1-4, 95 cm	5.8	0.9	44.2	Pelagic
1-4, 132 cm	8.1	0.1	66.1	Pelagic
2-1, 105 cm	1.5	1.2	2.7	Terrigenous
2-2, 46 cm	4.7	0.4	36.3	Pelagic
2-2, 79 cm	1.0	0.5	4.2	Terrigenous
2-3, 50 cm	1.6	0.8	6.8	Terrigenous
2-3, 74 cm	23.5	23.4	0.8	Sapropel
2-3, 80 cm	7.8	0.2	63.5	Pelagic
3-1, 120 cm	1.2	1.1	1.4	Terrigenous
3-1, 127 cm	7.7	0.8	57.4	Pelagic
3-2, 80 cm	1.8	1.2	4.7	Terrigenous
3-2, 90 cm	9.0	0.4	71.9	Pelagic
3-2, 104 cm	8.7	0.6	67.3	Pelagic
4-1, 130 cm	6.3	0.2	51.3	Pelagic
4-2, 95 cm	7.4	0.2	60.2	Pelagic
4-2, 105 cm	1.4	0.9	3.8	Terrigenous
4-2, 122 cm	8.1	0.2	66.1	Pelagic
5-2, 90 cm	1.4	0.9	4.3	Terrigenous
5-3, 60 cm	1.5	0.8	6.1	Terrigenous
6-1, 100 cm	3.6	0.6	25.1	Terrigenous
6-2, 95 cm	8.3	0.2	67.5	Pelagic
6-3, 40 cm	9.0	0.6	70.7	Pelagic
6-4, 45 cm	9.0	0.6	70.0	Pelagic
6-5, 30 cm	9.4	0.5	74.0	Pelagic
Hole 130A				
1-1, 94 cm	5.8	0.1	46.8	Pelagic
1-1, 137 cm	7.0	0.2	56.5	Pelagic
Hole 131				
1-1, 71 cm	0.3	0.1	1.6	Terrigenous
1-2, 130 cm	0.1	0.0	0.3	Terrigenous
1-3, 130 cm	1.3	0.8	4.6	Terrigenous
1-3, 50 cm	0.2	0.1	0.9	Terrigenous
1-4, 70 cm	0.2	0.1	1.1	Terrigenous
1-5, 20 cm	0.4	0.2	1.7	Terrigenous
1-5, 35 cm	0.2	0.1	0.5	Terrigenous

TABLE 5 – Continued

Core Section Interval	Percentage of Total Carbon	Percentage of Organic Carbon	Percentage Calcium Carbonate	Sediment Type
Hole 131A				
1-1, 110 cm	7.4	0.2	60.0	Pelagic
1-1, 130 cm	3.7	0.5	27.4	Pelagic
1-2, 15 cm	7.5	0.2	60.7	Pelagic
1-2, 90 cm	0.9	0.6	2.7	Terrigenous
3-1, 135 cm	1.8	1.2	5.3	Terrigenous
4-1, 95 cm	1.4	0.8	5.1	Terrigenous
4-1, 112 cm	8.7	0.1	71.5	Pelagic
4-2, 22 cm	1.5	0.9	4.6	Terrigenous
4-2, 136 cm	0.5	0.3	2.0	Terrigenous
4-3, 120 cm	0.7	0.5	2.0	Terrigenous
5-1, 134 cm	2.3	1.4	7.1	Terrigenous
5-2, 2 cm	1.8	1.2	4.5	Terrigenous

Chumakov, 1967) to 14.6 per cent ($\sigma=3.6\%$) in older strata of the Q₂ formation has been established, though its significance has not yet been discussed. In fact, we can see the time relationship best in the individual Hole 131A samples with 9.4 per cent epidote at 49 meters below bottom, 15.0 per cent at 140 meters, and 16.6 per cent in Core 4 at 207 meters. Zircon and garnet (mostly almandine) are two other minerals (ultrastable group) present in minor amounts in Site 131 sand layers which are also typically present in fluvial sediments and alluvium of the Nile River valley. They seldom reach more than a couple per cent each in relative abundance. Magnetite and other opaque minerals make up about one-third of the heavy mineral fraction.

Mineralogical Comparison of the Mediterranean Ridge Sands

The selected samples from Hole 130, on the Mediterranean Ridge some 35 km seaward of the northern edge of the present day Herodotus Abyssal Plain, are also dominated in the heavy mineral fraction by hornblende, epidote and clinopyroxene, though the relative percentages show some significant differences. For instance, the sand horizons in Core 4 average only around 3.5 per cent clinopyroxene as compared to 28 per cent for the Nile Cone piston cores, but they have relatively high contents of epidote, averaging 23 per cent. As mentioned previously, an increase in epidote has been noted by Chumakov (1967) in older Pleistocene deposits of the Nile Valley. It is also interesting that these same deposits have a clinopyroxene content as low as 5.5 per cent in the Q₂ formation and even 1.3 per cent in the still older Q₁ formation. Since Core 4 belongs to the *Pseudoemiliania lacunosa* nannofossil zone of the lower part of the pre-glacial Quaternary, we believe that its mineralogical content, even though not quite the same as that of surface piston cores of the Nile Cone, is still entirely compatible with Nile-derived sediments of equivalent early Quaternary age as established in boreholes of the river valley proper. The decrease in the amount of clinopyroxene could be partly due to the change in grain size. However,

we believe that the decrease, as is also true on land in the older Pleistocene deposits (Chumakov, 1962; Butzer and Hansen, 1968), is mainly the result of different inputs by the various tributaries of the Nile River in the early Pleistocene as compared with the subsequent period. Butzer and Hansen (1968) inferred that the Atbara River and, less probably, the Blue Nile, which drain the volcanic rocks of the Ethiopian plateau and thus supply large amounts of clinopyroxene, may have debouched into the Red Sea rather than the Mediterranean prior to Late Pleistocene.

In the light mineral fraction, all the samples are dominated by quartz, generally sub-rounded to rounded and characteristically pitted on its surface (Figure 2). One sample in particular from Core 1 of Hole 131 was comprised of extremely well-rounded grains which indicate the effect of eolian process (Butzer and Hansen, 1968). The frosted texture of the rounded grains, when examined under the scanning electron microscope, is seen to be the result of tiny pits. This pitting may be the result of abrasion by fines in the desert of North Africa as well as chemical etching (i.e., desert dew of Kuenen and Perdok, 1962). The larger indentations, which have a well-defined triangular shape (Figure 3), have been interpreted as percussion marks from high-energy grain impacts in a beach environment (Krinsley and Donahue, 1968).

Potassium feldspars are also present, but form an insignificant part of the bulk sediment composition in this eastern Mediterranean province. The feldspars are mainly plagioclase.

CLAY MINERAL RESULTS

Only two lithologies were sampled for the less than 2 micron clay mineral analyses. They include the buff-colored calcareous-rich pelagic oozes and the dark gray to black terrigenous clays. The purpose of the investigation was to see whether the mineralogy of the terrigenous clays could be distinguished from the pelagic oozes and if the Mediterranean Ridge clays were of similar composition to clays of known origin in the surface layers of the present Nile Cone. To facilitate the comparisons, the diffractograms of seven samples investigated are shown in Figures 4 and 5.

The terrigenous clays, as typified by Samples 130-4-2, 101-102 cm from the Mediterranean Ridge and 131A-4-1, 121-123 cm from the Nile Cone, are strongly dominated by montmorillonite (78 and 85 weighted peak area percentage, respectively). This particular montmorillonite (smectite group) is of a generally high "crystallinity" with a v/p ratio of 0.68 and 0.74. The dark terrigenous clays are also conspicuously low in illite, as seen by the very small 10Å peak, and have little or no recognizable chlorite in the 3.4Å range, as shown on the expanded scan on the diffractograms to the right of each trace.

In contrast, the calcareous pelagic oozes at both sites are characterized by considerably greater amounts of both illite and chlorite. In terms of the weighted peak area percentages of the kaolinite, both lithologies would be comparable; however, one can see in Figure 4 that the 3.58 Å peak of the terrigenous clays is invariably higher and better developed than that of the pelagic oozes. This observation probably reflects a greater total abundance of kaolinite in the clays of the Nile River origin (Elgabaly and Khadar, 1962), which however, end up diluted and thus masked by

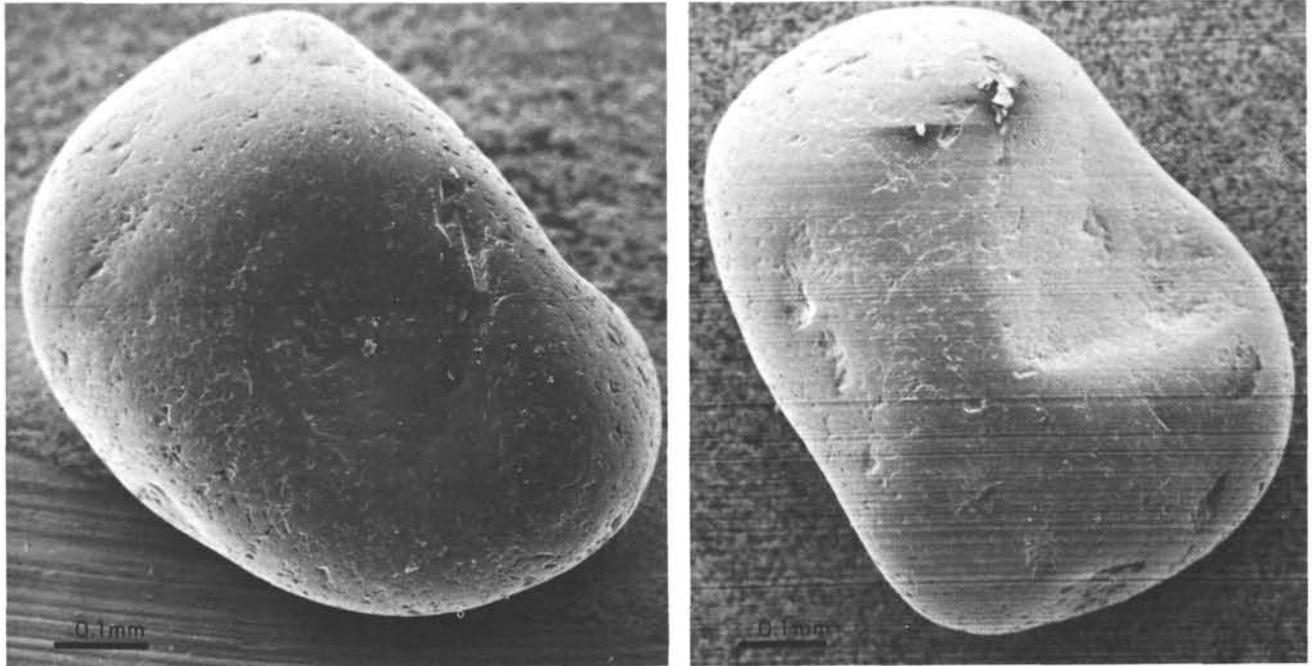


Figure 2. Well-rounded quartz grains from Site 131, Core 1 CC.

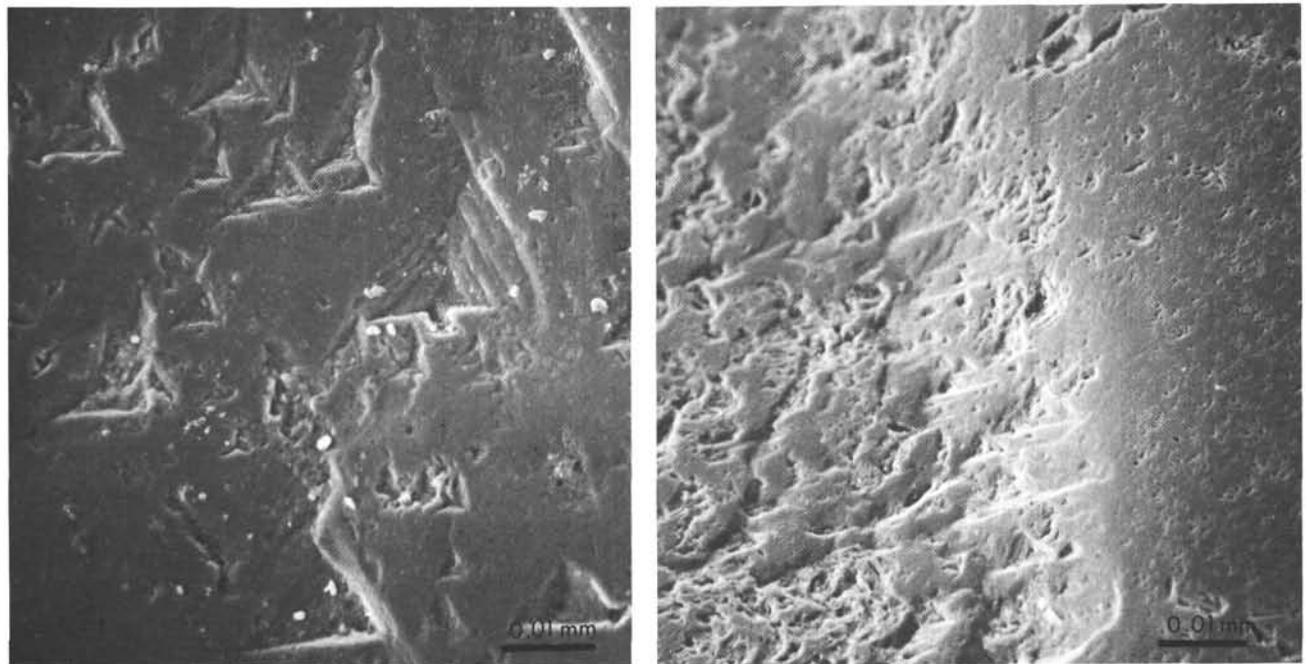


Figure 3. Enlargements of surface textures of the quartz grains illustrated in Figure 2. According to Kuenen and Perdok (1962), the fine-scale pitting seen to the right is believed to be partly formed from solution in desert environments as well as the mechanical action which produces the grain rounding. The large triangular indentations, however, are considered by Krinsley and Donahue (1968) to be diagnostic for littoral or beach environments. Perhaps these sand grains reflect a combination of high energy abrasion processes in coastal dunes on formerly exposed parts of the submarine Nile Delta.

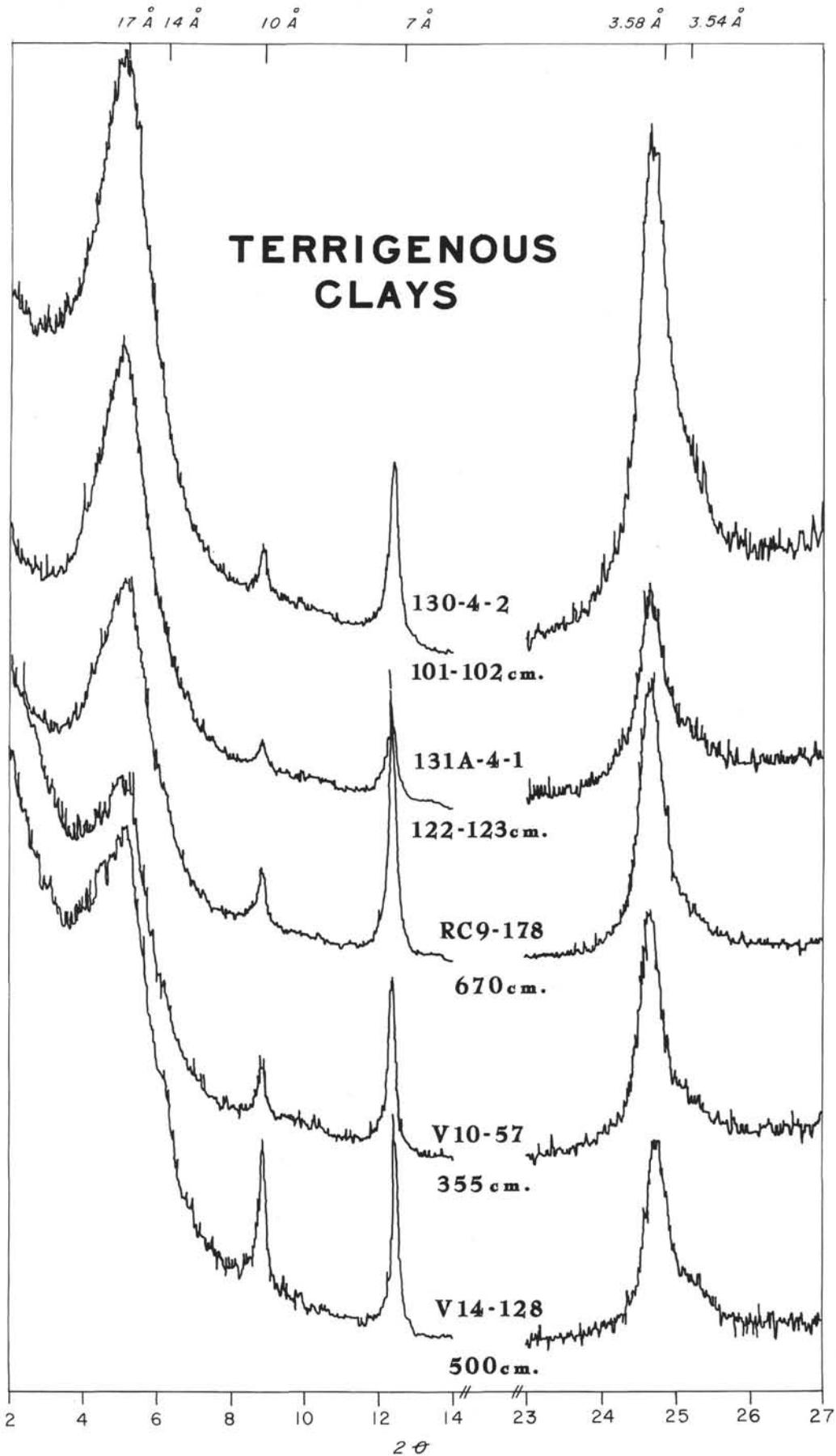


Figure 4. X-ray diffractograms of five samples of terrigenous clay from the Mediterranean Ridge, Nile Cone and Herodotus Abyssal Plain.

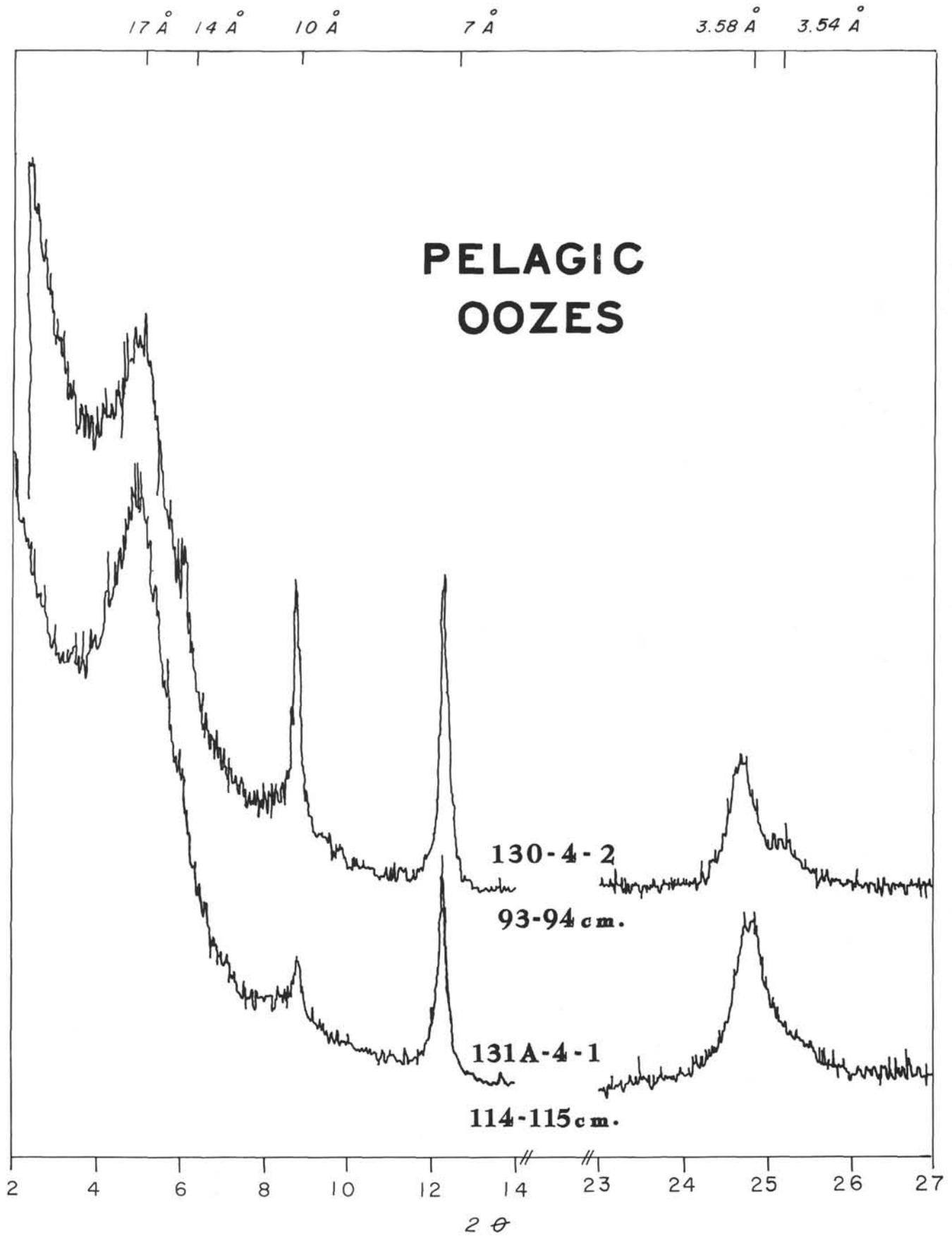


Figure 5. X-ray diffractograms of two samples of pelagic ooze from the Mediterranean Ridge and Nile Cone.

the vast excess of montmorillonite coming from further up stream.

Not only can the Site 130 terrigenous clay samples from the ridge be compared to the Nile Cone samples at Site 131, but in the same context the RC 9-178 sample also from the ridge is itself identical to the V10-57 sample on the Herodotus Abyssal Plain.

In contrasting the ooze with the clay, however, one does note that the pelagic ooze sample from Site 131 is somewhat affected by the proximity of the terrigenous clay source as revealed by its greater abundance of montmorillonite. The higher content of montmorillonite is repeated in the distribution patterns of the surface sediments of the eastern Mediterranean basins, where uppermost pelagic oozes in piston cores seaward of the Nile Delta characteristically display an appreciable abundance of montmorillonite (Figure 6).

Another criterion to distinguish the terrigenous clay is the ratio of kaolinite/illite (Figure 7). In fact, by this criterion alone it is possible to conclude in terms of fine-grained mineral components that the terrigenous clays found in the Nile Cone, Herodotus Abyssal Plain and subsurface Mediterranean Ridge are all from a common and unique mineral province. From the distribution pattern of both Figures 6 and 7, we can further conclude that these clays are most likely derived from the Nile River. As discussed by Emery and Neev (1960), Emery and George (1963), and Venkatarathnam and Ryan (1971), the dispersal along the coast of Israel and Lebanon of this "Nile Assemblage" simply reflects the strong counterclockwise gyre of the surface water masses of the Levantine basin, and that upon discharge from the delta to the sea the clays are carried for some distance in this water mass.

COMPARISON OF LITHOLOGIES AND TEXTURES

The terrigenous sediments recovered from the Mediterranean Ridge at Site 130 and from the Nile Cone at Site 131 can also be compared on the basis of their gross lithologies, carbonate content, and sedimentary textures. The cores from both sites are dominated by fine-grained sequences of dark gray to black clays of extremely low carbonate content averaging only 3.3 per cent for some 25 samples investigated (see Table 5). The clays are sometimes accompanied by thin laminae of silt and/or sand at sharp basal contacts of individual bedded sequences and are burrowed, if at all, only at the topmost portion of a bed.

As illustrated in Figure 8, the terrigenous clay layers occur in rhythmic sequences intercalated in a light buff-colored carbonate-rich pelagic foraminifera and nannofossil ooze of Quaternary age. The lower contacts of the ooze layers and the top of a subjacent clay layer are occasionally gradational as a consequence of burrow mottling (Figure 9). The homogeneous nature of most terrigenous clay intervals and their sparseness in marine fauna suggest a relatively rapid emplacement, consistent with the deduced gross rate of accumulation of 55 cm/10³y at Site 130 (see Chapter 11).

Evidence of resedimented materials is apparent with disturbed structures in the sandstones and intraformational breccias in the pelagic oozes (Figure 10). In Core 130-1-1

from the Mediterranean Ridge the illustrated breccia deposit contains plastic fragments of both dark-gray, low-carbonate terrigenous mud and light-buff pelagic ooze in a gray matrix of mixed components. The basal contact of the breccia has been disturbed by the coring process, but still retains its original sharp appearance above subjacent pelagic ooze. In Core 131-1-6 from the western Nile Cone, the resedimentation has involved partly imbricated terrigenous mud pebbles interbedded in a thick layer of graded quartz-rich sand. The mud pebbles are rounded and were probably derived locally from the paleo-surface of the cone or from the walls of submarine channels in the vicinity of the drill site. Similar sedimentary structures have been retrieved from a small distributary channel of the outermost part of the La Jolla fan valley off southern California (Von Rad, 1968). Quite similar mud intraclasts are common in the stable quartzose sandstone beds of the Numidian Flysch (late oligocene to early Miocene) in Tunisia and Sicily (Wezel, 1970).

Mud pebbles of a considerably smaller dimension ("chips" 1 to 2 mm in diameter) are also found along bedding laminae in graded sand layers of both drill sites. The mud is of a similar lithology to the previously discussed terrigenous clays and is most certainly reworked as is the case of the larger mud balls. In addition, the same fine-grained mud accompanied by calcareous material constitutes the grain matrix of the indurated sandstones.

Texture of the Sandstones

These sandstones, shown in reverse prints of thin sections in Figure 11, are massive in texture, occasionally with intervals of parallel laminations. It is in the latter intervals that the micro mud balls and chips are most prevalent. The sandstones are dominated by sub-angular to rounded quartz (up to 47% bulk) and minor amounts of rock fragments of crystalline origin.

X-ray diffraction (see Chapter 24.2) shows that the interstitial cement is low-magnesium calcite, and the tests of foraminifera are often partially or completely filled with sparry calcite. However, the amount of calcite as a detrital component is extremely low. As indicated in Table 3, the sandstones of Sites 130 and 131 are classified as stable quartz sandstones with matrix (composition near Q₈₅₋₉₀ F₁ L₁₄₋₉).

Quartz-rich sandstone was also found in Hole 129B (Sample 1 CC) in the Strabo Trench at the northern boundary of the Mediterranean Ridge. This sandstone was recovered floating in loose sand of similar mineralogy accompanied by foraminiferal tests indicative of a Quaternary age. Although the 129B-1 CC sandstone illustrated in Figure 12 also contains concentrations of mud along laminae, the total interstitial matrix (upper visual limit ≈ 20 microns) is considerably lower (15%) than the Nile Cone sandstones (44%) and is mainly noncalcareous. Nevertheless, there is enough overall similarity in the bulk composition and texture to suggest that the Site 129, 130, and 131 sandstones shared a similar quartz source, which we deduce to be from the south off Africa rather than from the orogenic metamorphic terrains of southern Turkey or Greece.

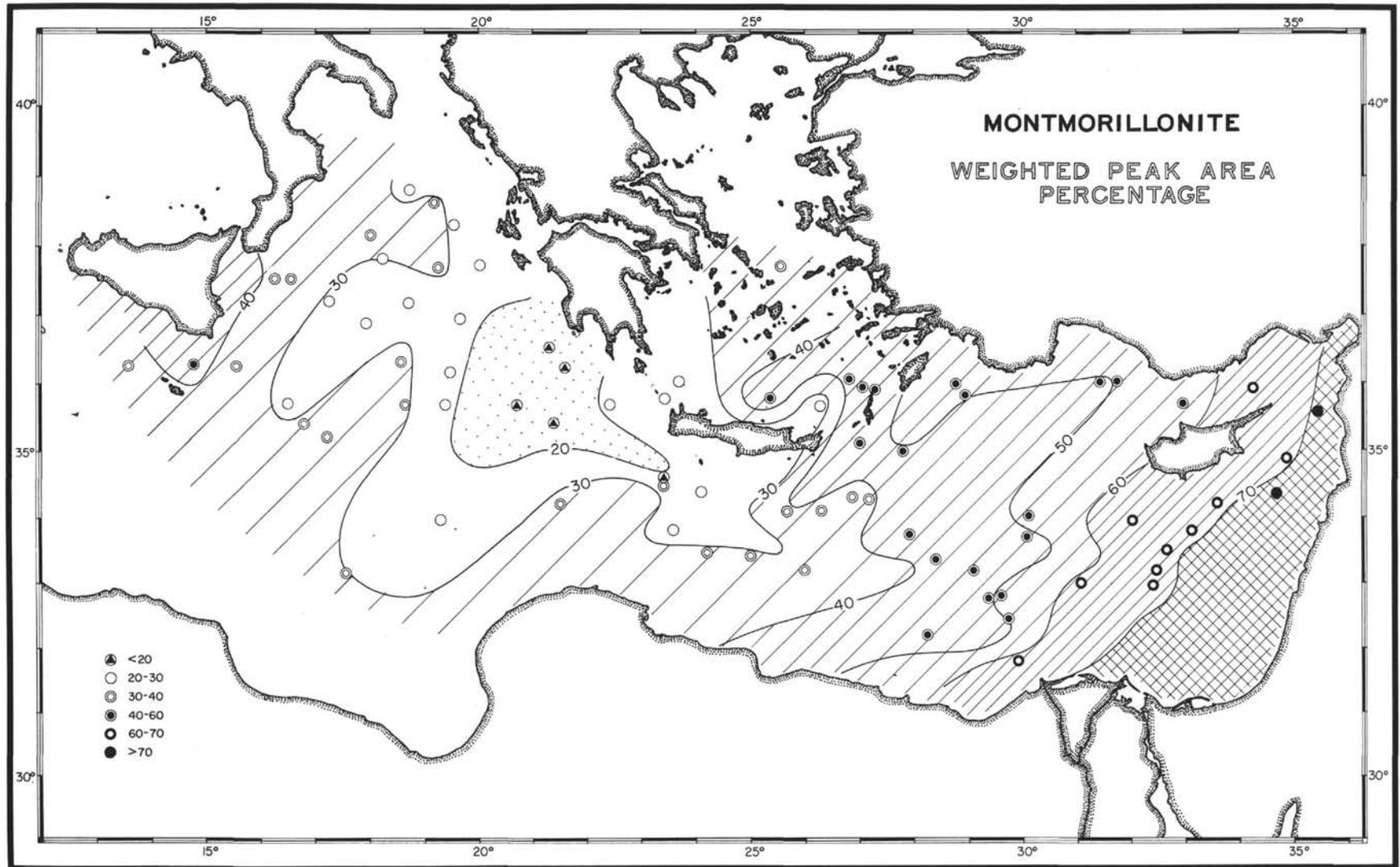


Figure 6. Distribution of montmorillonite in surface samples of pelagic sedimentation in the eastern Mediterranean (from Venkatarathnam and Ryan, 1971).

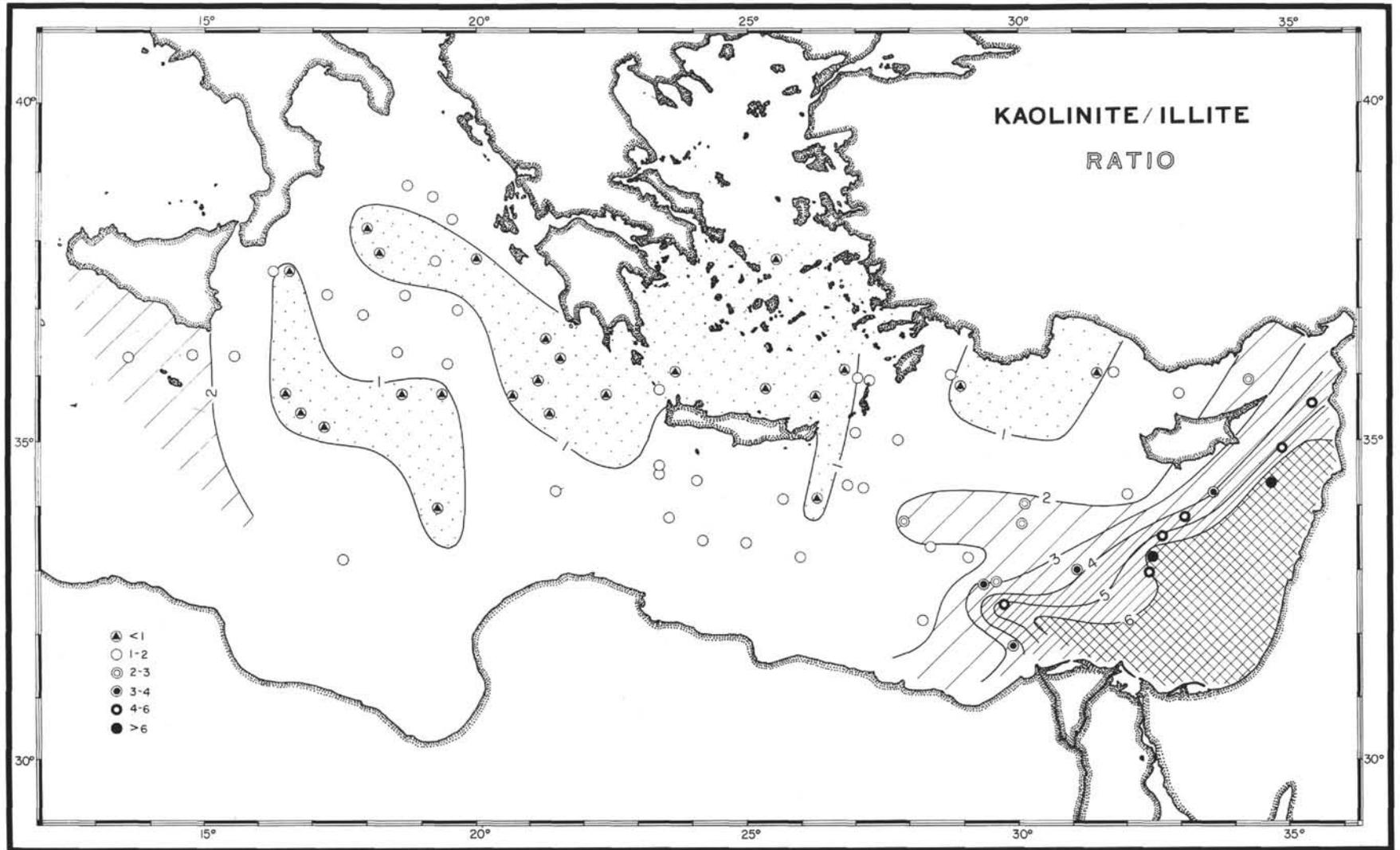


Figure 7. Kaolinite/illite ratio in surface samples of pelagic sedimentation. The distribution of high values along the coast of Israel and Lebanon reflects dispersal of kaolinite-rich Nile sediments into the surface water mass and subsequent transport in the established counterclockwise circulation gyre.

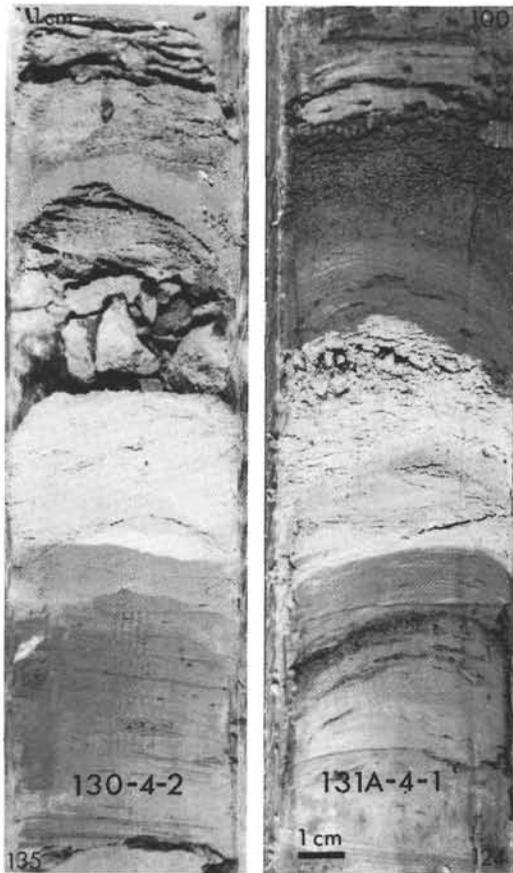


Figure 8. Examples of interbedded buff-colored pelagic oozes (light) in gray to black terrigenous clay with occasional beds of sand and silt. Hole 130 is on the Mediterranean Ridge and 131A on the Western Nile Cone.

For comparison to other sedimentary units of established North African origin we offer as an example the Upper Oligocene-Lower Miocene Numidian Flysch of Sicily. In Table 6 we have listed several properties of the sand (coarse clastic) facies from the Nile Cone drill sites and piston cores and sandstone outcrops of Sicily interpreted by Wezel (1970) to represent former continental margin sedimentation. Additional comparisons of the fine-grained facies are offered in Table 7.

Indications of a Northern Provenance

There is, nevertheless, documentation in samples of sandstone from Hole 129B (2 CC and 3 CC) in the Strabo Trench of a metamorphic and volcanic provenance not in itself attributable to North Africa. This rock, illustrated in Figure 13, contains only 12 per cent quartz (about one-third of the quartz is a polycrystalline-recrystallized and stretched metamorphic type with strong undulatory extinction) and is dominated by lithic rock fragments including andesitic volcanics, metamorphic fragments, chert, mudstone, and broken tests of calcareous foraminifera. Classified as a lithic sandstone (Q_{34.3} F_{5.6} L_{60.0}), the 2 CC sample more directly compares with the Hellenic Trench sand layers of Sites 127 and 128 than with the Nile-derived quartz wackes (Table 8). The age of the

129B-2 CC lithic sandstone is not known. It is difficult to imagine how current bedded clastics of this grain size could get to the Strabo Trench from the north, east or west across the present topographic barrier of the Strabo and Anaximander Mountains. A possible clue is offered from fragments of finer-grained lithic sandstones (Q_{24.6} F_{11.6} L_{63.8}) similar mineralogic composition in piston core V10-64 within the Hellenic Trough directly south of Crete. This second sample, also illustrated in Figure 13, was embedded in an interformational breccia with other indurated fossiliferous sediments of Middle Miocene (Langhian) age. The V10-64 sandstones are cross-bedded and heavily fractured. Veins are filled with a sparry calcite cement. If the lithic sandstones themselves date from this older period, they perhaps then had a northern source from the formerly orogenically active internal zone of the southern Hellenides and Taurids (Brunn, 1960; Aubouin, 1965). Their distribution seaward of bathymetric depressions and barriers suggests a younger or synchronous tectonism for the Strabo-Anaximander mountains complex, leading to a development of the present day island arc structure along the northern border of the eastern Mediterranean basins (Woodside and Bowin, 1970; Smith, 1971).

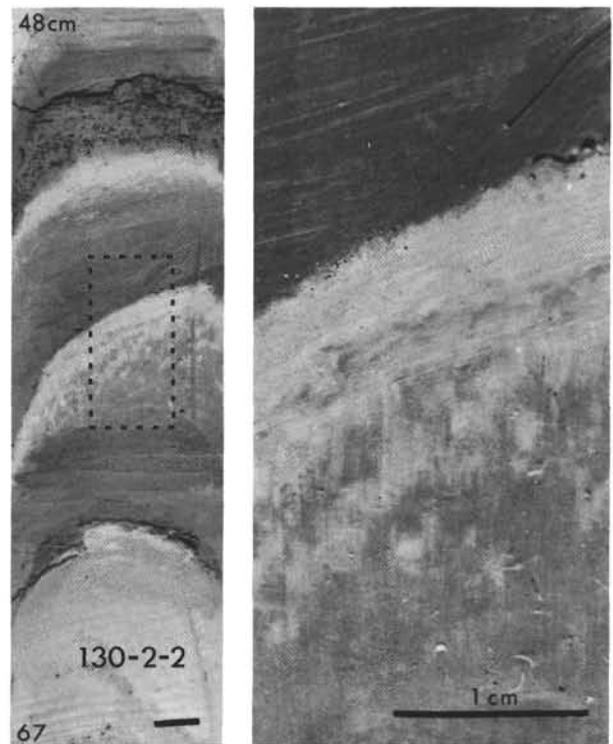


Figure 9. Example of burrow mottling in the light-colored pelagic oozes. The enlargement shows that the burrowing takes place while the light ooze is being deposited and involves both an upward mixing of terrigenous clay into the ooze as well as a downward mixing of the ooze exclusively into the subjacent clay. This deposit then becomes rapidly blanketed by another terrigenous clay interval. Note the presence of silt and sand in the basal portion of some of the dark terrigenous layers.

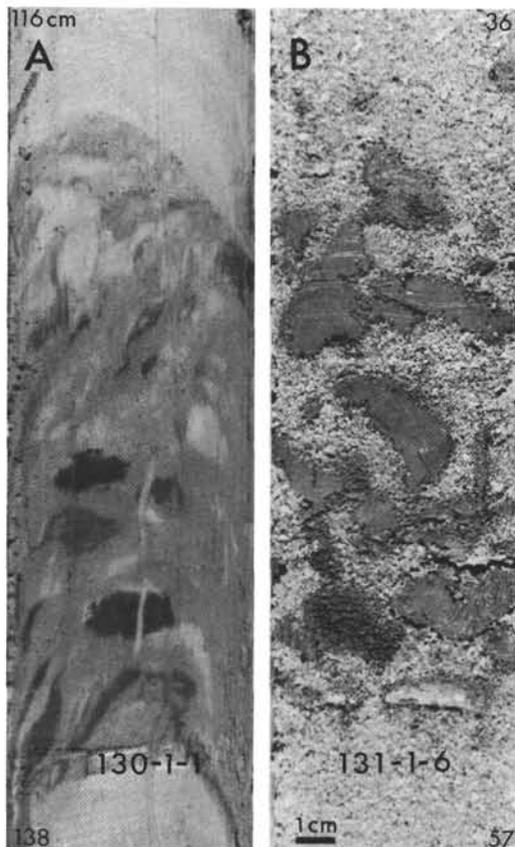


Figure 10. Example of redeposited sediment incorporated within (A) interformational breccias of mixed terrigenous mud-pelagic oozes on the Mediterranean Ridge (130) and (B) mud intraclasts in grainflow deposits on the Nile Cone (131). A burrow track (left center) through several of the lumps of ooze and mud demonstrates that this sedimentary structure was not created during the drilling and coring process.

CONCLUSIONS

The mineralogic investigations of the Nile Cone, Herodotus Abyssal Plain, and subsurface Mediterranean Ridge detrital sands and terrigenous clays indicate a common sedimentary provenance. From a comparison with present day patterns of sediment transport and dispersal, it is possible to conclude that the input of this sediment into the sea was by way of the Nile Delta. The lack of sands and low-carbonate terrigenous clays in present day surface samples from the Mediterranean Ridge indicates that both the fine- and coarse-grained sediment fraction is transported to the abyssal plain predominantly by gravity-propelled bottom flows (i.e., turbidity current and grainflow mechanisms). The discovery of great thicknesses of terrigenous sediment in the subsurface of the Mediterranean Ridge supports the hypothesis put forward by Hersey (1965) that the ridge is an uplifted and deformed wedge of former basinal sediments of predominant Nile origin. The findings of andesitic and metamorphic rock fragments in lithic graywacke sandstones from the Strabo Trench and Hellenic

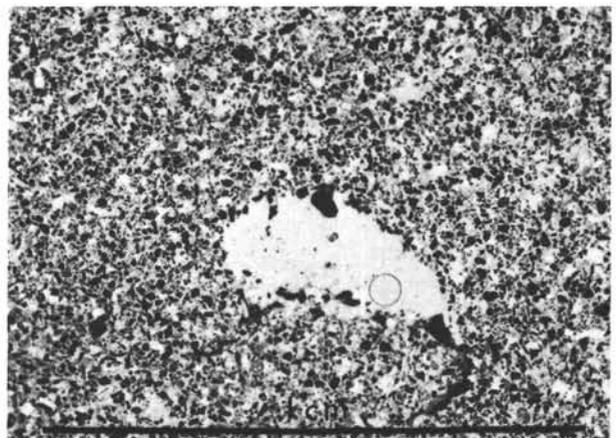
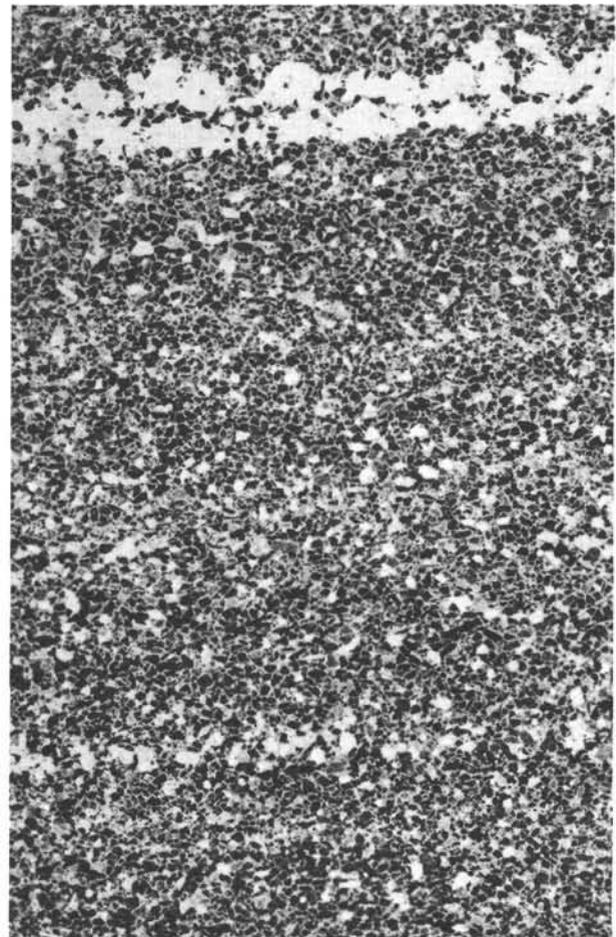


Figure 11. Reversal (negative) prints of thin sections of stable quartz sandstones with matrix from the Nile Cone (131A, 3 CC, top) and Mediterranean Ridge (130, 7 CC, bottom). Note the presence of small mud balls (pebbles) (light) imbricated along bedding laminae, and the occurrence of individual grains of quartz (generally dark) embedded in some of the mud fragments. Fine-grained clay matrix makes up some 55 per cent of the lower slide.

Trough indicates yet another distinct sedimentary provenance, probably associated with an island arc-trench complex (Mitchell and Reading, 1969; Wezel and Ryan, 1971).

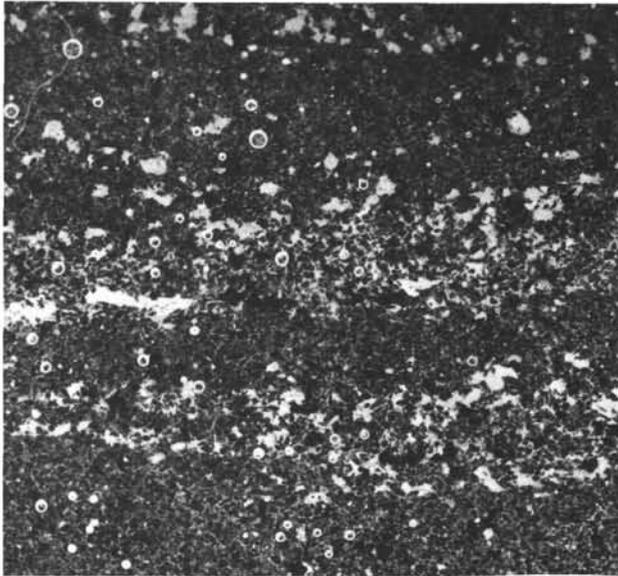


Figure 12. Reversal print of a slightly finer-grained sandstone (Sample 129B, 1 CC) from the Strabo Trench. Although this quartz arenite contains considerably less interstitial matrix, it still has the characteristic micro mud balls along bedding surfaces.

TABLE 6
Comparison of Nile Cone Sands and the North African Numidian Flysch (Facies 1) of Sicily

	Nile Cone Sands Site 131	Numidian Flysch of Sicily-Sandstones (Wezel, 1970) Facies 1
Bed Thickness	Up to 2.9 m	Up to 10 m
Internal Structure	Massive, homogeneous beds ungraded	Massive, absent to poor grading, sometimes repetitive
Sands Base and Top	Sharp	Sharp
Mud Pebbles Within Sandstones (intraclasts)	Up to 6 cm	Up to 40 cm Common character
Composition	Q ₈₅₋₉₀ F ₁ L ₁₄₋₉	Q ₉₀₋₉₅ F ₁ L ₉₋₄
Grain Textures	Rounded, subrounded frosted quartz grains	Rounded, subrounded frosted quartz grains
Heavy Minerals	Metastable group: Cl ₂₀₋₄₀ H ₃₅₋₆₀ E ₁₀₋₁₇ Ultra-stable group: Z (Cl=clinopyroxene, H=hornblende; E=epidote)	Ultra-stable group: Z ₆₃ T ₁₅ R ₁₃ Metastable group: G ₉ (G=garnet; Z=zircon; T=tourmaline; R=rutile)
Source	Recycled sands (Nubian sand)	Recycled sands (Nubian type sand facies: Sahara)
Mode of Transport	Turbidity currents Mass flows	Turbidity currents Mass flows
Environment of Deposition	Continental Rise-Cone (interchannel area)	Channel filling "fluxoturbidites" on an ancient Continental Rise

TABLE 7
Comparison of Nile Cone Fine-Grained "Black Clays" and the North African Numidian Flysch (Facies 2) of Sicily

	Nile Cone "Black Clays"	Numidian Flysch of Sicily Argilites (Wezel, 1970) Facies 2
Facies description	Terrigenous black clays	± Silty argilites
%CaCO ₃ calcium carbonate	low: < 5%	low: < 5%
Color	Dark gray to black	Dark brown or dark gray
Fe-Mn oxides	Trace metals complexed in organic matter and as stains on mineral grains, hydrotriolite bandings, abundant pyrite, and some siderite	The argilites are rich of diagenetic iron minerals
Composition	Montmorillonite + Kaolinite + Illite	Kaolinite + mixed layers of illite-montmorillonite + illite + chlorite
Source	Nile River bed load	Fe oxides seems to indicate laterite conditions
Mode of transport	Predominantly turbidity currents, perhaps also laterally reworked and distributed by contour currents	Turbidity currents and contour currents

This second source is inferred to be from the north and must have supplied the Levantine Basin before the formation of topographic barriers such as the Pliny Trench and Strabo Mountains. Consequently, it is fair to conclude that the present physiography of the eastern Mediterranean is relatively young, and that contemporary earthquake activity might be viewed as a manifestation of continuing deformation and reorganization.

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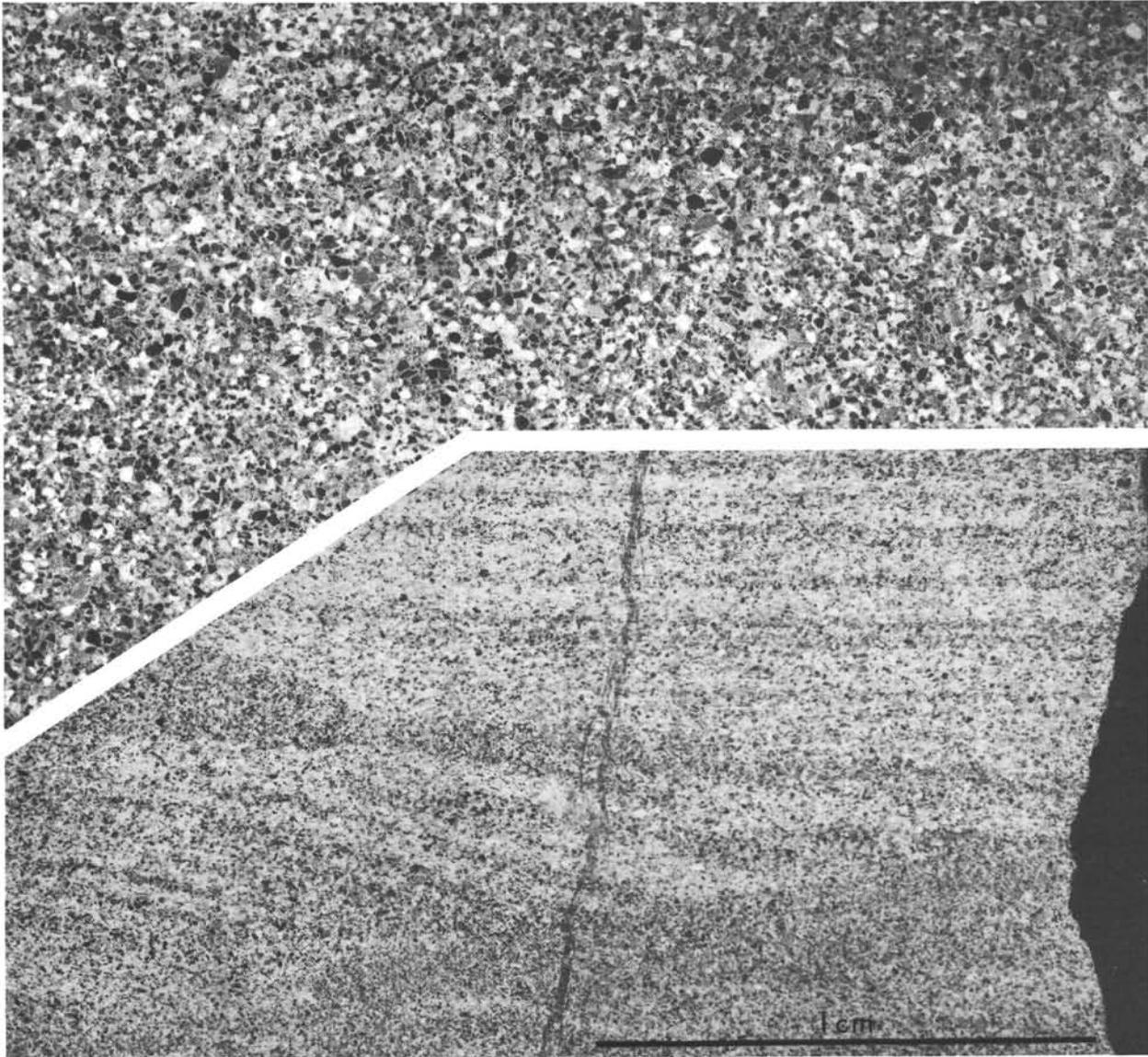


Figure 13. Reversal prints of volcanic and metamorphic rich (lithic sandstones) greywackes. The coarse-grained sandstone is Sample 129B, 2 CC from the Strabo Trench, and the cross-bedded siltstone is Sample V10-64 from the Hellenic Trough south of Crete.

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TABLE 8
Diagnostic Features Contrasting the Nile Provenance
and Inferred Northern Provenance

Nile Provenance (Nile Cone) Sites 130 and 131 Piston Cores V10-53,54,55 and 57 V14-128, RC9-178	Northern Provenance (Hellenic and Strabo Trenches) Sites 127, 128 and 129 Piston Core V10-64
<ul style="list-style-type: none"> ● High Q (>85%) ● Low carbonates ● Low feldspars 	<ul style="list-style-type: none"> ● Low Q (<35%) * High carbonates (largely fragments of foraminifera tests) = organogenic carbonates sometimes shallow-water benthonic forams ● Dolomite ● Volcanic glass ● Glaucofane ● Illite, chlorite, kaolinite * High micas (muscovite, chlorite..) ● High volcanic rock fragments
<ul style="list-style-type: none"> ● Montmorillonite ● Low micas 	
* Rounded and frosted quartzose grains	

* key properties

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