30. LITHOLOGIC SUMMARY

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INTRODUCTION

A broad spectrum of terrigenous and pelagic sediments was encountered on Leg 5. The terrigenous sediments occur only in those sites drilled closest to land masses. The more distant drill sites penetrated pelagic sediments. Pelagic deposits were also found in two nearshore sites at Holes 32 and 36. The distribution of these two classes of sediment for the Leg 5 drill sites is shown on Figure 1.

Of the 1808 meters[1] of sediment penetrated on Leg 5, 1344 meters (75 per cent) are terrigenous[2] and 464 meters (25 per cent) are pelagic.

In this inquiry, the main criterion used to differentiate pelagic from terrigenous deposits was color: pelagic sediments typically were red, brown or yellow; green, blue and black characterized the terrigenous sediments.

In the literature various reasons are given for these color differences. The original color of the detrital grains and/or silled basin conditions at the depositional site are cited sometimes as factors. Although several authors have described sediments reflecting these factors, they are not believed to have played a part here. For the Leg 5 sites, recent concepts favoring the amount of organic matter and its relative inertness (see Fomina, 1962, for data on organic-carbon content) seem more applicable.

Such factors, in turn, are related to the sedimentation rate, nature of the depositional processes and the distance the organic matter is transported before reaching the ocean floor. Indeed, Arrhenius (1963) distinguished between pelagic and terrigenous sediments on the basis of the rate at which only the *continent derived-fraction* accumulates. From the Leg 5 results, this appears to be an additional valid criterion for differentiating the two main sediment groups already defined on the basis of color.

[1]This total does not include the 100 meters of sediment penetrated at Hole 42.1, which duplicates that penetrated at Hole 42.0

[2]Actually, at Site 34 terrigenous sediments were encountered only to a depth of 356 meters, although the hole was drilled to a total depth of 384 meters. Therefore, the nature of the basal 28 meters of sediment is not really known.

Using this added distinction, one can account for the seeming contradiction that some pelagic sediments had a higher sedimentation rate than some terrigenous sediments. The former contained significant amounts (up to 95 per cent) of siliceous and/or calcareous tests of planktonic microorganisms. It is obvious that when employing a system of dividing sediments into pelagic and terrigenous deposits based on the rate continental detritus accumulates, the products of plankton production act as a biasing diluent. By compensating for the biogenous constituents, one can generalize that most terrigenous sediments found on Leg 5 did have a higher sedimentation rate than the pelagic sediments.

Table 1 lists the sedimentary constituents encountered in the terrigenous and pelagic deposits of the various holes on Leg 5. This table includes only those constituents which were recognized while making visual sediment descriptions or encountered during smear-slide examinations. Further discussions of all the constituents are found in later portions of the text.

On this table, an entry under "volcanic ash" does not always indicate discrete ash beds. Volcanic ash may occur as glass shards disseminated in the sediments, or as semi-indurated clasts or pods.

TERRIGENOUS DEPOSITS

Characteristics

Terrigenous sediments were penetrated by six of the twelve holes drilled on Leg 5. One, Hole 43, is located several hundred kilometers east of the Hawaiian Islands, and the other five, Holes 32 through 36, are located a similar distance off the western Coast of the United States. Terrigenous deposits are absent in the more distant offshore holes along the 140°W. traverse.

Thicknesses of the terrigenous sediments vary from 110 meters in Hole 36 to more than 390 meters in Hole 35 (excluding the aborted hole at Site 43, which penetrated 9 meters). Their ages range from Pleistocene through late Oligocene. Most are characterized by moderate to high depositional rates, and all are various shades of green, blue or gray.

Except for a few chert and siliceous mudstone layers, all terrigenous sediments are unconsolidated. Their water content and porosity are uniformly high. Few

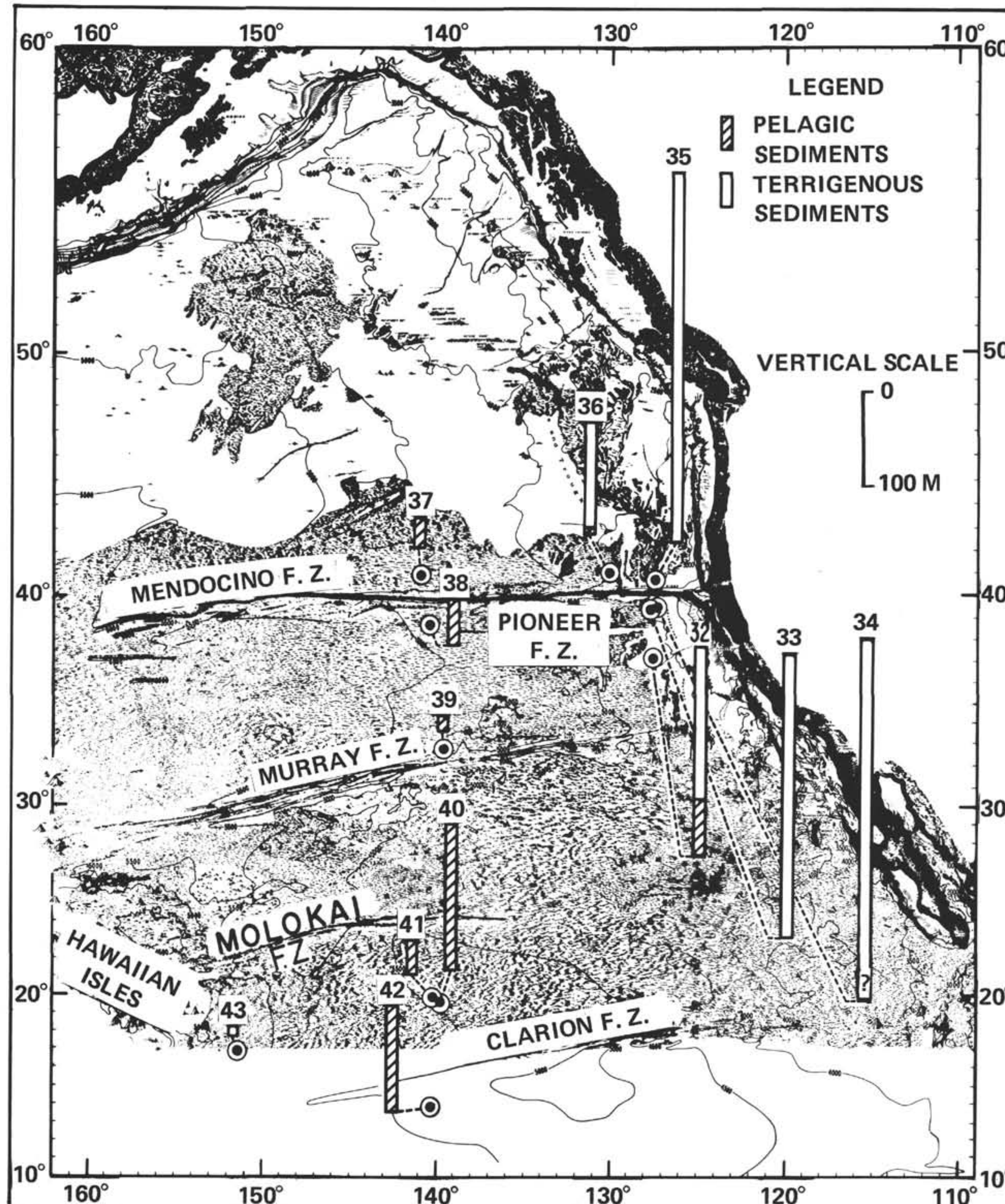

Figure 1. *Map showing penetrations of terrigenous and pelagic sediments at Leg 5 drill sites. (Base map after Menard, 1964. By permission McGraw Hill Book Company.)*

TABLE 1
Sediment Constituents From Leg 5

Constituent	Presence at Each Hole											
	32	33	34	35	36	37	38	39	40	41	42	43
Sand	x		x	x								x
Silt	x	x	x	x		1						x
Mud	x	x	x	x	x							x
Red clay	1				1	1	1	1	1	1		
Volcanic ash	x1	x	x	x	x1	1	1	1	1		1	x
Spherules	1					1						
Manganese nodules						1		1	1	1	1	
Manganese rinds	1									1		
Zeolites	x1	x	x	x	x	1	1	1	1	1	1	x
Carbonate particles	x	x	x	x	x1	1	1					
Dolomite rhombs	1		x						1			
Pyrite	x1	x	x		x	1						
Siliceous fossils	x1	x	x	x	x1	1			1	1	1	1
Foraminifera	x1	x	x	x	x1	1	1	1			1	
Nannofossils	x1	x	x	x	x1	1	1	1	1		1	
Siliceous mudstone		x	x								1	
Chert		x	x						1		1	
Amorphous Fe oxide						1	1	1				

x = In terrigenous sediment
1 = In pelagic sediment

sedimentary structures were noted, except for some burrow-mottles and graded-bedding. Where undeformed by drilling, dips vary from 0 to 15 degrees.

The terrigenous sediments contain a wide variety of lithologic constituents. Table 1 lists those encountered at each hole, and most are discussed in the following section. Of greatest importance are two groups of components: (1) mud, silt and sand derived from the continent and (2) siliceous and calcareous fossils resulting from biogenous productivity in the surface waters. The former group practically dominates the section of Site 35, whereas an end member representation of the latter group is present as an almost continuous section of nannofossil ooze at Site 36. The holes at Sites 32, 33 and 34 largely contain muds with some silts and a few sands; however, significant admixtures of siliceous fossils are also found. Authigenic components (zeolites, carbonate particles, pyrite, dolomite rhombs and chert) quantitatively constitute an insignificant portion of the sedimentary column, although locally they occur in high concentrations.

Table 1 indicates that Hole 43 is compositionally simple, reflecting the activity of only one major depositional agent. However, in Holes 32 through 36 there are complex associations of many constituents, which at times result in rapid lithologic variations. Nevertheless, the stratigraphic column at each of these holes can be subdivided into only a few broad stratigraphic units (see individual Hole Summaries and Chapter 31).

The simultaneous presence of broad stratigraphic units and rapid variations in lithology illustrates a characteristic of the sedimentation agents. At any one site there were many such agents contributing to the lithologic makeup of the stratigraphic column. Often a less important one would briefly become the prime contributor of sediments. However, when viewed over a significant span of the depositional history of a hole, only one or possibly two agents were the dominant contributors.

During any given period, a sedimentation agent unimportant at one site might be dominant at others. This leads to the development of lithofacies, with their temporal and geographic boundaries. When the various sedimentation agents and their importances are recognized, the reasons for lithologic similarities and differences between holes become more obvious. These aspects are described later, in the section on Physical Stratigraphy in Chapter 31.

Recognition and Importance of Sedimentation Agents

Most of the sedimentation agents which contributed to the terrigenous and pelagic sediments are easily recognized by their products. Their importance at each drill site can therefore be evaluated. For some agents, not only is their imprint on the sediments difficult to identify, but they themselves are hard to define. This is particularly true of the deep-ocean bottom currents which influenced sedimentation at all the Leg 5 drill sites. Such currents, because of the many forces influencing their motion, are a complex subject to study and describe. Unraveling this complexity is not simplified by the difficulties in conducting studies in the deep ocean. In addition, it is impossible to recognize, much less segregate, the depositional products of every type of bottom current. Until recently most marine geologists have simply included these products as a part of the pelagic sediments. They have also combined the various types of current-motion under the general heading of "bottom currents".

However, within the past few years much new information has been published concerning the sediment transport and flow patterns of bottom currents. An analysis of this data indicates that on the basis of their influence on sedimentation, these currents can be divided into two basic groups: (1) transient currents and (2) steady-state currents. (Neither group includes the turbidity current, a variety of deep-sea bottom current which is treated separately.)

Transient currents are influenced by tidal, centrifugal, gravitational, inertial or frictional forces, and by extra-long-period waves and internal waves. Their velocity and direction of flow is further controlled by topographic constrictions and obstructions. Normally, several, if not most, of these factors are acting simultaneously to affect the current motion. Typically the influence of each factor fluctuates through time, resulting in current motion marked by irregularity in flow direction and velocity. Often, even when monitored over a long time span, the net horizontal displacement of water particles is almost zero. As thus defined, transient currents do not move sediments into or out of an area, but only redistribute those sediments already deposited.

Because of their relatively short span of horizontal displacement, any skeletal remains transported by this mechanism should not result in compositional changes of the local biocoenosis. Transient current motion should not result in the development of displaced fossils. Most of these currents are characterized by flow velocities below 10 cm/sec (actually, more like 1 to 4 cm/sec) and, therefore, are unable to remove sediments from the ocean floor. Although lacking the ability to erode, they may nevertheless receive a dilute suspended load from bottom dwellers, who by their activities eject fine particles into the overlying water column. Consequently, in some areas the effect of transient currents on sedimentation can be judged by the density of the bottom population.

Occasionally, short-period, high-velocity fluctuations, in the range of 20 cm/sec, are recorded during transient current flow. These velocity excursions, although uncommon, could have a greater effect on the sea floor than the more persistent slower current motions. It is even conceivable that some transient currents may resuspend sediments and thereby contribute to the nepheloid layer.

Over a flat surface, such as, an abyssal plain, the effects of transient currents must be minimal. Even over a long period of time, the amount of sediment they remove from a site should be compensated by the amount they redeposit. However, in an area of irregular topography, such as, abyssal hills, their ability to alter sediment thicknesses should be greater. There the movement of a slow, dilute suspensoid responding to gravity results in a net sediment transfer from the abyssal hills to the intervening troughs. Quite typically this results in the development of a concave-upward meniscus configuration for the sediment surface in the troughs. This configuration contrasts with the flat, ponded surface developed by turbidites.

In regions of long, steep inclines, such as, continental slopes, the functions of transient currents may change. Here, where gravity plays an increasingly important role and flow velocities tend to be higher, their activity may result in considerable downslope displacement of sediment particles. They can now serve as a mechanism for transporting sediments from the shelf edge to the deep-water steady-state currents.

The characteristics of steady-state currents differ appreciably from those of transient currents. While these currents occur at all levels in the ocean, this discussion is only concerned with those flowing along the deep ocean floor. The driving mechanism of these currents consists perhaps entirely of the deeper effects of (1) the wind-driven circulation, and (2) deeper thermohaline circulation (both being in approximate geostrophic equilibrium).

Examining first the deeper thermohaline circulation, its flow is generated by vertical processes which occur mostly in the Antarctic and the Atlantic part of the Arctic Ocean. Upon reaching the deep ocean floor, its flow path generally parallels the sea-floor contours. However, this path (as is true of transient currents) is also influenced by frictional, gravitational and inertial forces. Topography is also a factor which can locally alter or divide the flow direction or change its velocity. The flow path and velocity of the thermohaline circulation may gradually shift during the year. Nevertheless, its permanence in overall flow direction and constancy of flow velocity differ markedly from those of transient currents.

The path of this type of bottom flow has been traced many thousands of miles in the Atlantic and Pacific Oceans. The thermohaline flow may vary in width from narrow streams in constricted places to oceanic widths in open areas. It may range in thickness from a few hundred to several thousand meters.

Typically, from the effects of the earth's rotation, the geostrophically-balanced currents flowing along the western margins of the oceans have a higher flow velocity than those flowing along the eastern margins. The Western Boundary Undercurrent (WBUC), found in the western Atlantic, is probably the most thoroughly studied deep current. Here Amos and Schneider (1969) detected current velocities of 5 to 30 cm/sec in its faster portions; they also noted scour and erosion features developed on the sea floor sediment surface.

These velocities should not be considered typical of deep thermohaline flow. Velocities of 5 cm/sec have been commonly observed in the WBUC; and, McCoy (1969) found velocities of 1 to 3 cm/sec or less associated with portions of this current.

The wind-driven circulation, in the context of steady-state currents, refers to the large ocean gyres and currents developed by the earth's planetary wind system. The influence of these currents may be felt on the ocean floor several kilometers below the ocean surface. Although their driving force is different, the flow characteristics of these currents, particularly in open ocean areas, bear many similarities to thermohaline flow. This is especially true as regards their relative permanence of flow direction and velocity. These similarities must be translated into comparable effects on the erosion, transportation and deposition of sediments; consequently, they are combined with the thermohaline flow under the heading of steady-state currents.

Initially recognized in the North Atlantic, nepheloid layers accompanying steady-state bottom currents have been identified in the South Atlantic, Arctic, Antarctic and possibly the Indian Oceans. First postulated by Ewing *et al.* (1968) as being present in the northeastern Pacific, Ewing and Connary (in press) recently described their occurrence over large portions of the Pacific Ocean.

The suspended sediment load of these geostrophically-balanced currents has been detected by various types of nephelometers and water samplers, and it is often referred to as the "bottom nepheloid layer". Particles in this nepheloid layer consist mostly of clay-sized and some fine silt-sized materials, although some currents have the competency to transport coarser material when it is available. The amount of sediment in suspension is a function of flow velocity and the availability of particulate matter.

Sources of sediment particles may be from: (1) erosion by the deep steady-state currents, (2) captured portions of turbidity currents, (3) activity of bottom dwellers, (4) microplankton in the water column, (5) turbid-layer transport, and (6) resuspension by transient currents. Actually, several or all of these sources probably contribute to nepheloid layers.

The amount of suspended sediment they contain differs. Hunkins *et al.* (1969) recorded only 0.01 mg/1 in a bottom-current nepheloid layer in the Arctic Ocean; however, concentrations in excess of 0.05 mg/1 are not uncommon in other nepheloid layers.

The distribution of suspended sediments within an individual nepheloid layer was thoroughly examined by Eittreim *et al.* (1969) in the WBUC. Within this 300 to 2400 meter thick layer, the sediment concentration varied considerably from high concentrations in thin intervals to low concentrations in thick intervals.

Where a nepheloid layer is entrained in the faster portion of a steady-state current, nondeposition or even erosion occurs, but with decreasing velocity deposition begins. Heezen *et al.* (1966) noted long abyssal ridges in a region of moderate flow velocity, and Rona (1969) has interpreted some abyssal hills as being large lutite dunes developed by a nepheloid layer.

No unique erosional or constructional features have been detected where nepheloid layers are transported at the slower flow velocities. At these velocities turbulence is diminished, and one would expect individual sediment particles to settle from suspension more nearly as they would during grain-by-grain settling. This should develop a uniform blanketing of the bottom topography, and unless reworked by transient currents, the sediments should be just as thick over the crests of abyssal hills as they are in the intervening troughs.

One other aspect of steady-state and transient currents must be considered. They do not flow independently of each other, but combine to form the total current motion present at any given site. When the flow velocity of the steady-state current greatly exceeds that of any transient current, the former will continue unimpeded on its flow path. Where the two types of bottom currents are flowing at comparable speeds or the transient current is the faster, the flow streamlines of the steady-state current will become highly distorted. Even so, the set of the steady-state current should persist, resulting in a net transport of any entrained sediments.

Although the influence of the two types of bottom currents on sedimentation is seen to differ considerably, actually segregating their effects on the sediments is difficult. Nevertheless, an attempt is made here to evaluate their individual importance at each of the Leg 5 drill sites, and they are discussed jointly under the general heading of Bottom Currents.

Entirely different in their behavior from bottom currents are turbidity currents. Their generation has usually been ascribed to slumping in relatively shallow water along the outer edge of the continental shelf or in submarine canyons. Such flows normally transport fine to coarse-grained terrigenous material, together with varying amounts of fossil remains.

Somewhat similar to the turbidity current as a mechanism of sediment movement is the "turbid layer transport" of Moore (1966), which is also generated in shallow water. (It is believed capable of transporting only fine detrital material.) However, recent literature describes turbidites which presumably originated in deeper water by sediments slumping on the continental rise or abyssal hills. Characteristically, these deposits are rich in biogenous material. In some of the cores taken from Leg 5 sediments, these are thin beds and lenses of microfossil-rich mud or ooze containing displaced fossils. The possibility that such sediments have a deep-water turbidite origin will be evaluated at those sites where they occur.

The definition of grain-by-grain settling as a sedimentation agent is restricted in this report to include only those slowly sinking particles in the water column that were derived by *sea-borne* transport from land masses. (Those derived by airborne transport are discussed under eolian transport.) Grain-by-grain settling has commonly been recognized as an important mechanism along the continental margin, but its importance beyond this region is often overlooked.

The slow descent of very fine silt and clay particles through the water column may require months or even years in the abyssal water depths encountered at oceanic sites. Recent work in the Gulf of Mexico (Jacobs and Ewing, 1969) has shown that such particles can be transported hundreds or even thousands of kilometers before settling to the ocean floor. Sites 32 through 36 are well within this range of transport. To be effective such transport requires both favorable marine currents and favorable conditions of fluvial discharge. These factors will be examined as they exist off the West Coast, to see whether they are favorable today. Sediments at Sites 32 through 36 will be examined to determine whether these factors were favorable in the past.

All of the sedimentation agents recognized as possible contributors are listed below, in their order of discussion:

1. Turbidity currents
2. Slumping
3. Eolian transport
4. Extraterrestrial components
5. Biogenous productivity
6. Volcanism
7. Grain-by-grain settling
8. Bottom currents

Turbidity Currents

Turbidity currents were definitely a depositional agent at Holes 32, 34 and 35. There is a good possibility that they were also active at Holes 33 and 43.

At Hole 43 evidence for turbidity current deposition of the 9-meter interval penetrated is based on sparse data. This hole is located in a depression between two groups of abyssal hills, 500 kilometers from the nearest sediment source (the Hawaiian Islands), at a depth of 5400 meters. Although its location is beyond the sediment apron fringing these Islands, it is difficult to postulate any mechanism other than turbidity currents capable of transporting silty clays and sandy silt to this site. Horn *et al.* (1969), who examined piston cores from north, west and south of the Hawaiian Ridge, found turbidites hundreds of kilometers from this Ridge.

At Site 32 the evidence for turbidity current deposition is quite conclusive. The echo-sounder traverse of the *Glomar Challenger* (Figure 2) indicates that Hole 32 was drilled on a flat, gently dipping abyssal plain. This plain is shown on Menard's (1964) physiographic map of the northeastern Pacific as being part of the distal portion of the Delgada Fan (Figure 3). Additional evidence comes from the sands recovered here. Cores 1 and 5 contain fairly well-sorted, fine-grained, silty sands in discrete beds 2 to 40 centimeters thick. Most beds have sharp lower contacts, sharp to gradational upper contacts, and many are graded.

A total of three meters of sand was cored in Hole 32. Additional sands probably exist in the uncored intervals, because the seismic profile indicates several reflectors between Cores 1 and 3 (9 to 80 meters). However, even if several tens of meters of sand were present, this would not be sufficient to construct the thickness of abyssal plain deposits developed at Site 32.

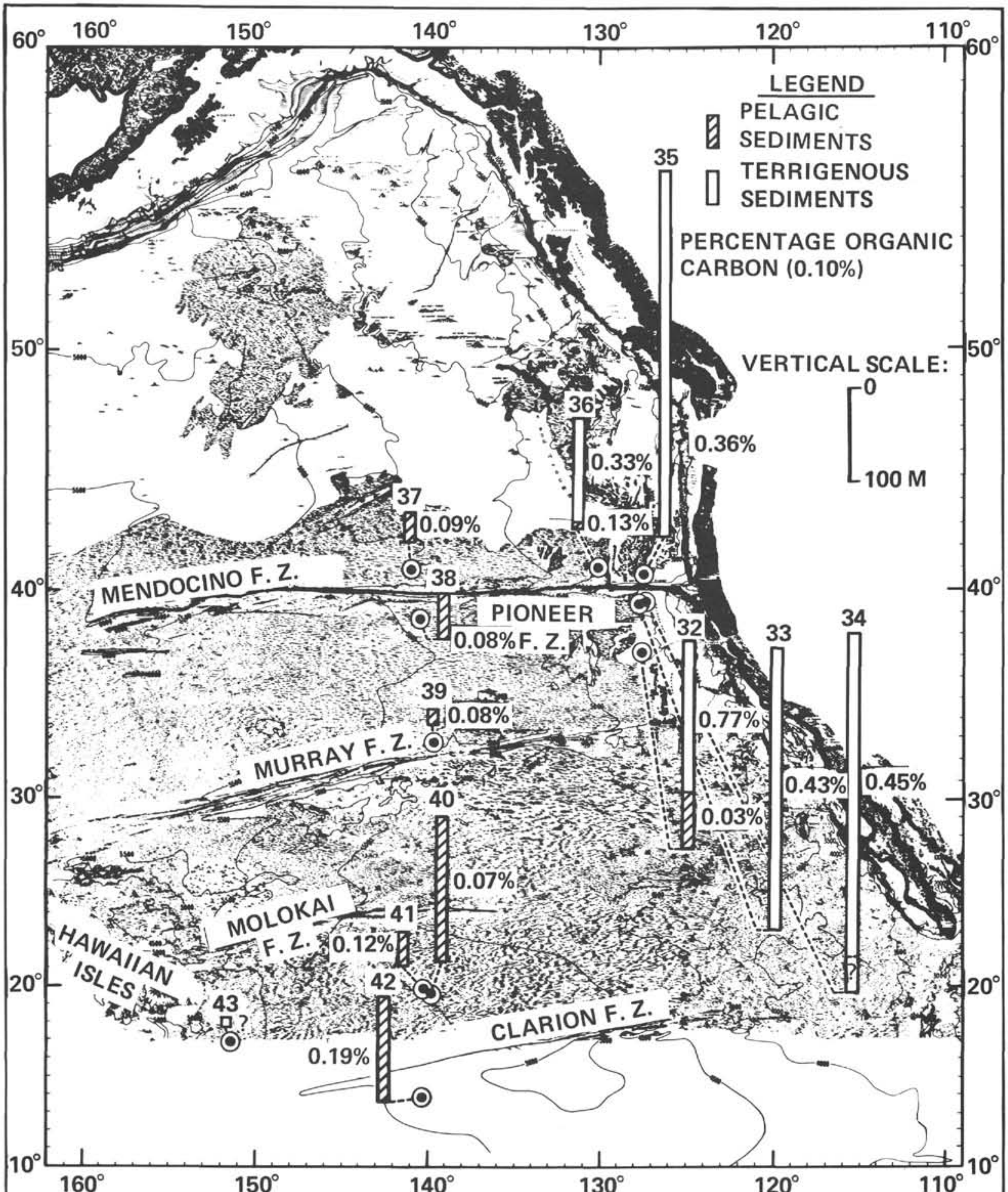

Figure 2. *Location of Hole 32 on lower of two abyssal plains. These and other nearby abyssal plains are ponded by a series of north-south abyssal ridges. (*Glomar Challenger *Site Survey.)*

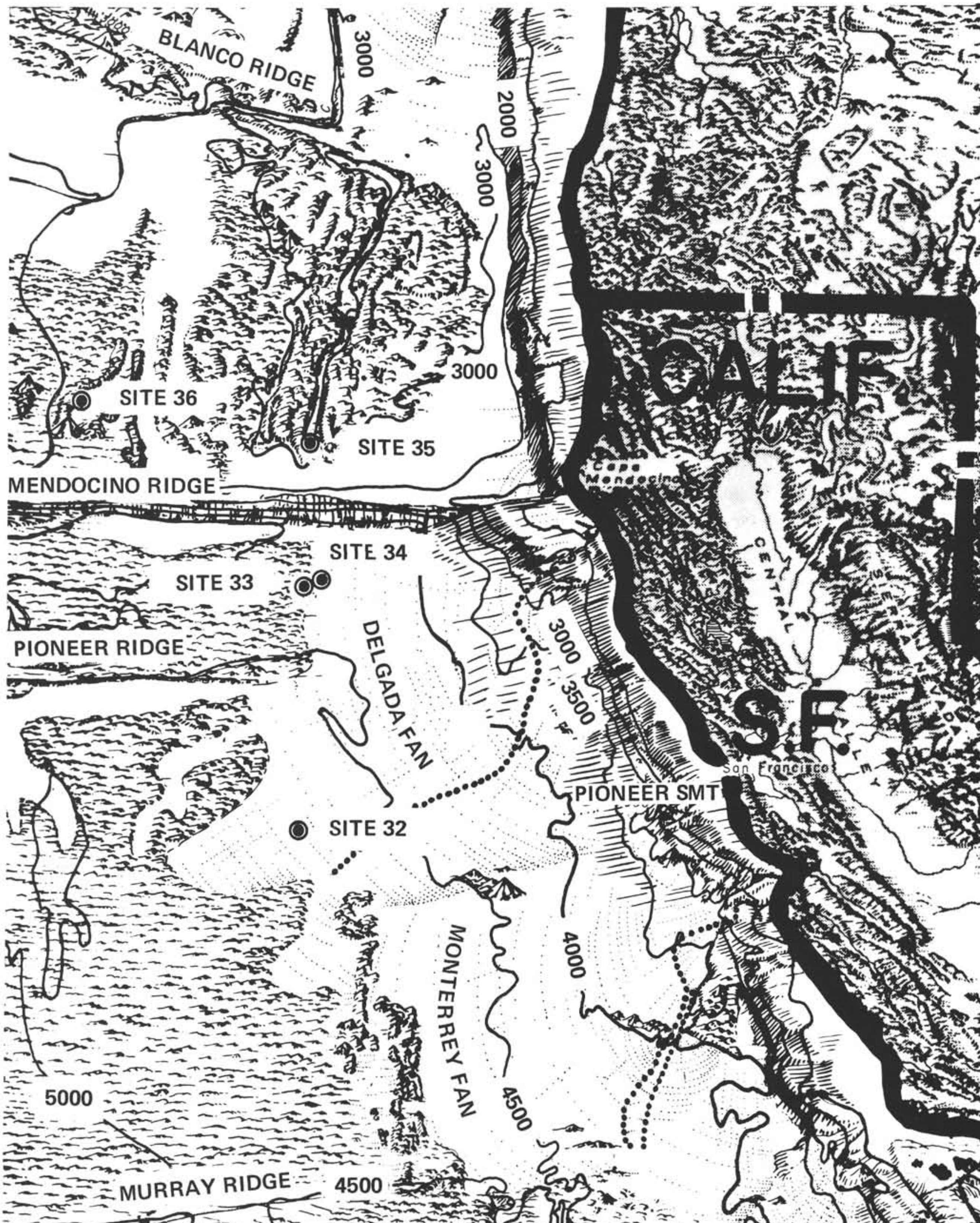

Figure 3. *Topographic map showing distribution of abyssal hill and plain regions near Sites 32 through 36. (Base map after Menard, 1964. By permission McGraw Hill Book Company.)*

This dilemma can be resolved by also attributing many of the silty muds found in Hole 32 to turbidity-current transport, a conclusion supported by several lines of evidence. Paleontologically, the entire interval—from Cores 1 to 7—contains a high proportion of redeposited microfossils, many of shallow-water origin. These displaced fossil constituents disseminated in the silty muds could easily have been transported by turbidity currents. Such transport is also suggested by the broken and abraded condition of many fossil tests.

Many of the silty muds occur as thin or very thin beds having sharp lower contacts and sharp or gradational upper contacts. Some of the coarser silts have graded-bedding. Individual beds are easily distinguished as alternating bands of green, blue or gray sediment. If none of these sediments represented pulses of turbidite activity, graded-bedding would be absent, the strata would be more massively bedded and the color changes more gradual.

Further evidence for their turbidite origin is provided by the acoustic-reflection profiles run during the *Argo* presite survey of Site 32 (N. T. Edgar, Chief Scientist). On these profiles, abyssal hills composed of oceanic crust either underlie the abyssal plains or protrude above them. Of the latter variety, those having low or moderate slopes are mantled by a fairly uniform 100 to 120 meter blanket of sediment, while those with steeper slopes have a slightly thinned sediment cover, probably the result of erosion or slumping. These relationships are graphically displayed on Track G (Figure 4). On the abyssal plains the sediment thicknesses vary from 100 to 350 meters, depending on the thickness of flat, ponded sediments overlying the buried abyssal hills. Figure 5 shows approximately 150 meters of flat, ponded sediments near Site 32.

According to the lithologic data at Hole 32, this region apparently had developed a 60-meter thick cover of pelagic "red" clay prior to the onset of terrigenous sedimentation. With a sediment cover totaling 100 to 120 meters, of which 60 meters consists of "red" clay, the protruding abyssal hills must have developed an additional blanket of 40 to 60 meters of non-turbidite sediments since the onset of terrigenous deposition. Probably much of it is biogenous in origin. This sediment would similarly be disseminated through the ±150 meters of flat, ponded terrigenous sediments at Site 32. By simple subtraction, there should be 90 to 110 meters of turbidite sediments in Hole 32.

Although based on several assumptions, the above figures are probably of the correct order of magnitude. This figure of 90 to 110 meters is too large to be accounted for entirely by turbidite sand deposition, and its magnitude therefore substantiates the conclusion that many of the silty muds are also of turbidite origin. Interestingly enough of the ±150 meters of terrigenous section, approximately 100 meters—including all of the sands—are a distinctive dark green color. These dark sediments very likely represent the contribution by turbidites to Hole 32.

The geophysical survey at Site 32 shows low relief plus a relatively uniform sediment blanket over the abyssal hills. This suggests that conditions were locally unfavorable for generating turbidites. Consequently, most turbidites here are believed to have been spawned in the shallow-water regions of the upper continental margin. Turbidity currents appear to have been the most important sediment contributor to Hole 32.

The evidence for turbidite deposition in Holes 33 and 34 is treated jointly, as these holes are only 20 kilometers apart. Menard's (1964) physiographic map indicates that they are located somewhere on the boundary between the Delgada Fan and the abyssal hills province to the west (also see Figure 3). A more detailed evaluation can be made by examining the *Argo* seismic profiler records relating to Sites 33 and 34. Figure 6 shows that Hole 33 was drilled on the slope of a ridge situated along the eastern edge of the abyssal hill topography, and is therefore beyond the Delgada Fan. Here, although no sands were cored, there are a few thin silt streaks present near the top of the hole. Seemingly too high topographically for present-day turbidite deposition, some of the topographic relief in the area may be due to fairly recent structural deformation. Therefore, even though turbidite sands may not have reached Site 33, their finer, silty mud equivalents may have been able to climb a small amount of reverse slope.

Hole 34 is located on the western margin of an abyssal plain whose relationship to the Delgada Fan is not clear from the *Argo* presite survey. However, the *Argo* approach profiler record for Sites 33 and 34 indicates that this abyssal plain rises continuously to the east and represents the distal-most portion of the Delgada Fan (Figure 7).

Turbidite sediments occur in the upper part of Hole 34 (i.e., Core 6), where 3 meters of fine-grained, well-sorted, silty sand are found. These sands occur in beds 5 to 30 centimeters thick. Sharp lower contacts and graded-bedding are evident. This interval, which is of early Pliocene age, corresponds to the 0.18-second reflector on the seismic profile. No other seismic reflectors were noted above it, which suggests that additional sand bodies are not present in the uncored intervals above Core 6.

Several seismic reflectors do occur below Core 6, including some which depthwise are equivalent to uncored intervals. Apparently these intervals also lack sand because the seismic reflectors, which depthwise are equivalent to cored intervals, are represented by cherty

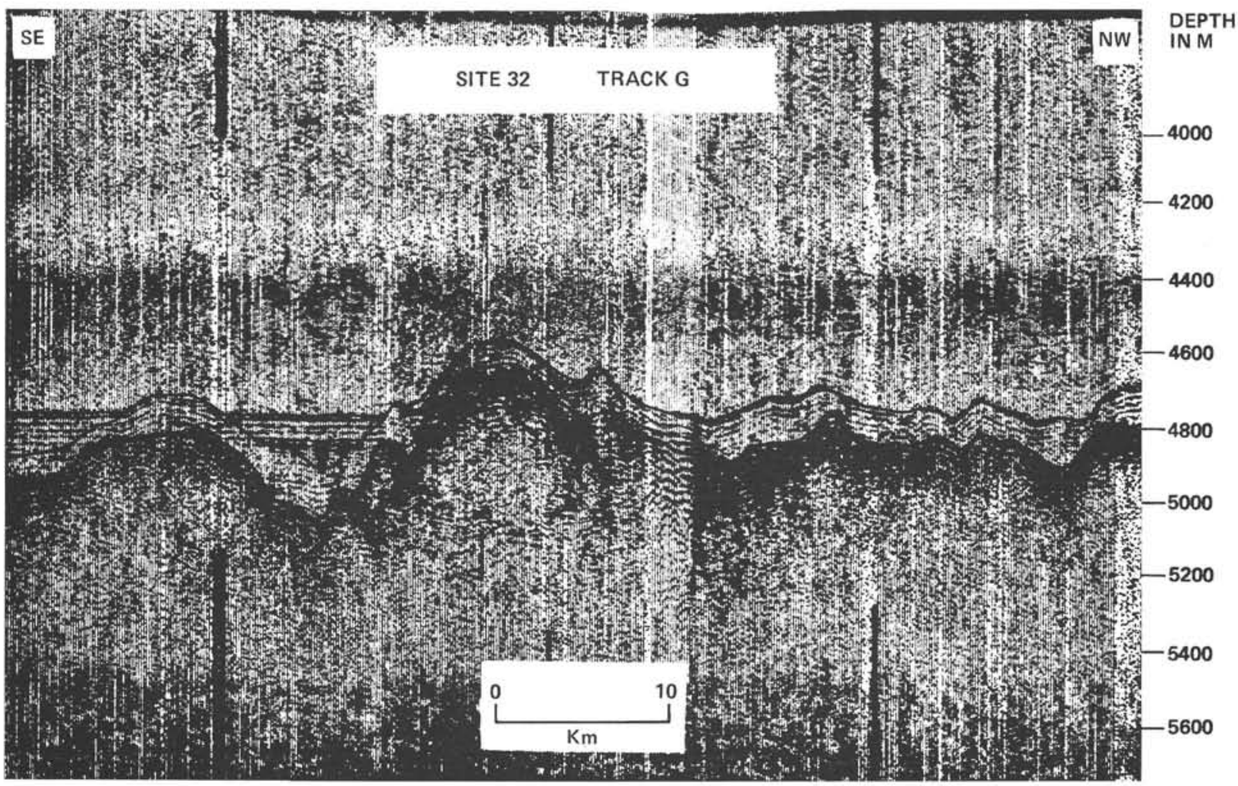

Figure 4. *Seismic-profile near Site 32 showing area of abyssal hills unaffected by turbidite deposits which accumulated in adjoining abyssal plain. Prominent reflector represents basaltic basement. Note: Basement reflector and pelagic sediment-turbidite sediment contacts have been emphasized, because of poor record quality. Track G runs 25 kilometers SW of Site 32. (*Argo *seismic profile, 7 March, 1969, 1930-2300.)*

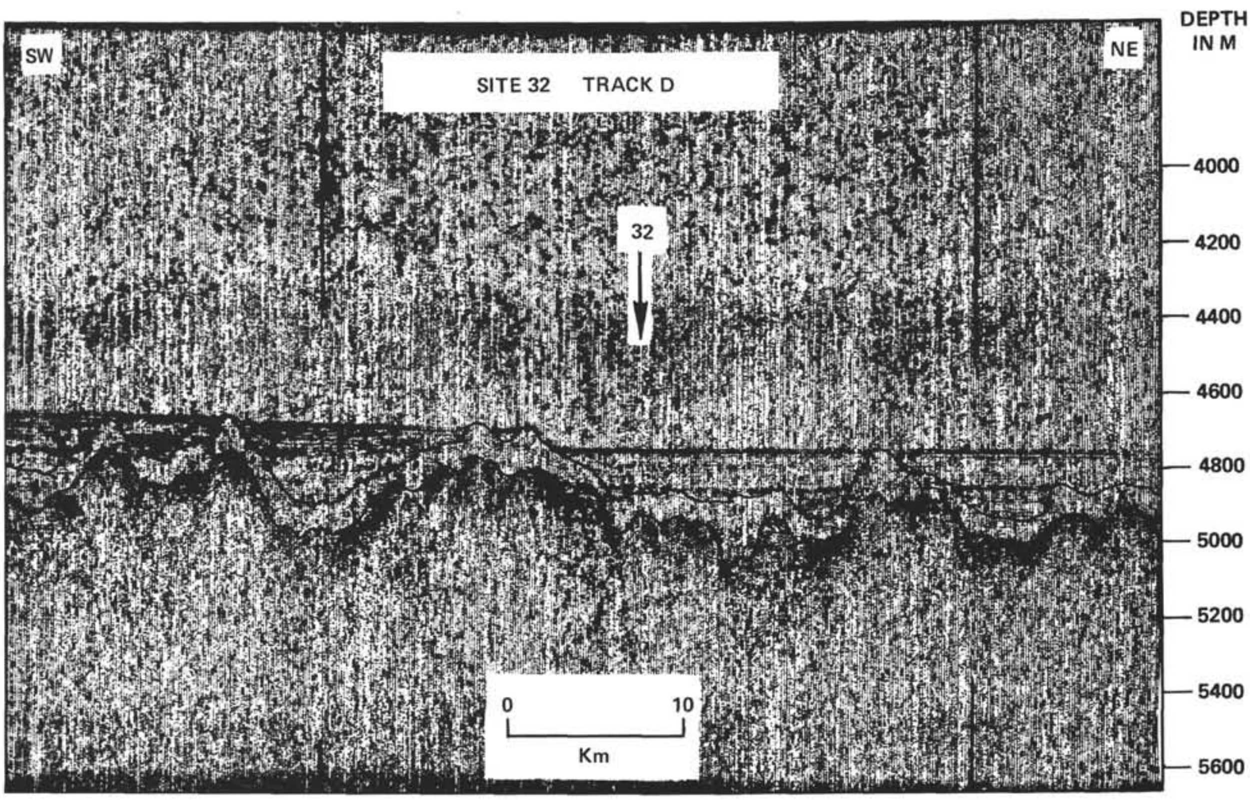

Figure 5. *Site 32 projected approximately 3 kilometers north, onto Track D. Turbidite reflectors are seen to overlie or abutt the thin mantle of pelagic sediments whose surface parallels configuration of underlying oceanic crust. Note: Basement reflector and pelagic sediment-turbidite sediment contacts have been emphasized because of poor record quality. (*Argo *seismic profile, 7 March, 1969, 0530-0930.)*

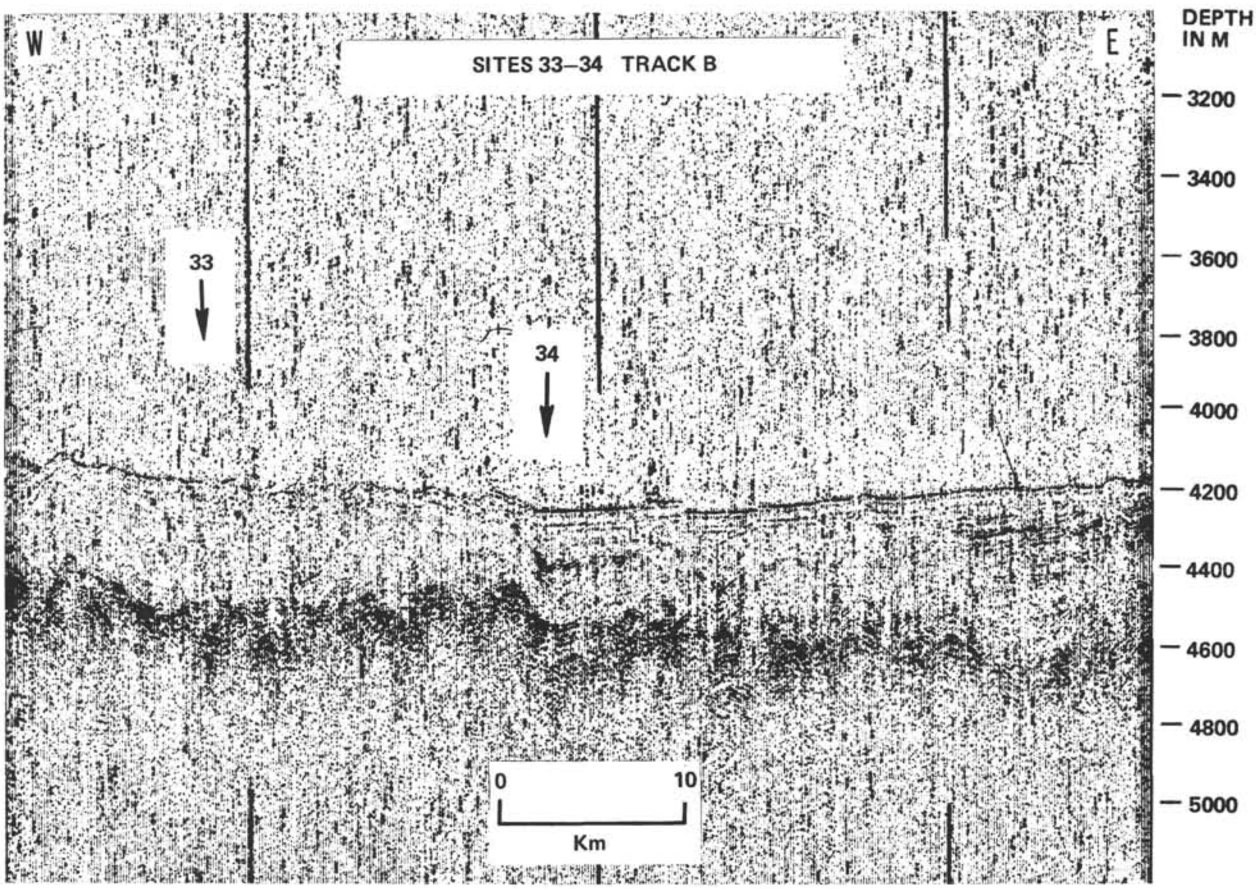

Figure 6. *Seismic-profile showing location of Site 34 at extreme margin of Delgada Fan. Only one turbidite reflector is present here. Site 33 is seen to be positioned beyond Fan, on flank of broad-arched region of abyssal hills. (Sites 33 and 34 were projected on Track B rather than C because, although latter is closer to sites, it was run beyond the edge of abyssal plain developed at Site 34.) (*Argo *seismic profile, 11 March, 1969, 0030-0430.)*

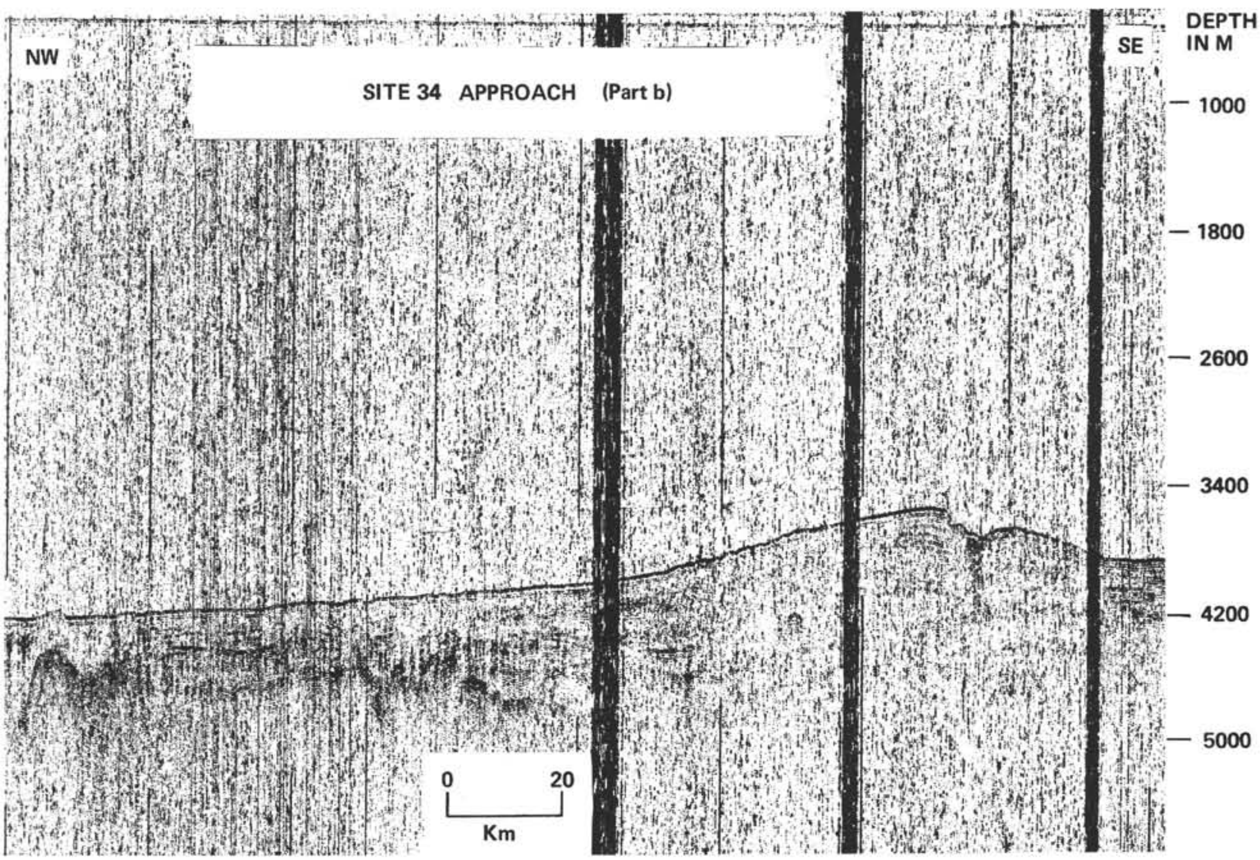

Figure 7. *Portion of approach seismic record for Sites 33 and 34. Sloping surface of Delgada Fan immediately adjacent to fan margin shown on Figure 6. Prominent notched hill probably is broadly-leveed Delgada Channel. (*Argo *seismic profile, 10 March, 1969.)*

or siliceous mudstones. In addition, the mechanism of distal turbidite fan enlargement is one of prograding growth. As most fans in the area are believed to have begun their activity no earlier than middle Tertiary time, they most likely had not prograded this far west prior to Pliocene time.

The interval equivalent to the sandy unit of Hole 34 was not seen in Hole 33, but because portions of the hole were not cored it could have been missed. As the 0.18-second seismic reflector of Hole 34 does not extend to this site (see Figure 6), this sandy unit is apparently also absent from the uncored intervals. Furthermore, as pointed out previously, the abyssal-ridge-flank location of Hole 33 suggests that coarse-grained turbidites would not reach this site.

While the seismic data rules out the presence of additional sandy turbidite intervals, it does not preclude the presence of fine-grained turbidites. The lithologic data indicates, however, that these are also absent, at least in the cored intervals. As already mentioned, sands occur only in Core 7. Associated with this sand interval are distinctive dark green, silty muds. (Similar muds characterize what are believed to be the turbidite intervals in Holes 32 and 33.) By way of contrast, all the other muds in Holes 33 and 34 are finer-grained and lack the distinctive dark green color.

Redeposited fossils, which so often accompany turbidites, also are found in Holes 33 and 34; however, not nearly in the amounts found in Hole 32. Also, as shown in a later section, they can be accounted for by other sedimentation agents.

There is good reason to believe that slumps originating along the upper part of the continental margin were the major source of turbidites for Site 34, as the local relief is too subdued for turbidites to have been generated in nearby areas. Occasionally, dilute sediment suspensions might have been derived from the Mendocino Ridge to the north. Seismic shocks could easily generate slumps of unconsolidated sediment from the tectonically active portions of this Ridge. Sediments are found here on terrace-like areas protected from currents. Among them (Krause *et al.*, 1964) are clayey calcareous oozes, manganiferous-coated siliceous sponges and basalt in pebbles and fragments; no sands have been noted.

A study of the (*Argo*) profiler records does indicate some local wedges of presumably locally derived material at the base of the Mendocino Escarpment. (These wedges have been steepened by subsequent uplift of the escarpment.) However, these sediments abutt (rather than grade into) the turbidite reflectors to the south (Figure 8). Such a contact indicates a lack of continuity between these sediments and the reflectors, and therefore suggests that the Mendocino Ridge was not a source for turbidites.

Overall, the effects of turbidite deposition are not nearly as great in Hole 34 as they are in Hole 32, and they appear to be even less in Hole 33.

At Site 35, located on the Gorda Rise, turbidity currents played a major role. Significant amounts of turbidite sands were cored in the upper and lower parts of the hole. These sands are fine-to medium-grained, have poor to moderate sorting, and occur in thin to very thick beds. The electric logs and the seismic profile (Figure 9) indicate that additional sands are present in the uncored intervals. It is likely that most of the silty clays encountered here are also of turbidite origin.

The presite survey shows Site 35 to be located in a gently northward sloping, deformed trough having a block-faulted, abyssal plain surface. This trough connects to the south and east with what appears to be a fan area developed at the toe of the continental slope and fronting Northern California and Southern Oregon. Furthermore, it also appears to be connected to the Astoria Channel via the Blanco Trough (Figure 13) which, as Duncan *et al.* (in press) have shown, carries sediments derived from the Astoria Submarine Canyon.

In some places the trough at Site 35 is bounded by steep, high ridges which are devoid of sediments (Figure 10). The absence of a sediment cover may imply its removal by periodic slumping and the subsequent transformation into turbidity currents, which could contribute to this trough. More likely, though, the ridges were swept clean of sediments by currents, since there are no fan-like sediment wedges at their bases.

At Hole 36 no sands were recovered, though redeposited Miocene-Eocene microfossils are encountered within the calcareous nannofossil oozes. These fossils could have been transported by various sedimentation agents including turbidity currents. If turbidity currents were active, there is a problem deciphering where they were generated. Some might have come from nearby abyssal hills, which could account for the presence of the reworked Miocene fossils, but this does not explain the presence of Oligocene and Eocene calcareous forms which must have been derived from an area many hundreds of kilometers to the west. (This conclusion is based on defining the location of Oligocene and Eocene oceanic sediments on the basis of the sea-floor spreading concept.) In this case, it would have been necessary for these fossils to have traveled upslope, as the sea floor slopes downward toward the west. This does not appear to be a likely source.

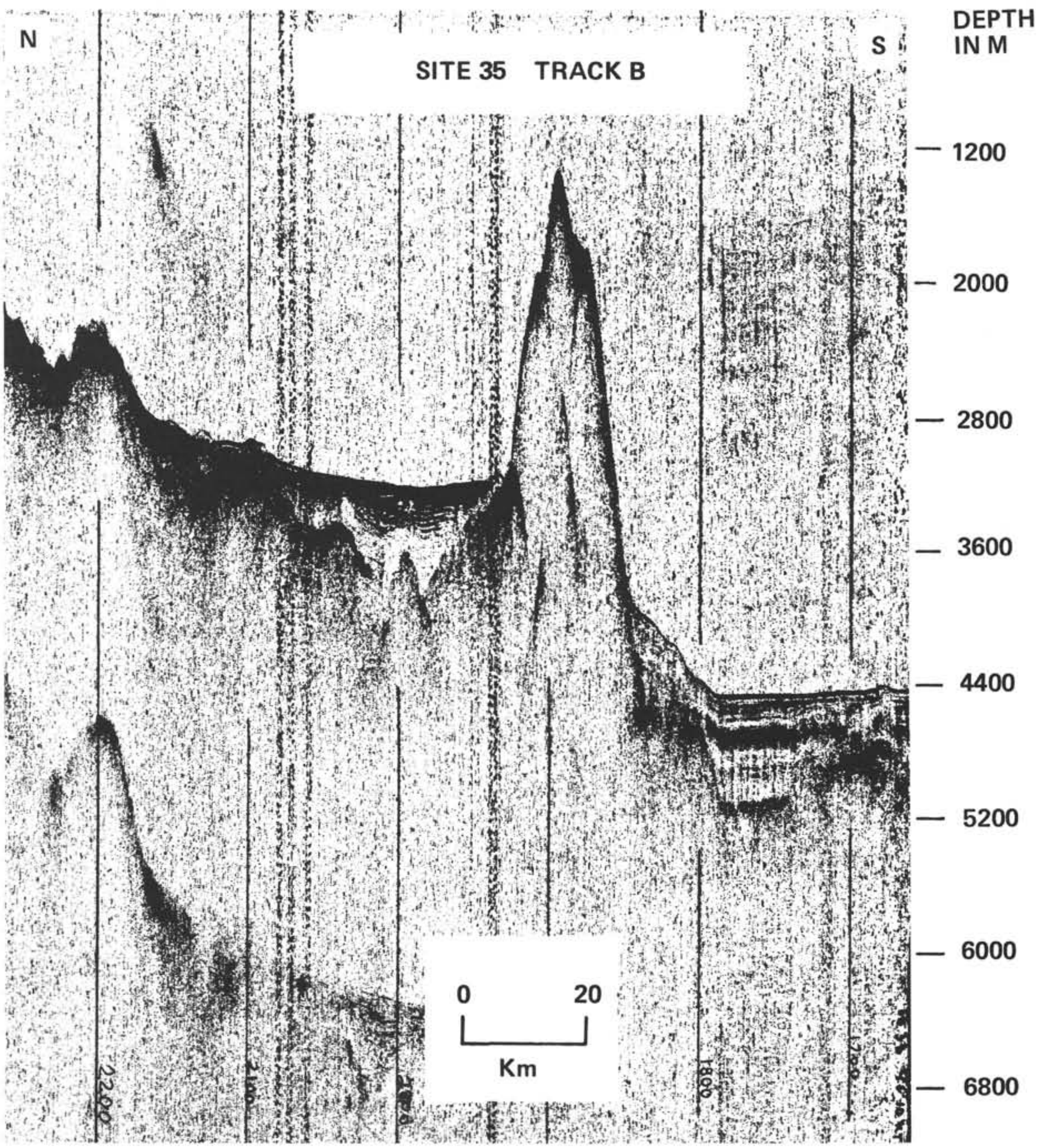

Figure 8. *Delgada Fan turbidites at base of Mendocino Ridge. They sharply abutt wedge of sediments probably derived from Ridge. Other turbidites are seen at higher elevation north of Ridge, and are contiguous with those filling Gorda Rise. (*Argo *seismic profile, 13 March, 1969, 1100-1530.)*

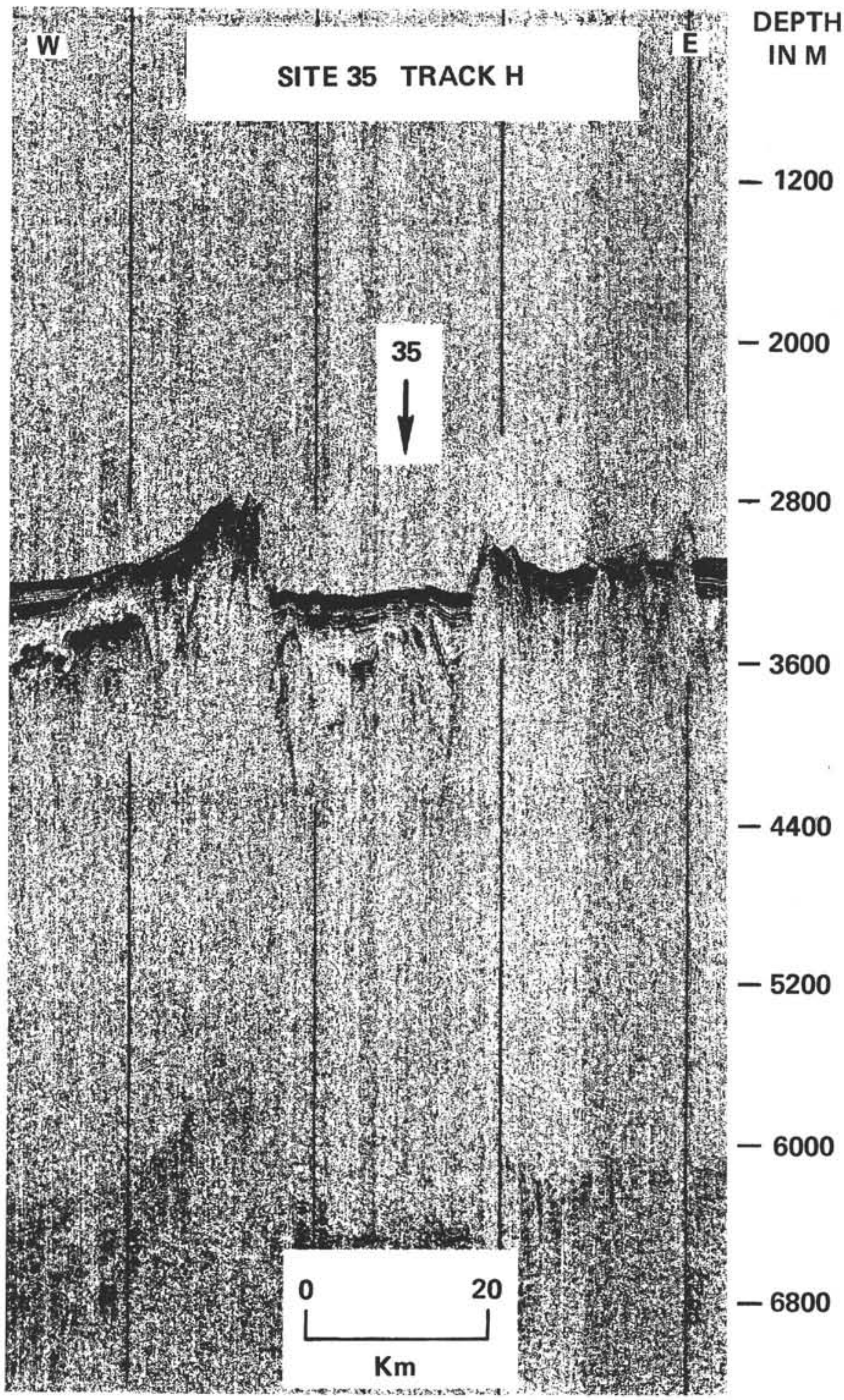

Figure 9. *Location of Site 35 over off-centered medial ridge on Gorda Rise. Abundant turbidite reflectors are evident. Ridges bounding trough have relatively low relief here. (*Argo *seismic profile, 14 March, 1969, 2145-0130.)*

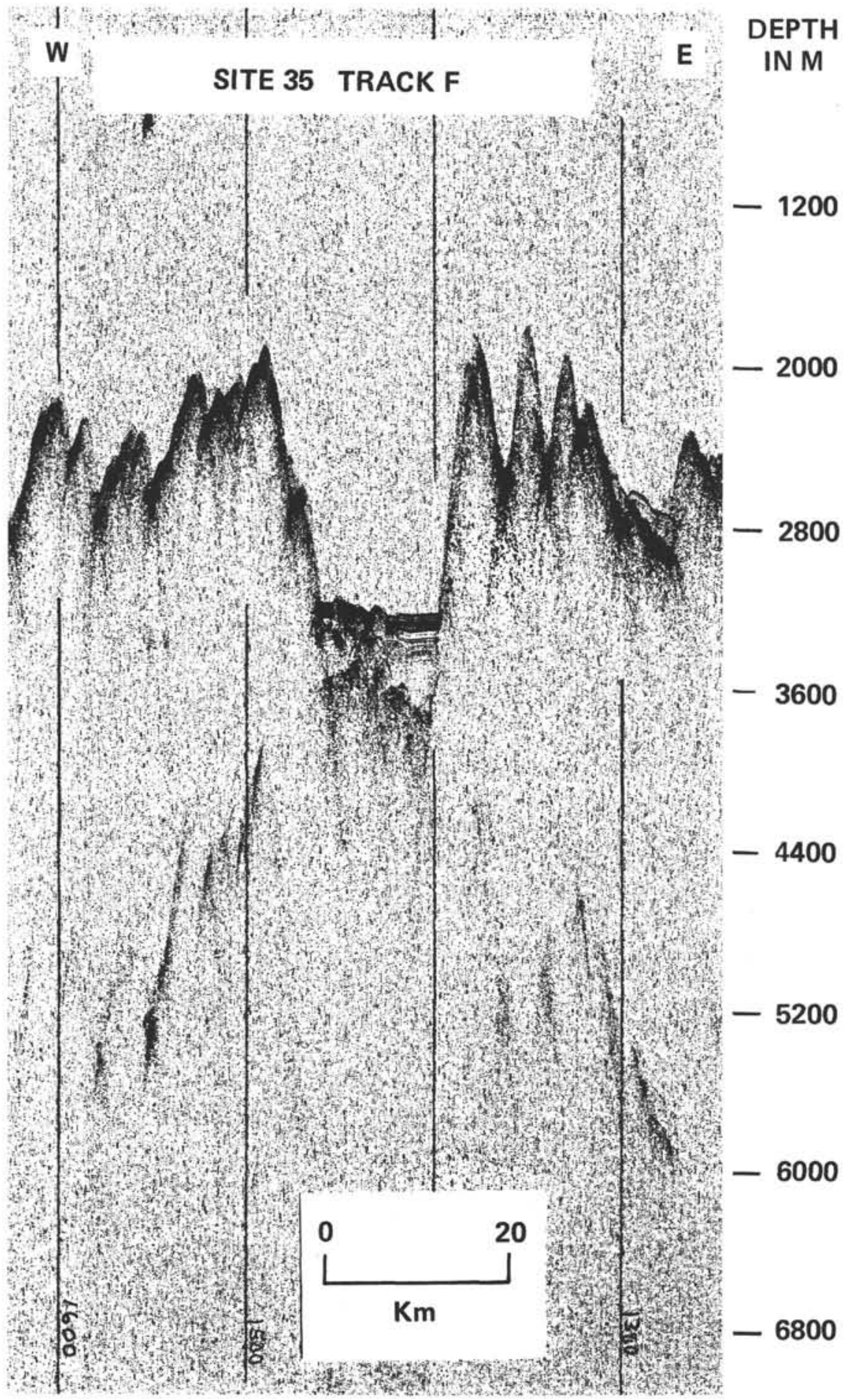

Figure 10. *Seismic-section across Gorda Rise approximately 25 kilometers north of one shown on Figure 9. Note: high relief of ridges bounding the trough.* (Argo *seismic profile, 14 March, 1969, 1230-1530.)*

The possibility also exists that some turbidite flows may have been generated along the Mendocino Ridge. Here, directly south of Site 36, there may be Oligocene and Eocene sediments on the Ridge. This also appears to be a rather tenuous explanation since it requires the absence of any slope reversals in the area of rugged relief between the Ridge and Site 36.

Finally, there is the possibility that turbidity currents were derived from the continental margin to the east. However, Hole 36 is located west of a large north-south ridge which probably acted as a barrier to turbidity current flows from that direction. The absence of turbidite sands here and their presence on the other side of the ridge seems to demonstrate the effectiveness of this barrier (see Figure 11).

In summary, it is difficult to reconcile turbidite transport for any of the Hole 36 sediments because of the many barriers, topographic or otherwise, which exist. The absence of abyssal plains at or near the depositional site indicates, as well, that turbidity currents were inactive in this region. As will be shown, the presence here of redeposited nannofossils is more easily explained by a different sedimentation agent.

Slumping

Slump deposits are characterized by contorted strata or brecciated sediments. Because both of these features are commonly induced by the drilling process, they are questionable as criteria diagnostic of slumping. No contorted or brecciated sediments of definite slump origin were noted. The generally flat to low angle seismic dips seen on the Site 32-34 seismic profiles indicate that slumping would be uncommon there. A few semi-indurated pods of volcanic ash and nannofossil ooze in Hole 36 may have been derived by slumping from a nearby hill. The high relief in this area plus good evidence for slumping in the underlying pelagic sediments suggest that slumping also contributed to the terrigenous deposits.

Eolian Transport

Present data allows only for speculation concerning the influence of wind transport on sedimentation at Sites 32 through 36. The region encompassed by these sites is one for which a high rate of tropospheric transport has been postulated (Rex and Goldberg, 1962). In pelagic sediments the products of such transport are commonly identified under the microscope by the amount of silt-sized quartz grains present. These grains are present in varying amounts in the terrigenous sediments; and, unfortunately in these sediments, other depositional agents can also account for their presence, thus they lose their diagnostic value.

The effects of eolian transport obviously are somewhat dependent on the influx rate of other sediments. On this basis one would expect Hole 35 to have the lowest percentage of eolian material in its sediments, and the older (Oligocene) sediments at Hole 34 the highest. However, because of the high influx rate of most terrigenous sediments, eolian transport is believed to have been a minor contributor to most intervals at terrigenous sites.

Extraterrestrial Components

No extraterrestrial constituents were noted in the terrigenous sediments of Leg 5. This is a constituent not normally identified during rapid scannings of smear slides, so its reported absence here should not be taken to mean cosmic materials are not present.

Biogenous Productivity

Biogenous material is of varying importance at Sites 32 through 36 and Site 43. Two basic groups of biogenous material are noted: fine-grained organic matter and the calcareous or siliceous tests of microfossils.

The organic matter is present in either a finely disseminated state or concentrated in thin beds ±1-centimeter thick. These thin beds are quite noticeable throughout most of the terrigenous sections of Holes 32, 33, 34 and 36.

To determine the amount of organic matter in the sediments, samples were submitted to Scripps for organic carbon analyses. Only samples representing the dominant lithologies in a core were selected; and, in this case, no samples were submitted from Site 43. The results of the analyses, given as the percentage of organic carbon, are shown in summary form on Table 2. (The results of analyses of Site 43 samples, which were submitted later, were not available for incorporation into the test.)

The results indicate that the organic-carbon content of the sediments was influenced by the nature of the depositional agents, sedimentation rates and distance from land. In Hole 32, the abundance of turbidite deposits and a moderate rate of sedimentation combined to produce the highest average organic-carbon content, 0.77 per cent, of any hole on Leg 5. This was

TABLE 2
Organic Carbon in Terrigenous Sediments

Hole	Number of Samples	$\% C_{org.}$
32	12	0.77
33	30	0.43
34	35	0.45
35	19	0.36
36	53	0.33

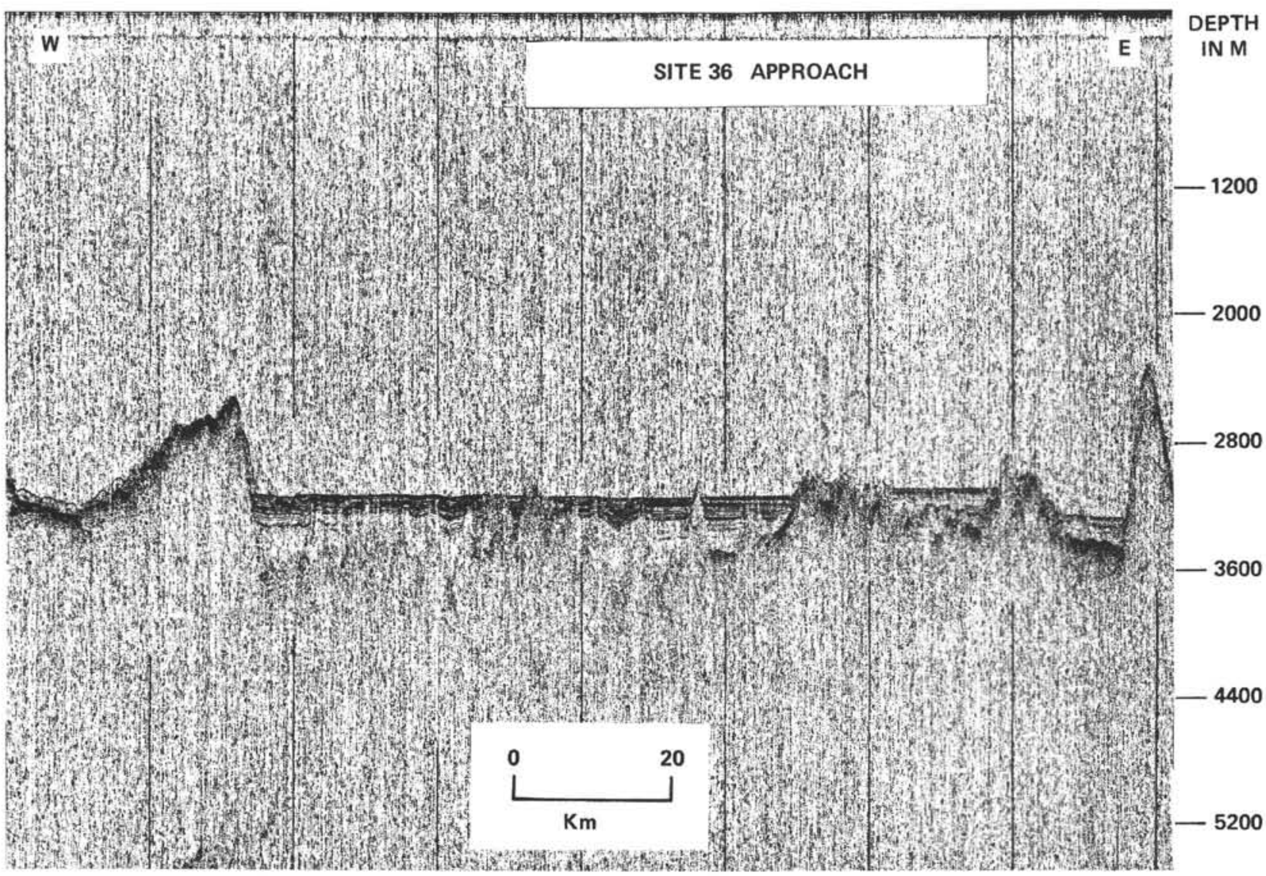

Figure 11. *Turbidites related to Site 35, ponded by barrier of abyssal ridges just east of Site 36. Changes in sedimentation conditions west of barrier are reflected by thinner sediment cover, whose surface parallels irregular abyssal hill topography. (*Argo *seismic profile, 15-16 March, 1969.)*

despite the fact that Holes 33, 34 and 35 are somewhat closer to land. The organic-carbon contents for Holes 33 and 34 are almost identical (0.43 per cent and 0.45 per cent, respectively), which would be anticipated from their proximity to each other. These values are greater than that for Hole 35, which had the highest sedimentation rate of any terrigenous hole, but the lowest organic-carbon content.

Romankevich (1968) and others feel that a high sedimentation rate should result in the quick burial and preservation of organic matter, which would favor a higher organic-carbon content. However, an analysis of data presented by Emery (1960) for the Continental Borderland off Southern California leads to a different conclusion. There a comparison of basinal sediments shows that those deposited at intermediate distances from shore and having intermediate sedimentation rates have the highest organic content. This same relationship probably applies to Holes 32 through 35. Hole 36 has an organic-carbon content almost as low as Hole 35. The high content of calcareous tests and the hole being a greater distance from land are factors which lower the organic-carbon content in Hole 36 relative to those holes found south of the Mendocino Ridge.

The organic-carbon content of near-surface sediments in the deep Pacific Ocean was recently studied and mapped by Romankevich. His method of analysis, although differing from the technique employed at Scripps, gives similar results. To derive comparable data, the organic-carbon content of the shallowest samples from Holes 32 through 36 was tabulated. This tabulation is shown in Table 3.

The map by Romankevich and the data in Table 3 are in good agreement. All of the Leg 5 data plot within an area shown on his map as containing 0.50 to 1.00 per cent organic carbon. The two sets of data differ mainly in that the map indicates a pattern of progressive decrease in organic carbon with distance from land, whereas, Leg 5 data indicate that the offshore decrease is irregular. The most likely causes of this irregularity are variations in sedimentation rate and the nature of the depositional agents active in an area.

Microfossil Tests

Of far greater quantitative significance are the tests of microfossils. This group can be divided into three subgroups, which are listed below according to their quantitative prominence in the Leg 5 sediments:

Siliceous microfossils:	Mostly diatoms and silicoflagellates, with some sponge spicules and radiolarians.
Calcareous nannoplankton:	Coccoliths, with minor amounts of discoasters and other calcareous nannoplankton.
Foraminifera:	Planktonic and benthonic forms.

Microfossils are found in most cores recovered from Holes 32, 33, 34 and 36. They are only absent from some of the deeper cores, such as, Cores 10 and 11 of Hole 32, and Cores 14, 15 and 18 in Hole 34. In Hole 35, they are present in Cores 1 through 6 and Core 12.

Ignoring the thinner intervals of biogenous ooze, the important subsurface occurrences of biogenous material can be grouped into two stratigraphic units. One, high in siliceous fossils, extends from near the Pliocene-Miocene contact down into the upper part of the Middle Miocene in Holes 32, 33 and 34. The other interval occurs throughout most of the Pleistocene-Upper Miocene deposits of Hole 36, and contains mostly calcareous nannofossils. Further drilling will be needed to determine the areal extent of these major biogenous intervals.

The development of these two major (and innumerable minor) intervals of high microfossil content is related to: (1) the solution of microfossils by sea-water, (2)

TABLE 3
Organic Carbon in Near-Surface, Terrigenous Samples

Hole	Core	Section	Depth (m)	% $C_{org.}$	Offshore Distance (km)
32	1	1	0.40	0.78	350
33	1	1	0.16	0.38	295
34	1	4	24.56	0.50	275
35	2	1	39.70	0.37	250
36	1	1	1.30	0.42	540

diagenetic alteration, (3) dilution by influx of clastic material, (4) surface productivity, and (5) processes of resedimentation. The latter factor is a product of other transport agents and, therefore, is treated elsewhere. Suffice to say, it was responsible for a significant proportion of the microfossils found in Holes 32, 33, 34 and 36.

The solution of microfossils is a highly selective process influenced by shell morphology and composition, the occurrence of certain trace elements in the test walls and/or the presence of organic sheaths. Solution begins when the organisms die, and it continues as they slowly sink through the water column. It progresses until they reach the ocean floor and are finally covered by a layer of sediment. Even then, post-depositional solution may occur. As a result, the thanatocoenosis incorporated in the sea floor sediments may be quite different from the biocoenosis in the surface waters. This is true of both the siliceous fossils (Lisitzin, 1967) and the calcareous forms (Berger, 1967).

Fossil tests may be completely dissolved within the water column if they reach their compensation depths before arriving at the sea-bottom. For calcareous tests this depth is near 4000 meters in the temperate regions of the Pacific. For siliceous tests it is closer to 5000 meters. The extreme water depth at Hole 43 (5405 meters) may partly explain the almost complete lack of fossil remains in its sediments. The greater depth at Hole 32 (4758 meters) relative to Holes 33 (4284 meters) and 34 (4322 meters) could also be the reason why the former hole has the smallest proportion of microfossils in its stratigraphic column. Such conclusions, however, must be tempered by the inability to determine the compensation depth at the time the older sediments were deposited.

The effects of solution on the fossil assemblages are obvious in all the terrigenous sediments. It affected the populations of siliceous fossils and calcareous nannoplankton as well as the foraminifera. (Further remarks on this subject are made by R. K. Olsson and E. D. Milow in Chapter 29.)

Diagenetic changes did not alter significantly the biogenous content of the sediments. Local pyrite replacement of siliceous tests was noted in Holes 32, 33 and 34. Occasionally, pyrite was also found in burrow tubes. Iron and manganese coatings occur on some siliceous fossils. Alteration of opaline tests probably contributed to the formation of chert nodules and layers in the lower portions of Holes 33 and 34.

A common, though minor constituent of most cores from the terrigenous holes is a highly birefringent mineral which appears to be a carbonate. It occurs usually as irregular-shaped, silt-sized particles, and appears to represent an alteration product of calcareous fossils. Whether most carbonate particles encountered in the Leg 5 holes originated in this manner is not known. Some high concentrations found above basaltic basement may reflect the alteration of volcanic materials.

In Hole 35, microfossils are few or absent. Significantly, the finer-grained sediments within this interval contain a higher proportion of carbonate particles than any other cored interval on Leg 5. If these particles are diagenetic alteration products of calcareous tests, their prominence here may reflect the location of the depositional site above an active ridge of sea-floor spreading.

At Hole 35, the dilution of fossil content by the influx of clastic material was also a factor. Here a depositional rate 20 to 30 times greater than that in adjacent holes has no doubt contributed to the small proportion of fossil tests in the sediments.

More difficult to discern is the factor responsible for the high fossil content of the U. Mio-Pleistocene interval at Hole 36. At first, based on a comparison of the sedimentation rate and fossil abundance of this interval with that of the equivalent interval at Holes 33 and 34, one might simply attribute this to higher surface productivity. Although the sedimentation rate for this interval is not much higher at Holes 33 and 34 than it is at Hole 36, the average fossil content of the latter is nearly four times that of the former holes. This indicates that fossil tests accumulated at a much higher rate at Hole 36.

The fact that Hole 36 (3273 meters) is well above the compensation depth for calcium carbonate while the other holes are not suggests, however, that solution also played a part. Consequently, it is difficult to say which factor was more important, solution of microfossils or greater surface productivity.

Differing rates of surface productivity seems to be the explanation for one fossil characteristic of Holes 32, 33 and 34. The Upper Tertiary section in all three holes contains significantly more siliceous fossils than the Pleistocene strata. Again this conclusion may be illusory, as Pleistocene siliceous organisms are believed to have been relatively thinner-walled than their predecessors (Moore, 1969). They would be less likely then to survive ablation while settling through the water column.

These are some of the difficulties encountered in deciphering which factor or factors explain the fossil peculiarities of the Leg 5 sediments.

Volcanism

Table 1 indicates that volcanic ash was encountered in each of the terrigenous holes. It occurs as discrete beds, discontinuous lenses or pockets, and as disseminated glass shards. In places, alteration of the glass shards has taken place.

The beds of volcanic ash are fine-to medium-grained, 1 to 12 centimeters in thickness, and some exhibit graded bedding. Their presence in Holes 32 to 36 is close to, or south of, the southern margin of their occurrence on Horn's map of the northern Pacific (Horn, *loc. cit.*). It should be remembered, however, that this map is based only on the shallow data obtained by piston coring.

Volcanic sediments are minor constituents in every terrigenous interval. They constitute no more than 5 per cent of the total sediment section.

Grain-by-Grain Settling

North of the equator the Pacific Ocean is dominated by a large, subtropical gyre of surface water flowing in a clockwise direction throughout the year. This flow is fastest in the western Pacific where the analog of the Gulf Stream, the Kuroshio Current, flows northward and finally turns eastward at between 30° and 40°N. Variously known as the North Pacific, Westwind Drift or Japan Current, this eastward moving current diminishes somewhat in flow velocity as it continues across the Pacific. Upon approaching the eastern margin of the Pacific, this current, whose northern boundary is now at the latitude of northern Washington, splits into two segments. One, a smaller flow, travels north and develops a counterclockwise gyre in the Gulf of Alaska. The remaining flow sets south as a broad, deep, slow-moving water mass known as the California Current. As it passes the California coast, this current extends approximately 1000 kilometers offshore, with an inshore subsurface countercurrent perhaps 100 to 500 kilometers wide (Reid, 1965). Thus, there is a broad offshore band of southward flowing water available to distribute lutites over the region encompassing Sites 32 through 36 (Figure 12).

The problem now becomes one of moving continentally-derived particulate matter into this distribution system. An examination of the present system of nearshore marine currents shows that they are transporting fine sediments across the shelf, but are not moving them as far as the inshore edge of the California Current. It therefore becomes necessary for the rivers themselves to directly transport their load into the California Current. Where such transport exists it can be recognized by the presence of muddy, fresh-to-brackish water plumes on the surface of the ocean. Although these plumes develop off the mouths of many West Coast rivers while in spate, their fluid discharge is in most cases insufficient to allow the plumes to continue more than 20 to 30 kilometers offshore. Consequently, they do not reach the mainstream of the California Current. There is one exception, the Columbia River, which has both the highest fluid discharge and the largest sediment load of any West Coast drainage system. Its sediment load prior to the damming of various tributaries was 6.8×10^7 metric tons per year (Judson and Ritter, 1964).

Park (1968), working with surface salinities, noted that the influence of Columbia River water could be identified 300 kilometers offshore; and, Reid (personal communication) has traced it as far south as San Francisco. However, Pak (1970) noted that the particulate matter of the Columbia River plume could be traced only 225 kilometers to the southwest (Figure 12). He believes that with optimum wind and current conditions, the suspended matter could travel perhaps 375 kilometers in the surface waters. Even so, this is still a considerable distance north of Sites 32 through 36. Furthermore, the plume sediments probably represent a small part of the total suspended load of the Columbia River, as there is evidence that most of this load is deposited soon after it enters the ocean. Thus, Duncan *et al.* (*loc. cit.*), who analyzed clay minerals on the floor of Cascadia Basin, found that the influence of the Columbia River material carried only a short distance into this basin. Pak also noted that the coarser suspensoid dropped out rapidly and, in addition, actually traveled northward. Finally, there is evidence that particle scavenging by organisms in the surface waters accelerates the fallout of suspended matter to the ocean floor. In summary, only a small part of the Columbia River suspensoid is entraining into the California Current of which an even smaller portion is available for deposition at Sites 32 through 36.

The Columbia River is believed to have been active during much of late Cenozoic time. During this period, there is no reason to believe that it ever was a more important contributor to the California Current than it is now (except possibly during the Pleistocene Epoch). Consequently, the amount of grain-by-grain particles available from this source was, if anything, less during the past.

There is the possibility that the Mendocino Ridge acted as a minor source of particulate matter for the California Current. The *Argo* Site Survey records indicate that the Mendocino Ridge is almost completely barren of sediments, but biogenous oozes are found on protected ledges. Some of these oozes contain fossils coated with iron or manganese (Krause *et al.*, 1964), a characteristic of some of the displaced fossils in Holes 32, 33 and 34.

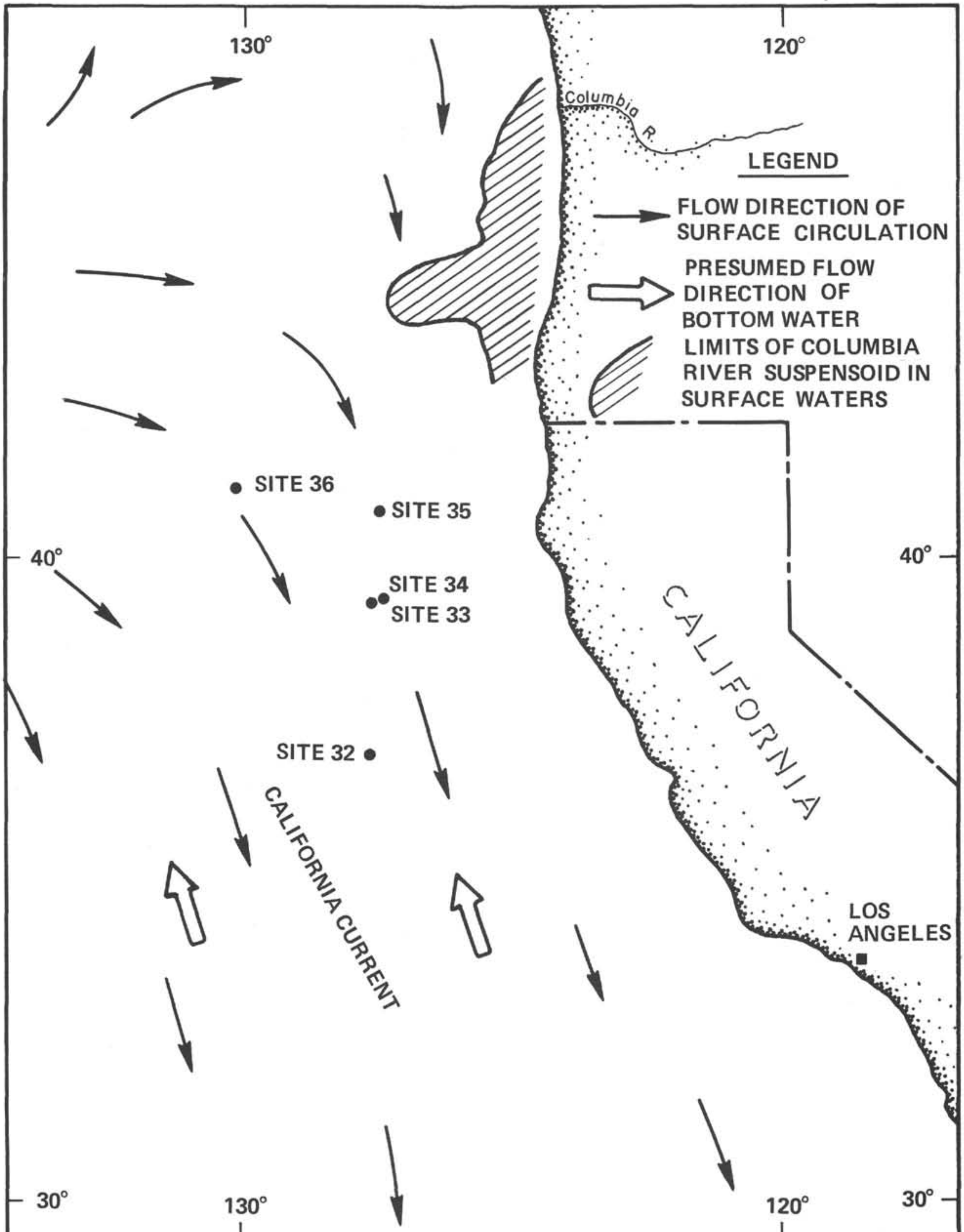

Figure 12. *Pattern of current flow in region of Sites 32 through 36. Flow of bottom water is poorly charted south of Mendocino Ridge, and is completely uncharted north of Ridge.*

Normally, the California Current has slow surface flow velocities (Reid, *op. cit.*). However this current is fairly thick, at least off Point Arguello, California, where Reid believes its flow may extend down to 3 kilometers. If it extends to similar depths off northern California, it would be constrained to flow faster as it passed over the topographic prominences on the Mendocino Ridge. The resulting amplification of current velocity might resuspend any oozes which settle there.

The older sediments just north of the Mendocino Escarpment in Hole 36 contain a small terrigenous component, present as an admixture of mud in the biogenous oozes and as several thin, fine-grained lutite intervals. As previously explained, this component does not appear to be of turbidite origin. There is good reason to believe that most of it was carried in by bottom currents (as is demonstrated in a later section), and that grain-by-grain settling was, at best, only a minor contributor.

Grain-by-grain settling could be expected to have been a more important agent at Site 35 than at Site 36, as the former is closer to the point where fine-grained sediments enter the ocean. On the other hand, the much higher depositional rate at Site 35 (due to the influx of turbidites) would probably dilute grain-by-grain settling to where it was even less of a factor. It certainly does not seem to have been an agent of more than minor importance.

Being farther from the point where particulate matter entrains into the California Current, Sites 32, 33 and 34 could be expected to have received even fewer grain-by-grain deposits. At Site 32 the equivalent of only ±30 meters of sediment are unaccounted for by previously discussed depositional mechanisms. This sediment occurs in thin-bedded, light-colored intervals between the darker-colored strata which seemingly represent the pulses of turbidites dominating the section. The less prominent lighter-colored intervals apparently accumulated during the long periods of quiescence between turbidite flows.

Similar light-colored muds are found at Sites 33 and 34. With the exception of one darker lutite interval in Core 6 at Site 34 and a few thin beds at Site 33, they dominate the section here. Also, they are thickly instead of thinly bedded. At these sites the equivalent of ±175 meters of terrigenous detritus occurs within the light-colored muds which have not been accounted for by depositional mechanisms already described. Apparently, slow deposition and quiescent conditions were the rule rather than the exception at Sites 33 and 34. Paleontologically, there is also a difference between the light- and dark-colored muds. Both contain redeposited fossils, although they are much fewer in number in the lighter-colored muds.

That the dominant mode of sediment emplacement differs between Site 32, and Sites 33 and 34 is also evident from the *Argo* profiler records (particularly when comparing Sites 32 and 33). At Site 33, where turbidites contributed little to the stratigraphic column, the irregular configuration of most of the surface sediments reflects in a subdued manner that of the underlying oceanic crust (Figures 14 and 15). At Site 32, where turbidites were so important, there is a ponded, rather than a mantled configuration of the surface sediments (Figure 5).

The question now is, do the lighter-colored muds represent grain-by-grain deposition? That the mantling of basement topography in this region is indicative of grain-by-grain settling was first suggested by Winterer *et al.* (1968). Nevertheless, there are reasons to believe that this settling did not take place by sediments settling from a broad, distributive surface current (as the California Current). First, if the California Current was capable of transporting ±175 meters of sediment 750 kilometers south to Sites 33 and 34, then it should have been able to transport almost the same amount 250 kilometers farther south to Site 32.

Another figure can be cited on the disparity in thicknesses of nonturbidite sediments for sites located north and south of the Pioneer Fracture Zone. The abyssal hills near Site 32, which protrude above the abyssal plains, have a 100 to 120 meter sediment cover. The total sediment thickness at Site 33 is ±350 meters. Even allowing for a somewhat greater contribution of biogenous ooze to Site 33, these figures still represent a significant difference in thickness. This is in spite of the fact that Site 32 has had a longer depositional history than Site 33.

A second reason for believing that the California Current was not too significant as a distributor of grain-by-grain sediments is the large time lag between the first appearance of green terrigenous muds at Sites 33 and 34 versus Site 32. With a broad, southward-flowing surface current as a distributing agent, the terrigenous muds should have appeared simultaneously at all three sites. Instead, they are present in the oldest sediments, dated as late Oligocene, at Sites 33 and 34; but, they do not appear until late Miocene time at Site 32. This suggests that whatever agent transported them to the more northern sites was not operative at the southern site, a description hardly fitting the California Current.

The preceding discussion on grain-by-grain settling indicates that as an agent of sedimentation it was at best of minor importance. This is true even at Site 33, where a thick blanket of sediment mantles the abyssal hill topography.

Bottom Currents

Before describing the effects of bottom currents on the Leg 5 terrigenous deposits, a brief description of their present activity in the northeast Pacific is in order.

Several deep-water bottom-current measurements have been made by others at stations north, east and south of Sites 32 through 36 (Figure 13). Data from stations 2 and 5 represent short-period observations, whereas, at stations 1, 3 and 4, observations were for periods of greater than one day. Their data, when examined on the basis of average flow velocities, indicate weak current flow on the order of 1 to 4 cm/sec. However, Nowrozzi *et al.* (1968), Luyendyk (1969), and Korgen *et al.* (in press) also present data on short-period velocity fluctuations which show that speeds of 6 to 8 cm/sec are not uncommon, and that even occasional maxima of 17 to 19 cm/sec occur.

The effect of bottom currents on sediment redistribution in a region of abyssal hills was examined by Luyendyk in an area south of the Monterey Fan (Figure 13). This region was also characterized by abundant tracks of benthonic organisms on the sea floor. He concluded that their effect on local sediment redistribution was appreciable.

Those authors who analyzed the bottom-current measurements for their transient and steady-state components concluded that most of the flow velocity was due to transient currents. Isaacs *et al.* (1966) recorded a 2 cm/sec component, and Nowrozzi a 0.6 cm/sec component of steady-state flow. Such low velocities agree with concepts regarding the strength of geostrophic flow in this part of the Pacific.

The bottom-current measuring stations contribute little information on the flow direction of the steady-state currents. Although some southeasterly flow directions were recorded by Isaacs and Sternberg (1969), these data are not considered to be reliable (Reid, personal communication). More valid is the data of Nowrozzi, who observed a 273-degree direction of net transport at a station east of Site 32. This direction fits in with general theories of ocean-bottom circulation which, since the studies of Wüst, favor a north to northwesterly current-set off the continental margin of North America. This has recently been borne out by the studies of Ewing and Connary (in press) who cite evidence that Antarctic Bottom Water (AABW) flows northward in this area. This slow-flowing bottom current must be strongly influenced by the Mendocino Ridge. It would not be unrealistic to assume that its flow direction is diverted westward by this topographic prominence.

The pattern of bottom flow north of the Mendocino Ridge is poorly understood. It is likely, as will be shown later, that the sea floor at Sites 35 and 36 is now (and was during the geologic past) affected by steady-state currents.

Information concerning nepheloid layer transport in the eastern Pacific was lacking until the recently published data of Ewing and Connary. Their work indicates the presence of a bottom-current nepheloid layer flowing north along the continental margin off western North America (from which it apparently also receives much of its sediment load). South of the Mendocino Ridge this layer extends from a depth of about 3500 meters down to the sea floor. Its intensity is *weak* in the area south of Site 32, but from there north to the Mendocino Ridge its intensity is *moderate*. North of the Mendocino Ridge, the top of the nepheloid layer extends into shallower water, because of the shallower bottom topography. Near the Mendocino Ridge (i.e., near Sites 35 and 36) its intensity is *moderate* to *strong*.

The data of Ewing and Connary suggest active bottom currents near Site 43. They note that the flow velocity of AABW is amplified as it flows eastward in the constricted passage between the Hawaiian Platform and the Christmas Island Ridge. Currents with velocities of 15 cm/sec were found by Reid (1969) in another passage where the flow of AABW was constricted. Ewing (personal communication) measured velocities of 7.5 ± 2.9 cm/sec at a station southeast of Hawaii and just north of Site 43. A bottom-current nepheloid layer having a *strong* intensity was also detected there.

With this background on present conditions of bottom-current flow and nepheloid layer transport at Sites 32 through 36 and Site 43, it becomes easier to examine their past sedimentation record.

There admittedly is a hazard in extrapolating from present-day conditions of bottom-current flow and nepheloid layer transport to the effects their ancient counterparts may have had on older sediments. Fundamental to such extrapolation is the concept of "the relative permanence of the ocean basins". From this concept there stems the belief that the locations of the Leg 5 drill sites were *seaward of the continental margin* throughout their depositional history. If anything, during the geologic past they may have been even farther seaward than they are today–which would follow from the effects of sea-floor spreading tectonics. It appears likely that these drill sites were always in the abyssal realm, where factors influencing the flow patterns and velocities of ocean currents change very slowly.

At Site 32 the effects of burrowing organisms were minor, as evidenced by the few burrow-mottles in the sediments. In addition, as this site is located on an abyssal plain, transient currents were probably ineffectual in modifying sediment thicknesses. Present-day evidence of the flow of a *weak-to-moderately* intense

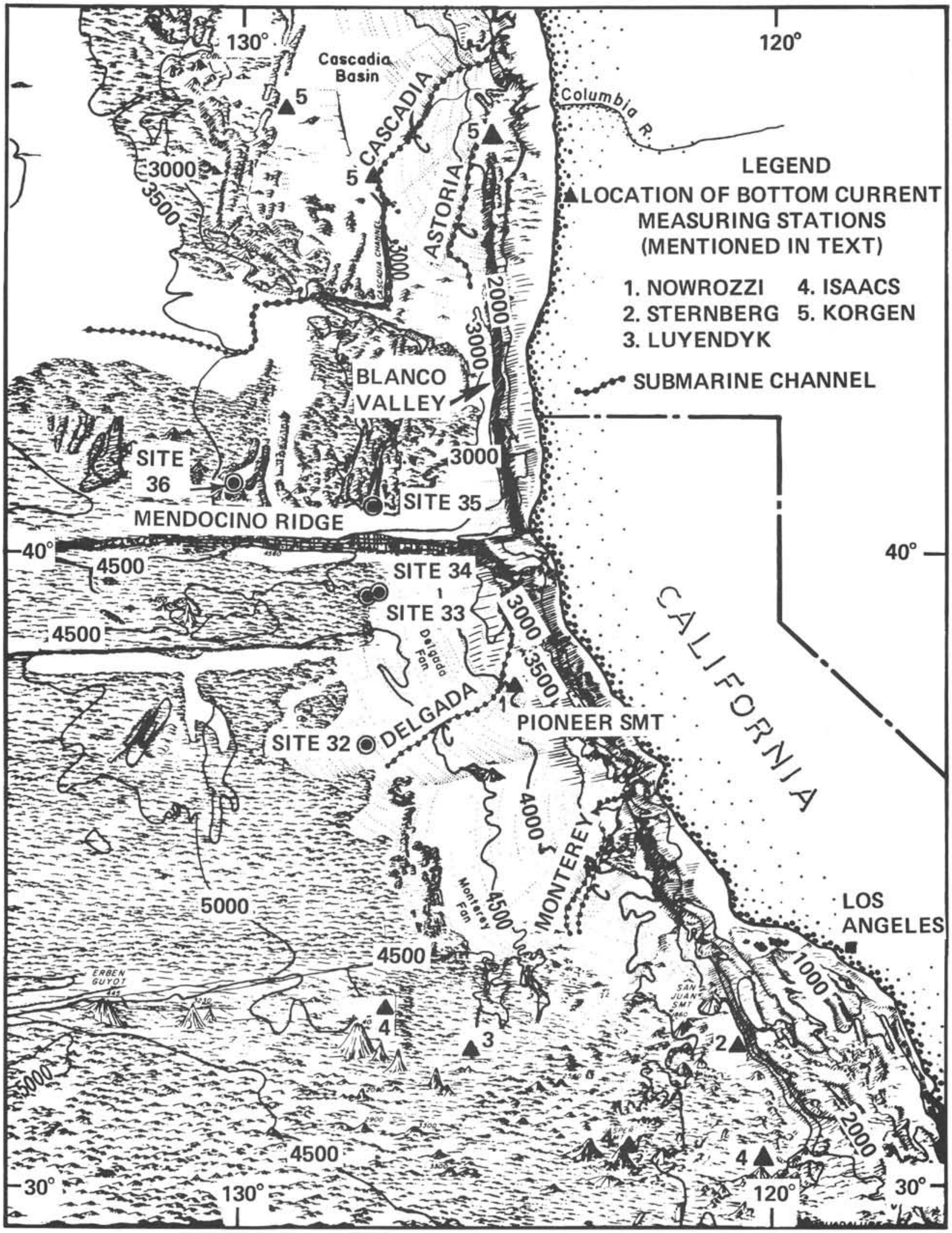

Figure 13. *Locations of bottom-current measuring stations in region of Sites 32 through 36. Prominent submarine channels are also shown.*

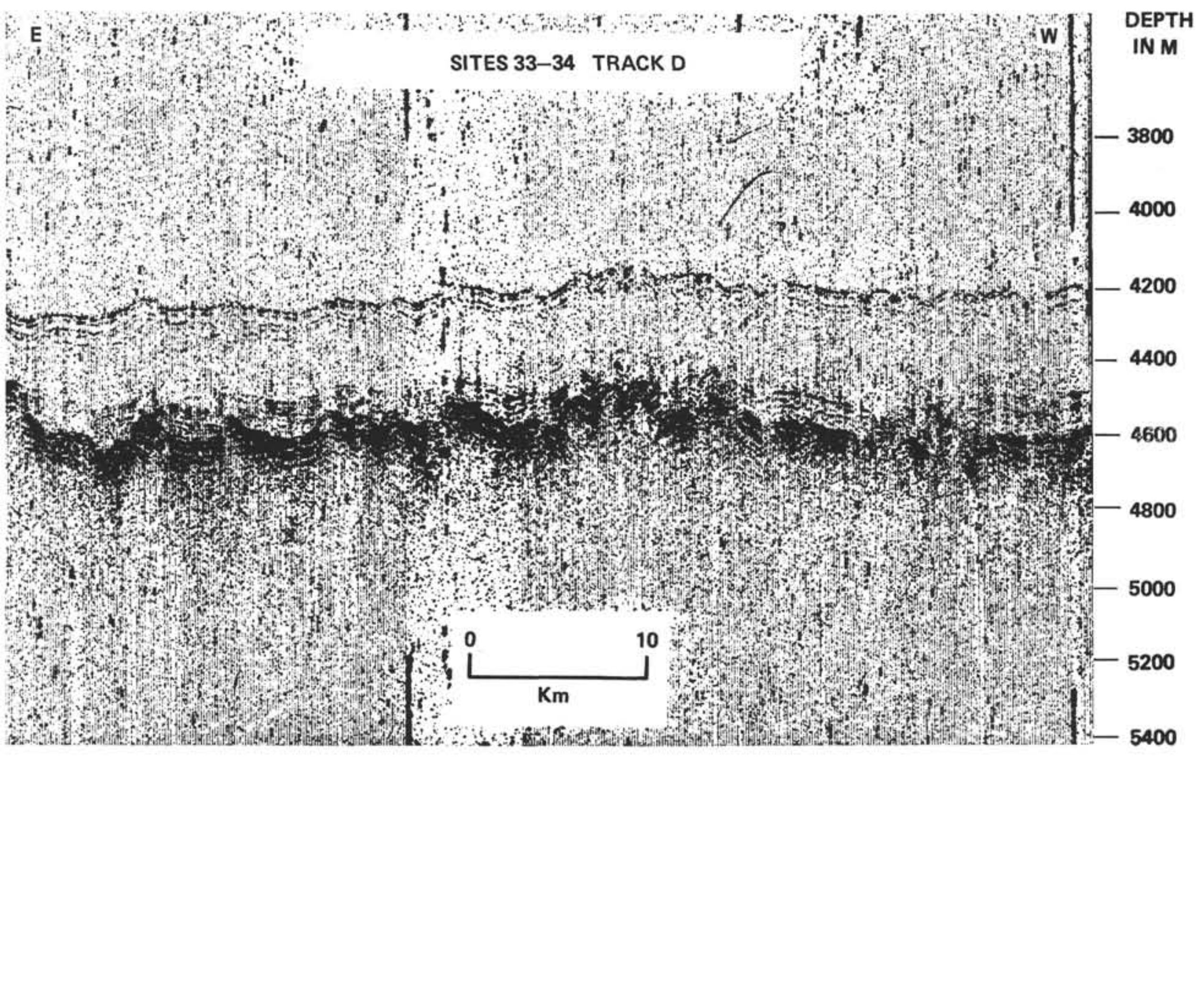

Figure 14. *Irregular sediment surface is seen to reflect configuration of underlying basement topography. Such mantling typifies region near Site 33. Discontinuous reflectors above basement are probably Middle Miocene siliceous mudstone and chert layers. Track runs 22 kilometers north of Sites 33 and 34. (*Argo *seismic survey, 11 March, 1969, 1040-1435.)*

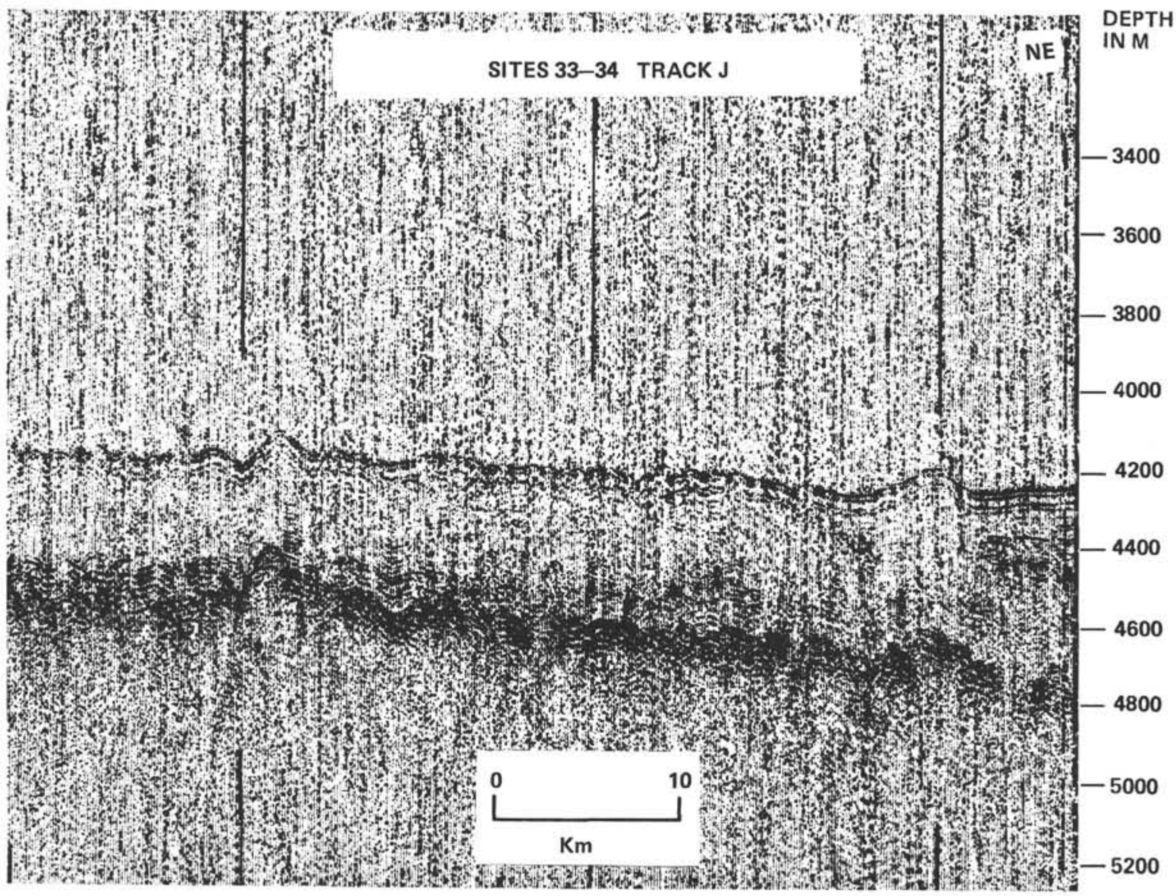

Figure 15. *Features similar to those seen on Figure 14 are visible. Sediments here are mostly fine-grained muds, with some oozes. Muds are believed to represent nepheloid layer deposition. Site 33 is located 4 kilometers south of right hand margin of figure.* (Argo *seismic profile, 12 March, 1969, 1535-1840.)*

nepheloid layer near here suggests that steady-state currents may have contributed appreciably to the approximately 30 meters of fine-grained lutites unaccounted for by other agents. Therefore, bottom currents appear to have been a depositional agent of moderate importance at Site 32.

Transient currents may have been an important factor in redistributing sediments at Sites 33 and 34. (This would have terminated at Site 34 following the development of an abyssal plain.) The *Argo* presite survey of Site 33 indicates that the original basement relief is much subdued at the sediment surface. Also, the sediments in Holes 33 and 34 exhibit more burrow mottling than those in Hole 32. Both factors suggest that a significant transfer of sediments, from abyssal hills into troughs by bottom-current flow, may have taken place. However, as components of both transient and steady-state current motion were probably active, it is difficult to assess which may have been responsible for the redistribution of sediments. The present assumption is that both were.

Attesting to the present activity of bottom currents in this region is a feature which can be seen on Figure 16; the profiler section shows a moat developed at the base of a large hill protruding through the sediment cover. Such moats are formed where the bottom-current flow is locally amplified by topographic prominences. The resulting more rapid flow causes erosion or non-deposition of sediments.

Some of the evidence which indicates that steady-state currents were an important depositional agent at Sites 33 and 34 has already been presented in the discussion on grain-by-grain settling. In summary form this and other evidence consists of the following points:

1. A steady-state current containing a nepheloid layer, whose intensity increases toward the Mendocino Ridge, now flows in this region.

2. There are ±175 meters of fine-grained sediment whose deposition cannot be explained by turbidity current transport, grain-by-grain settling from the California Current, or by any depositional agent other than nepheloid layer transport.

3. The manner in which the basement topography is mantled by fine-grained sediments can be accounted for by the way particles settle from a *slowly* moving nepheloid layer.

4. The older and thicker accumulation of terrigenous muds at Sites 33 and 34, relative to Site 32, is not compatible with known distribution paths of other depositional agents. It is compatible with a model which assumes a nepheloid layer flowing northward along the continental margin and then being diverted in a westerly direction near the Mendocino Ridge. With this model and by utilizing the theory of sea-floor spreading, one can visualize that during Oligocene time Site 32 was too far offshore to be affected by a northward-flowing nepheloid layer transporting terrigenous material along the continental margin. Sites 33 and 34, although situated a similar distance offshore, would receive this material because there the path of the nepheloid layer was being directed westward. Eventually, as sea-floor spreading continued, Site 32 neared the continental margin and, also, began receiving such deposits.

In addition to these points, the presence of redeposited fossils through most of the sediments at Holes 33 and 34 can also be reconciled to the concept of nepheloid layer transport. This transport is known to be capable of redistributing fossil tests as well as terrigenous particles over wide areas.

Another observation favoring deposition from a nepheloid layer is provided by Griffin *et al.* (1968). They noted a uniform band of high montmorillonite clay fringing the western borders of the North American continent south of the Mendocino Ridge, and felt that this marked the seaward limits of continental detritus. Such a widespread band is most easily explained as resulting from the homogenizing effect of a broad nepheloid layer.

Finally, bottom-current transport of nepheloid layers is being increasingly recognized as a depositional agent along continental margins.

The preceding discussion, although not conclusive, makes a strong case for steady-state currents having had a strong influence on sedimentation at Sites 33 and 34. This influence, plus that of transient currents, indicates that bottom currents were of major importance at these two sites.

At Site 35 burrow-mottles are rare in the sediments, and the depositional site is located on an abyssal plain. Therefore, transient currents were probably ineffectual in redistributing sediments.

The presence of a *moderately* intense nepheloid layer in the vicinity of Site 35—similar to that found at Sites 33 and 34—has been demonstrated by Ewing and Connary (*loc. cit.*). In addition, they recognize an intensification of the nepheloid layer below 3000 meters. That there is steady-state bottom current flow in this area seems certain, although whether it results from the flow of deeper portions of the surface gyre or by a separate bottom current is not known. No measurements of the steady-state component of bottom-current flow have been made there, although Korgen's *et al.* (*loc. cit.*) data suggest that it must be slow in this part of the Pacific.

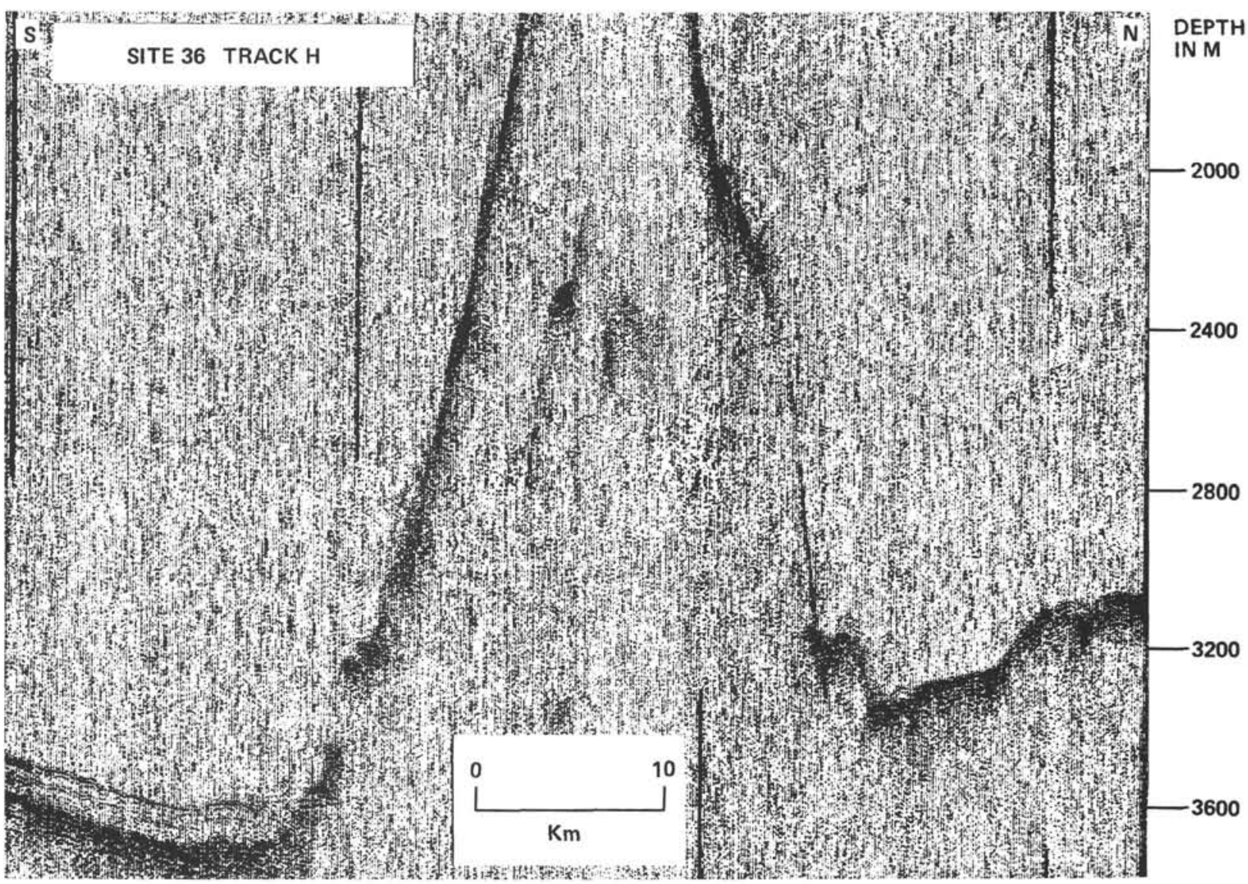

Figure 16. *Development of moat around prominent abyssal hill, believed to reflect effects of bottom-current flow. Track F was run about 25 kilometers west of Site 33.* (Argo *seismic profile, 11 March, 1969, 1930-2230.)*

Having established the present active flow of a nepheloid layer at Site 35, it is difficult to determine the rate at which it may have supplied sediments here in the past. By assuming that ±175 meters of fine muds accumulated in this manner at Sites 33 and 34 over a span of 32 million years, and by further assuming that a similar rate of accumulation prevailed at Site 35, it can be ascertained that nepheloid layer deposits account for no more than 1 per cent of the sediments. On this basis it is concluded that both transient and steady-state currents were of minor importance.

The effects of bottom currents near Site 36 apparently varied. There are large tracts at Site 36 where uniform thicknesses of sediment mantle the low-relief abyssal hills, and no sediment ponding has developed (Figures 17 and 18). This feature, plus a general lack of burrow-mottles in the sediments, suggests that sediment redistribution by transient current flow was unimportant at Hole 36.

By way of contrast, other slightly more distant areas are completely devoid of sediments. This can be seen over some large tracts of the low-relief abyssal hills (Figures 18 and 19), as well as over the larger abyssal hills and seamounts (Figures 17 and 19). Sediment removal in these regions may reflect flow perturbation of steady-state currents. As these currents encounter major bathymetric prominences, local large-scale eddies develop. This is exemplified in the North Atlantic, where the flow of the Gulf Stream impinges on seamounts.

The detritus which can be eroded in this fashion may represent a significant contribution to the nepheloid layer detected by Ewing and Connary (in press) in this portion of the Pacific Ocean. Nepheloid layer transport may also have been a factor in the past at Hole 36, as its effects could account for some of the features observed in the sediment column. It is a transport mechanism that could more readily explain the minor amounts of terrigenous detritus present here than could turbidity currents, which had their access to this site blocked by sea floor barriers. This mechanism could also account for the broken and disaggregated nannofossil fragments, so prominent in some beds. Finally, it most easily explains the presence of those redeposited fossils which, on the basis of their age, must have been derived from a source many hundreds of kilometers away.

Bottom currents apparently also removed sediments at the pelagic-terrigenous contact in Core 12. Whether one or both sediment types were affected, obviously, cannot be determined.

In any event, bottom currents, represented mostly by the steady-state components of flow, appear to have been of moderate importance at Site 36.

An evaluation of the effects of bottom currents on the Hole 43 sediments cannot be made. That moderately-strong bottom currents exist in the area and have the potential to erode or deposit has been established. However, the eight meters of uniformly nonfossiliferous silty clay recovered there give no clues as to the effects these currents may have had. Also, the lack of seismic data at this site precludes making any further interpretations.

Summary Evaluation of Sedimentation Agents

The relative importances of the sedimentation agents recognized as having contributed to the various terrigenous sites are summarized on Table 4. Three of these, namely: turbidity currents, biogenous productivity and bottom currents, are identified as having had a major influence at one or more sites.

The importances of these agents are based on their contributions throughout the depositional history of a hole. When evaluated over a short period, their importances may have differed. For example, a rating of "minor" for volcanic activity at Hole 33 indicates that volcanic ash contributed little to the sediment column. However, at rare intervals volcanism was the dominant agent.

Several of the terrigenous sequences were developed by one major sedimentation agent. Hole 36, through the dominance of biogenous productivity, is characterized by nannofossil oozes. The persistent activity of turbidity currents at Hole 35 developed the monotonous sand-shale sequence.

In other stratigraphic intervals, two sedimentation agents acted simultaneously as major contributors. Thus, at Holes 33 and 34, steady-state bottom currents and biogenous activity combined to form the fossil-rich Middle Miocene-Lower Pliocene interval. The major contributors expanded to three in the interval represented by Core 6 of Hole 34, where for a short period turbidity currents were active along with the two aforementioned agents.

PELAGIC DEPOSITS

Characteristics

On the Leg 5 cruise, pelagic sediments were found at all open-ocean drill sites (i.e., Holes 37 through 42). Additionally, they occurred in sediments at nearshore Holes 32 and 36 (Figure 1).

In the open-ocean areas, the pelagic sediments vary in thickness from 17 meters (Hole 39) to 156 meters (Hole 40). Their geologic ages range from Pleistocene to early Eocene. Within this age span no definite Miocene fossils were found. The nearshore holes contain only 5 to 60 meters of pelagic sediments, which range in age from early late Miocene to late Oligocene.

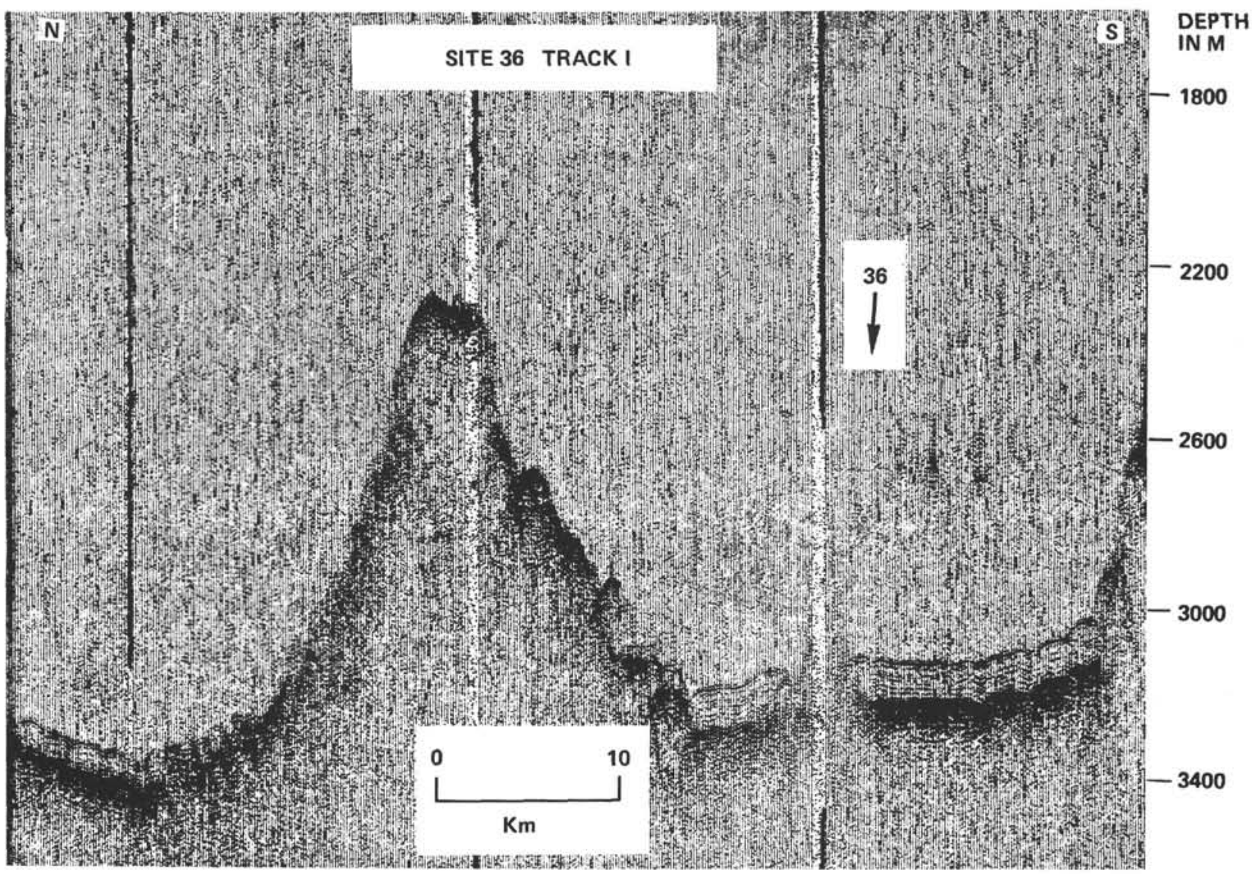

Figure 17. *Uniform ±100-meter-thick layer of sediment is seen covering low-relief basaltic basement on both sides of large hill, which appears to be free of any sediment cover. Site 36 projected from 3 kilometers east. (*Argo *Site Survey, 18 March, 1969, 0100-0420.)*

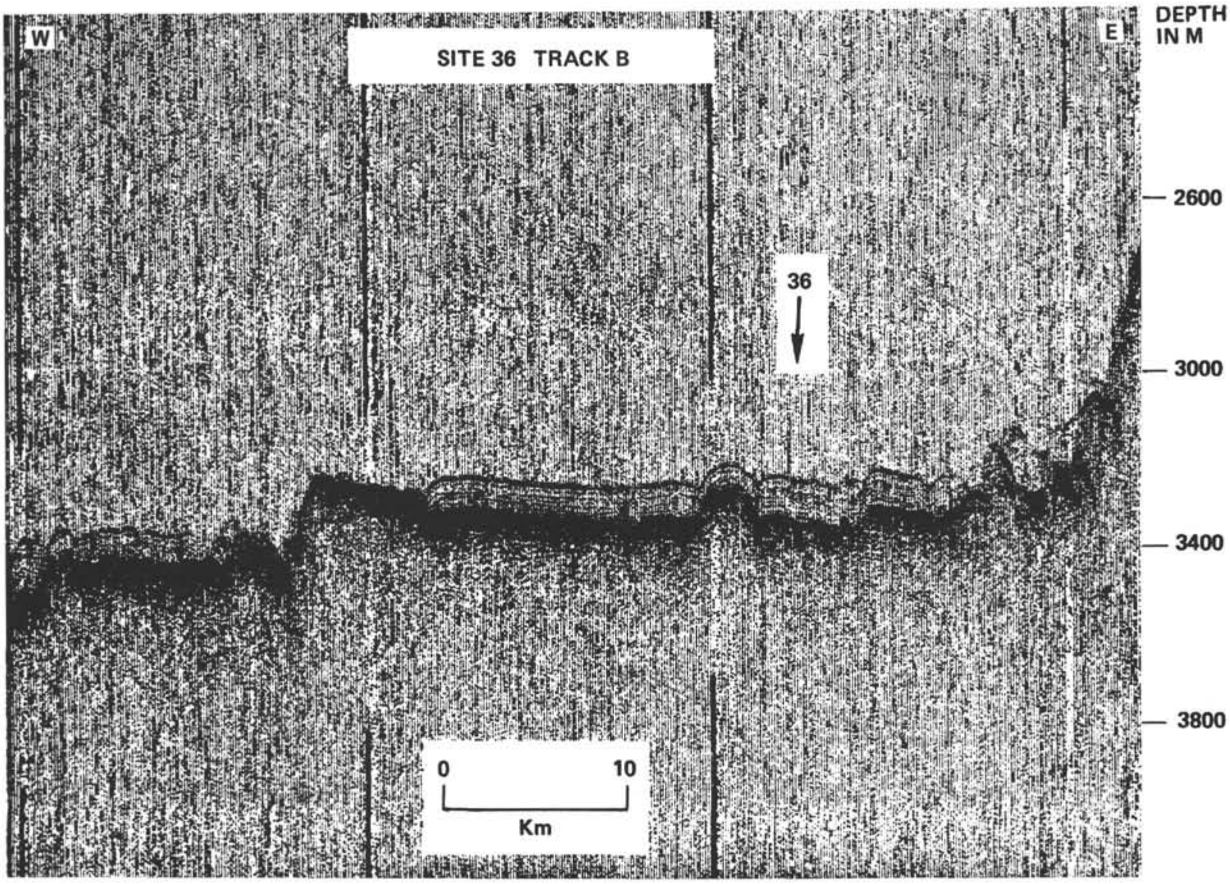

Figure 18. *Area of low topography near Site 36. Although sediment cover is fairly uniform throughout most of area, there are sharp local prominences barren of sediments. Site 36 projected from 2 kilometers north. (*Argo *Site Survey, 16 March, 1969, 1630-2000.)*

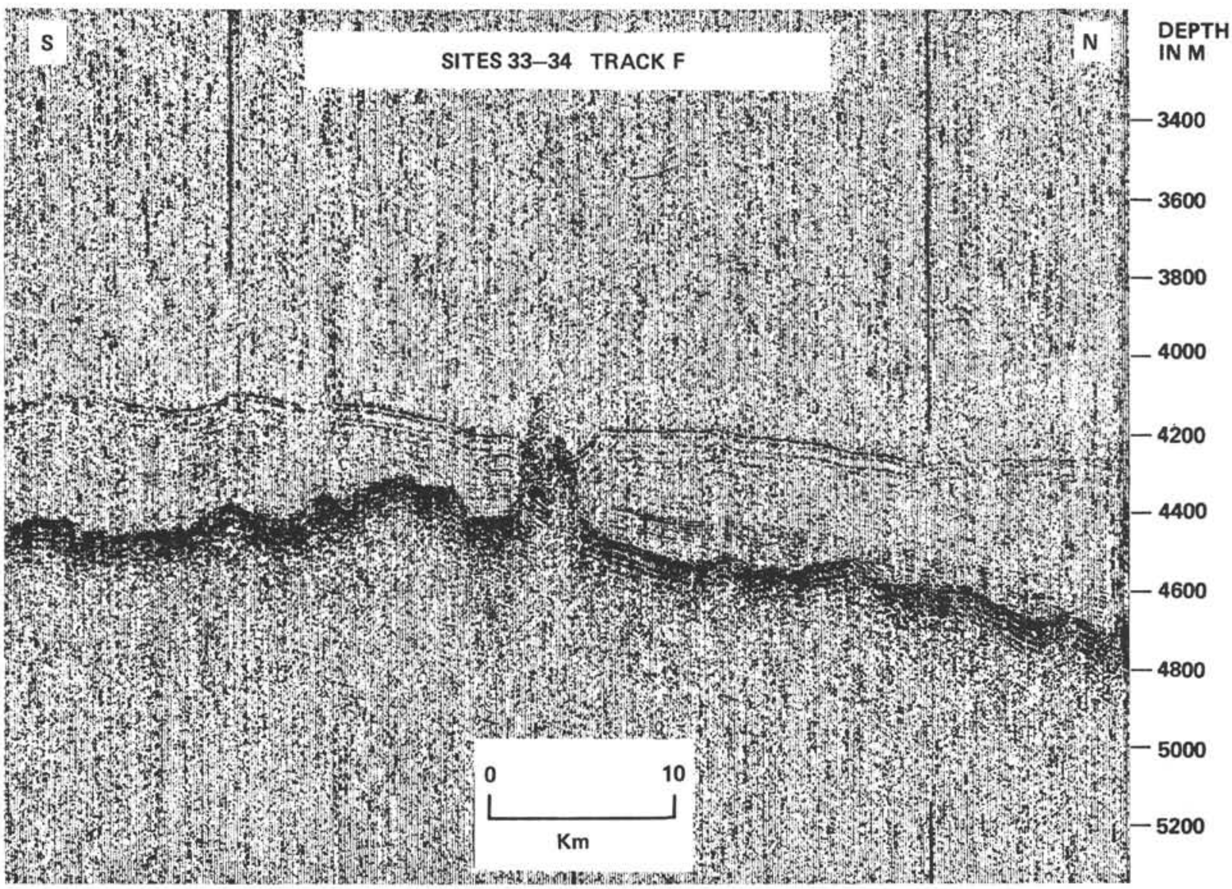

Figure 19. *Area of low topography south of seamount with uniform sediment cover. Similar area to north is barren of sediments as is the seamount itself. Track runs 25 kilometers west of Site 36. (*Argo *Site Survey, 17 March, 1969, 2000-2330.)*

TABLE 4
Importance of Sedimentation Agents at
Terrigenous Holes from Leg 5

Sedimentation Agent	Rankings in Order of Importance at Each Hole[a]					
	32	33	34	35	36	43
Turbidity currents	1	3	2	1	–	1
Slump deposits	–	–	–	–	3	–
Eolian transport	3	3	3	3	3	–
Extraterrestrial components	–	–	–	–	–	–
Biogenous productivity	1	1	1	3	1	3
Volcanism	3	3	3	3	3	3
Grain-by-grain settling	3	3	3	3	3	3
Bottom currents	2	1	1	3	2	2

[a] Rankings indicated here are:
1 = Major; 2 = Moderate; 3 = Minor; and, – = None.

The grain-size analyses indicate that some of the pelagic sediments are coarser-grained than the terrigenous deposits. This is particularly evident when comparing the grain-size plots of sediments from Holes 40 and 42 with those from most of the terrigenous holes (see Chapter 14). In the sediments from Holes 40 and 42, the silt and sand-sized fractions are quite pronounced. However, in many instances these fractions do not reflect the influx of terrigenous material, but instead mirror the large radiolarian content of the sediments.

All the sediments are soft and friable, except for some cherty, siliceous mudstones in Holes 40 and 42. The pelagic deposits are highly porous, and their average water content is greater than that of the terrigenous sediments. Seventy to eighty per cent interstitial water is common, and over 90 per cent was encountered in one hole. In these sediments, the radiolarian oozes consistently have the highest water content and porosity values. This probably results from the many unbroken radiolarian tests, which are largely water-filled. The "red" clays have intermediate values, and the nannofossil oozes have the lowest values of all. This relationship of water content between the latter two lithologies is similar to the findings in Keller and Bennett's (1968) study of the North Pacific.

Sedimentary structures are few, except for occasionally moderate-to-abundant burrow-mottles. No sediment structures reflecting current action were seen within the sediments. Bedding planes were commonly highly contorted by the coring process.

Sediment colors vary considerably, the so-called "red" clays showing various hues and intensities of red, pink, brown and yellow. Generally, these colors occur in the lighter shades of red, yellow or brown in the shallow horizons, and darker reds and browns in the deeper layers. The biogenous pelagic sediments often are shades of pale yellow, light-to-dark brown, or gray-brown; their indurated equivalents range to very dark brown.

The degree of lithologic variation is much less than that encountered in the terrigenous sediments, yet almost the same number of depositional agents contributed to both. This apparent contradiction can be explained by the manner in which these agents contributed their products to the pelagic sediments: except for the effects of biologic productivity and solution, the contribution from the various agents remained relatively constant both in quantity and time. Consequently, lithologic changes within any hole are usually gradual. The greatest variability is encountered in Hole 42, and here it simply reflects alternating types of microfossil tests in the biogenous oozes.

In spite of the higher degree of lithologic homogeneity in the pelagic sediments, it is still difficult to carry stratigraphic units for any distance. However, the reasons for this difficulty are different from those for the terrigenous strata. Most of the pelagic drill sites are farther away from each other than are the terrigenous sites. This by itself does not cause the difficulty, as the ability to trace such units is strongly dependent upon whether one is correlating along or across depositional strike. In the region of Holes 37 through 42, depositional strike for some of the sedimentation agents is zonal because their material is distributed in a more nearly east-west direction. Consequently, the north-south track of Holes 37 through 42 crosses their depositional strike.

Another factor contributing to the difficulty in carrying stratigraphic units in the pelagic sediments is the presence of depositional hiatuses and/or erosion. This is exemplified by the stratigraphic dissimilarity of Holes 40 and 41, which were drilled only 15 kilometers apart. Finally, there is the absence of fossil remains in the "red" clays which makes it impossible to age date them.

Broadly speaking, the pelagic sediments can be divided into two major types: "red" clays and biogenous oozes. These can be further split into two subtypes, the former on the basis of its zeolite content, and the latter on whether the fossils have siliceous or calcareous tests.

"Red" clay deposits are found in all holes containing pelagic sediments, except for Hole 42. In Holes 37 and 39, "red" clay makes up almost the entire stratigraphic column. Additionally, in Holes 32, 36, 38 and 41 it is the predominant facies of the pelagic sediments. The maximum thickness of "red" clay, ±60 meters, occurs in Hole 32.

Biogenous oozes in the pelagic sediments generally contain fewer admixtures of other sedimentary materials than their equivalents in the terrigenous deposits. They have their greatest development at Hole 42, where they make up the entire 113-meter interval, and at Hole 40, where they constitute 142 meters of the 156 meter sediment column.

The biogenous oozes characteristically had a fairly high sedimentation rate, at times surpassing that of some terrigenous units. "Red" clays, where data are available, had low sedimentation rates. This subject is expanded in Chapter 31.

Many minor constituents are present in the pelagic sediments. As Table 1 indicates, the number of lithologic constituents is not much smaller than that in the terrigenous deposits.

One problem in recognizing and evaluating the contributions of the depositional agents to the pelagic sediments is the development of authigenic minerals. Although such minerals also accompany terrigenous deposits, they are more prominent in the pelagic realm. Two authigenic minerals of significant interest associated with the pelagic sediments are manganese nodules and zeolites. The manganese nodules do not appear at the nearshore pelagic sedimentation sites, Holes 32 and 36. At both of these sites the pelagic sediments are overlain by terrigenous deposits. However they were photographed on the sea floor at Site 36 by the *Argo* presite survey. They are also absent at Site 38. In the other pelagic holes, they occur both at the surface and in the cores. Almost all the down-hole occurrences can be attributed to drilling contamination, except possibly at Site 37.

The zeolites, found in all but Hole 36, are present in both the biogenous oozes and the "red" clays. In the oozes they occur only in local concentrations, as fairly pure deposits. The zeolites have a similar mode of occurrence in the "red" clays, but here they are more often disseminated through the sediments. Their abundance relative to sediment color and inhole depth is covered in a later section.

Recognition and Importance of Sedimentation Agents

As in the terrigenous deposits, the importance of some sedimentation agents was easily determined, whereas, the influence of others could only be approximated from the data available.

Most difficult to evaluate is the origin of the "red" clays. X-ray studies of Pacific Ocean "red" clays by previous authors (Griffin and Goldberg, 1963) indicate a great complexity of clay minerals in the North Pacific, suggesting a multisource origin. By contrast, the less complex mineralogy of the South Pacific clays points to a relatively simple origin, probably largely authigenic in nature. Because of the uncertainty regarding the ultimate derivation of the "red" clays, the sedimentation agents are not ranked as to their importance on the summary table as was done for the terrigenous sediments.

The sedimentation agents will again be described in the order listed below:

1. Turbidity currents
2. Slumping
3. Eolian transport
4. Extraterrestrial components
5. Biogenous productivity
6. Volcanism
7. Grain-by-grain settling
8. Bottom currents
9. Magmatic exhalations

Turbidity Currents

Although turbidites originating in shallow water can and do occur in pelagic sediments, no such deposits were recognized on Leg 5. Their absence in Holes 37 through 42 is easily understood because of the great distance between these holes and the continental margin. Heezen (1963) shows that much of the North Pacific, including the locales of Holes 37 through 42, is inaccessible to turbidites derived from continental landmasses.

Their absence in Hole 36 is basically for the same reason, although turbidites are now accumulating just east of here as well as to the north and northwest. Hole 36 is isolated from flows from the east by a prominent abyssal ridge (Figure 11), and from north and northwest flows by being on slightly higher topography. In addition, during the period of Middle Miocene pelagic deposition at Site 36, turbidites, assuming they were being generated along the continental margin, probably had not prograded very far seaward.

In Hole 32, the lack of shallow-water turbidites in the pelagic sediments is in marked contrast to their abundance in younger terrigenous sediments. Here innumerable abyssal ridges, each acting as a sediment dam, had to be overridden before the prograding fans could reach Site 32. This apparently did not happen until late Miocene time.

The above factors would also eliminate the possibility of the deep-water variety of turbidite, generated along the lower continental rise, reaching the pelagic depositional sites. These factors would not interfere with the development of deep-water turbidites spawned in the abyssal hills. The controlling influence for such an origin is the presence of a sufficient thickness of low shear-strength, unconsolidated sediments reposing on moderate-to-steeply inclined slopes. An examination of the *Argo* Site Surveys shows a sediment mantle averaging 20 to 100 meters thick covering most of the abyssal hills. This mantle is also present on many of the steeper hillside slopes, although some are barren of sediment. Regarding their shear strength, Keller and Bennett (1968) found low values for red clays and calcareous oozes in their study of North Pacific sediments. Thus the conditions favoring the generation of turbidites in the abyssal hills appear to be favorable.

It is therefore somewhat surprising to find that, except for their possible occurrence at Hole 37, they seem to be completely absent. However, an examination of the site survey records shows that many drill sites were located on the crestal or flank positions of abyssal hills. This is true of Holes 32, 38, 39, 41 and 42 (Site 32 was an abyssal hill locale only during pelagic sedimentation). Hole 40 is unusual in that it was drilled on a ponded surface at the base of a large hill, and yet contains no turbidites. According to the *Argo* Site Survey, this site is slightly above the depth of the surrounding area and, therefore, had access to a rather limited source area from which turbidites could be generated. Only Hole 37, located in a ponded trough, was favorably situated to receive local turbidites. This relationship is shown on Figure 20.

It should be mentioned that identifying turbidites in the "red" clays on the basis of visual core examinations is difficult. In such fine-grained sediments, the sedimentary features which characterize turbidites are absent or poorly developed. They would be even more difficult to recognize if the color of the turbidite "red" clays were identical to that of the normal "red" clay sediments. Their presence might be suspected where interbeds of different colored "red" clays are found, particularly if the color changes are abrupt and nonprogressive.

Such a situation occurs in Hole 37. Here there is a progressive change from light-brown to dark-brown "red" clays with depth. The color changes are for the most part gradual. However, in Core 3 there are distinctive beds of yellow "red" clay which have sharp upper and lower boundaries. Obviously, this by itself does not constitute evidence for a turbidite origin, since there may be other environmental factors which could cause these relationships. Also, it is difficult to visualize yellow "red" clays accumulating on nearby low abyssal hills while dark-brown "red" clays were developing in the troughs.

One could theorize that as a mass of "red" clay goes into suspension after slumping off these low abyssal hills, the heavier ferromanganese minerals settle out first, so that only the hydrodynamically lighter clay minerals continue their transport. With the ferromanganese minerals selectively removed, the resulting clay deposit might not develop into the typically darker-colored "red" clay. This thought is admittedly conjectural, but one which could easily be tested by laboratory experiments.

Identifying turbidite transport in biogenous sediments is simpler than it is in the "red" clays. Three characteristics indicative of such transport may develop. Alternating deposits containing fossils representing either differing water depths or ages would be two such characteristics. Also, being coarser than "red" clays, the biogenous sediments would more readily develop the megascopic sedimentary features associated with turbidite transport. Combinations of these characteristics would be even more diagnostic.

Alternating strata containing differing ecologic fossil assemblages were nowhere evident in the Leg 5 pelagic oozes. This is not unexpected, as the amount of bottom

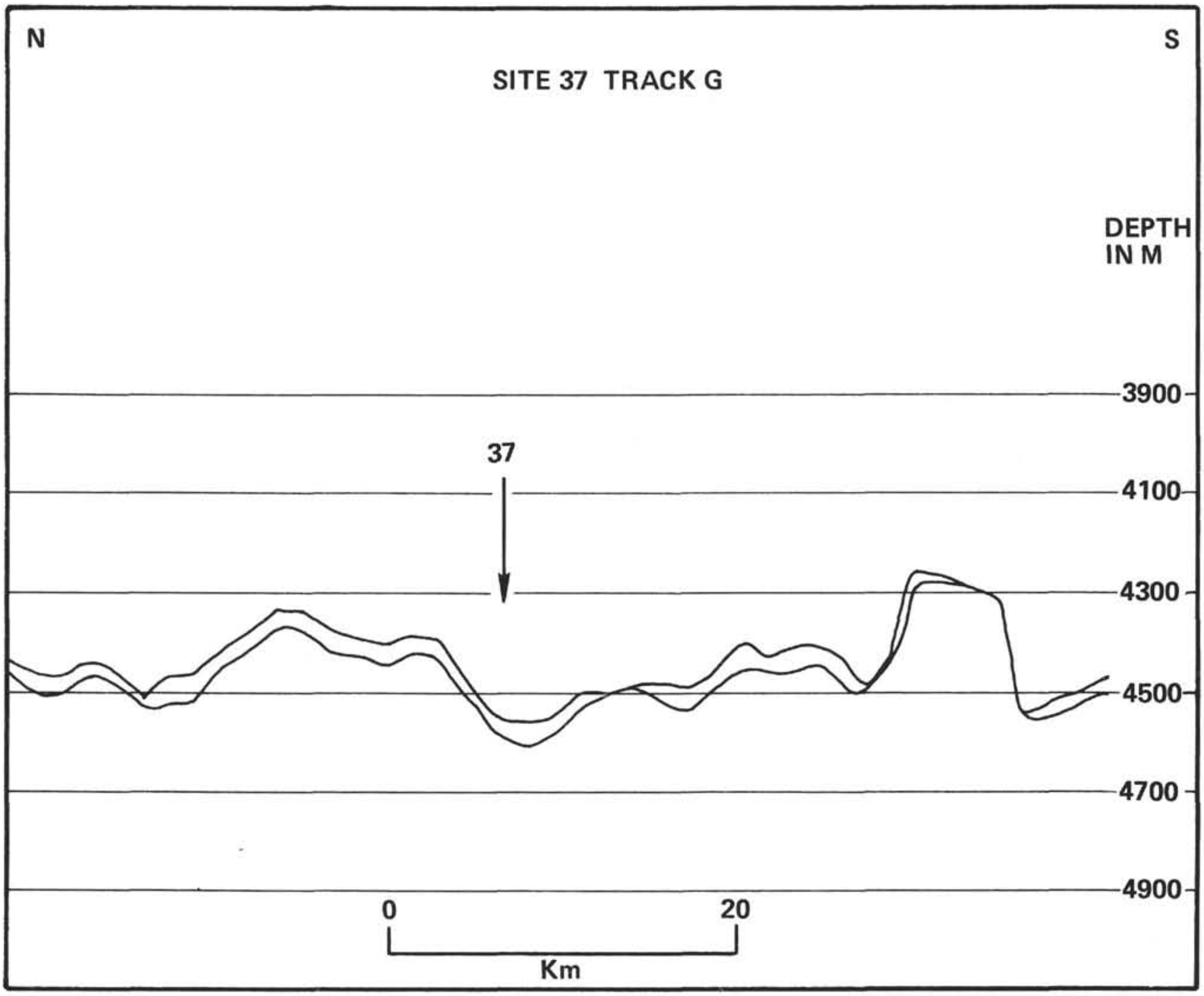

Figure 20. *Line drawing of seismic profile, showing irregular 50 to 100 meter sediment cover over basaltic abyssal hills. Site 37, located along edge of ponded trough, is projected 1 kilometer east onto line of traverse. (From* Argo *seismic profile, 21 March, 1969, 2010-2330.)*

relief necessary for differing biotopes to develop is usually not present in the abyssal hill regions. At several sites, interbedded sequences containing fossils of differing ages were encountered; but, most of these instances could be attributed to drilling disturbances.

This was not true of the paleontological relationships observed in Hole 37. There Pliocene foraminifera and calcareous nannofossils have two modes of occurrence in a "red" clay interval which contains a Pleistocene siliceous fossil assemblage. They occur either as rare, disseminated individuals or in thin, distinctive laminae and streaks of nearly white nannofossil ooze. Occurring in units 0.1 to 5.0 centimeters thick, they comprise a total of ±20 centimeters of section in the upper 5 meters of "red" clay. These fossils are obviously redeposited, a fact verified by their absence from the pre-Pleistocene "red" clays in Hole 37.

The source of these redeposited fossils is not quite so obvious. It could not be the ubiquitous, low-lying (50 to 100 meters) abyssal hills in the area; these hills have already been designated the source of the turbidite (?) yellow "red" clays found in this hole. Furthermore, it is unreasonable to postulate that the compensation depth for calcareous tests was within the 50 to 100 meters of relief present. It seems more likely that the oozes were derived from the tops of the occasionally larger abyssal hills which tower ±900 meters above the trough areas. Such a hill, according to the *Argo* presite survey, is not too far from Site 37, although this need not be *the* hill from which the Pliocene oozes were derived.

These nannofossil oozes vary in their content of fossil material. Some are fairly pure; others have very few fossil tests. Evidence that these fossils were redeposited by current-action comes from the condition of some of the calcareous nannofossil tests. A large number do not exist as whole individuals, but rather as a matte of broken fragments. This is true of many of the coccoliths and discoasters.

Most critical to interpreting the type of current which transported these oozes is the nature of their bedding contacts. Both their lower and upper contacts are gradational. This feature is as difficult to reconcile with the concept of turbidite transport as is the occurrence of scattered individual fossils in the clays. A more likely mode of current transport for the redeposited Pliocene fossils is presented in a later section.

By way of summary, the only interval having indications of a turbidite origin—as determined by core examinations—is the yellow "red" clay unit in Hole 37, and even here the evidence is not very strong.

The evidence from the airgun records at the pelagic sites indicates that ponding of sediments in the troughs between abyssal hills was absent or only occasionally present. Where present, the ponded surface developed a prominent meniscus at the junction of the troughs and abyssal hills. No flat-floored troughs were seen. This also suggests that locally generated turbidites, if present, played an insignificant role in trough filling.

Slump Deposits

As in the terrigenous deposits, sediment deformation during coring operations makes it difficult to evaluate slumping as a sedimentation agent in the pelagic deposits. However, there is good evidence of minor slumping in the pelagic interval encountered in Hole 36. Here, isolated basalt pebbles are scattered through Core 13. They most likely slumped from the high abyssal hills prevalent near this site. Most of these hills, even today, are completely devoid of a sediment cover.

The evidence for slumping in the other holes is less positive. Fragments of volcanic ash beds are present in minor amounts in Holes 37 through 40; some are partially or completely replaced by zeolites. All of these fragments are semi-indurated, fairly well-rounded and flat to spherical. They range in length from a fraction of a centimeter to 3 centimeters. Some probably originated by down-hole contamination during coring operations. Thus, in Hole 39 they occur 1 meter below a bed of similar material. In most instances, overlying ash beds, which could provide such fragments, were not present. Therefore a sedimentary origin, either by bottom-current transport or downslope slumping, is possible for many of them. Kolpack (1968) observed both types of transport in the abyssal depths of the Drake Passage. His photographs show fragments of semi-indurated volcanic ash lying in the troughs of current ripples or at the bases of low escarpments. As current ripples were not observed in the Leg 5 sediments, the mechanism of slumping is a more likely alternative.

When transported in this fashion, the ash fragments might not always reach the trough floors, but could repose on the slopes of the abyssal hills; thus, accounting for their presence in the holes drilled on hill flank sites. Pebble beds and individual clasts of material similar to those described here were found by Luyendyk (1969) in an area of abyssal hills several hundred kilometers west of San Diego. This area and the Leg 5 pelagic sites are comparable as regards water depth, lithology and bottom topography. Luyendyk also believes that the clasts in his area are of slump origin.

Tending to confirm the efficacy of the slumping mechanism is a unique feature of the manganese nodules found in Hole 37. These nodules occur in Core 1, Section 2, and in Core 2, Sections 4 through 6. Such down-hole occurrences are not unusual, and their presence in the other Leg 5 holes can be explained by the down-hole movement of surface nodules during coring operations. However, several of the nodules in Hole 37 have thin surface rinds of whitish-yellow nannofossil ooze. Paleontological examinations of these rinds show that they consist entirely of Pliocene nannofossils which are similar to those found in the thin streaks of nannofossil ooze. If Pleistocene strata were absent at Site 37, the presence of these nodules could be explained by down-hole contamination during drilling. But, as has been previously pointed out, Pleistocene sediments (probably 3 meters thick) are at the surface. Consequently, one must consider slumping from the higher abyssal hills during Pleistocene time as a more reasonable explanation for the presence of the manganese nodules.

The possibility that the manganese nodules are in place must also be included. Perhaps the protruding surface of these nodules during the time of their formation generated a microenvironment favorable for the preservation of any calcareous fossils settling down to the sea floor. If true, it would signify a Pliocene age for most of the "red" clays in Core 2.

Eolian Transport

Many eolian particles occur in the 10 to 20 micron-size range, and as such comprise much of the detrital-silt fraction of pelagic sediments. Arrhenius (1963) found, however, a size-frequency centered in the finer silt fraction (at 3 to 10 microns) in north equatorial Pacific clays.

Among the mineral grains found in eolian deposits are quartz grains. These are considered to be diagnostic of eolian transport when they occur in pelagic sediments. They can be identified by X-ray studies, occasionally by grain-size analyses, or by optical means. At the time of this writing, X-ray data were not yet available. The shore-lab grain-size data show that many of the pelagic sediments are silty clays. In addition to quartz grains in the silt fraction, the presence of fossil tests, zeolites and ferromanganese minerals make the grain-size data nondiagnostic. Interpretations of eolian origin had to be based upon petrographic identifications of quartz grains, which were made at shore-lab facilities. Only smear slides from Holes 32 and 37 were re-examined for this purpose.

Quartz grains are evident in many of the smear slides, being more prevalent in the "red" clays than in the biogenous oozes. This is to be expected since the biogenous material, depositing at a faster rate than the "red" clays, would act as a dilutent to other lithologic components in the sediments.

Two significant variations in the quantities of silt-sized quartz grains are detectable. At Hole 32 the "red" clays generally contain a higher percentage of such grains than do those at Hole 37. This can be explained by the proximity of the former to the Northern American continent.

In Hole 37, an abundance of quartz grains occurs within a 5-meter interval of light-brown "red" clay in the uppermost part of the hole (Core 1, and Core 2, upper half of Section 1). This also is the interval in which Pleistocene siliceous fossils are recognized. Such a restricted occurrence for prominent eolian activity confirms the findings of Rex and Goldberg (1958). They noted that the northeastern Pacific sediments of Quaternary age have a higher content of quartz grains than do the underlying Middle Tertiary deposits. They likewise noted that these Quaternary "red" clays are a lighter-brown than the underlying strata.

At Sites 38 and 39 there are 11 meters and 3 meters, respectively, of these same light-brown "red" clays. These clays were not re-examined for their quartz grain content—nor could their age be determined, since they did not contain any fossils. However, Rex and Goldberg (1958) did note a high quartz content in sediments from the same portion of the Pacific in which all three holes were drilled (see Figure 21). The prominence of eolian transport in this region is also substantiated by the later findings of Griffin *et al.* (1968), who interpreted an abundance of illite clay minerals there as reflecting an eolian origin. Also, Windom (1969) interpreted more than half the detritus in sediments which he sampled at mid-latitude sites in the North Pacific as being of eolian origin. On this basis, it seems likely that the light-brown "red" clays in Holes 38 and 39 correspond to the eolian-rich interval at Site 37.

Whether the 3 meters of light-brown "red" clays cored at Site 39 represents their total thickness there is not certain. Present indications are that the uppermost 4 meters of sediments at Site 39 were not cored (see Operations Summary for Site 39).

No doubt eolian transport also contributed to the dark-brown "red" clays, although to a lesser extent.

Extraterrestrial Components

No material of definite cosmic origin was identified in the pelagic sediments. However, small glassy objects from Holes 32 and 37 have similarities to both microtektites (cosmogenic) and microlapilli (volcanogenic). They are indicated, therefore, as being of questionable extraterrestrial origin on Table 1. A more complete description of their occurrence and characteristics is covered in Chapter 23.

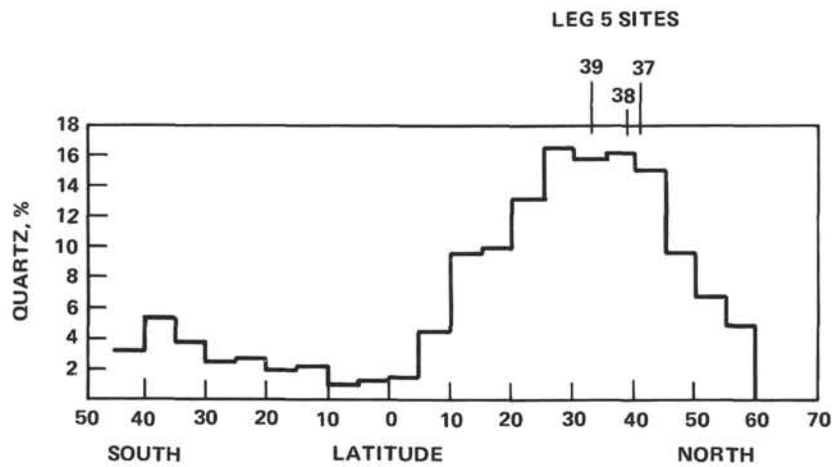

Figure 21. *Quartz content of Pacific pelagic sediments.*

In the pelagic sediments recovered at other drill sites, cosmic particles, although not recognized, are no doubt present in minute amounts.

Microtektites are not the only cosmic components found in sediments. Pettersson (1960) believes that meteoritic dust is quantitatively a more significant contributor than microtektites. This contribution would be greatest to the slowly depositing "red" clays; however, for now it remains unrecognized.

Biogenous Productivity

The importance of biogenous constituents as contributors to the pelagic sediments varies considerably. Such constituents are present as disseminated organic matter and as microfossil tests.

The organic matter was not visible while examining the cores or under the microscope. It was detected in the shore-lab studies carried out at Scripps, where it was tabulated as the percentage of organic carbon. These studies show that its content in individual samples ranges from barely detectable amounts to 0.22 per cent. The averages for the total pelagic interval within each hole are shown on Table 5.

As can be seen, all the pelagic intervals are characterized by low values of organic carbon. Further analysis indicates that the variation of organic-carbon content is not related to either of the major classes of pelagic sediments, that is, "red" clay and biogenous ooze. Holes 41 and 42, which contain appreciable thicknesses of calcareous or siliceous oozes, have only a slightly higher organic-carbon content than most holes. Hole 40 also contains such sediments, yet it has less organic carbon than most other holes.

Within the "red" clays, a correlation was found between color and organic content which is particularly evident in Hole 37. In Hole 37, the color spectrum of the "red" clays progressively darkens (except for a few meters of yellow "red" clay in Core 3) from light brown at the surface to almost a black-brown near the bottom. Accompanying the darkening is a progressive decrease in organic carbon from 0.16 per cent in the lighter-colored clays to 0.06 per cent in the darker clays (the latter clays are those with a high amorphous iron oxide content).

There appears to be no correlation between the organic-carbon content of the sediments and their geographic locations. The values for each hole are plotted on Figure 22. This map shows that these values have no pattern in either a north-south or east-west direction. Even proximity to land does not seem to affect them.

Quite noticeable, however, is the difference in the organic-carbon contents of the pelagic and terrigenous deposits (Figure 22). The latter contain 2 to 25 times the organic carbon of the pelagic deposits. Particularly obvious is the difference in amount of organic carbon

TABLE 5
Organic Carbon in Pelagic Sediments

Hole	Number of Samples	$\%C_{org.}$
32	6	0.03
36	3	0.13
37	19	0.09
38	17	0.08
39	9	0.08
40	19	0.07
41	10	0.12
42	44	0.19

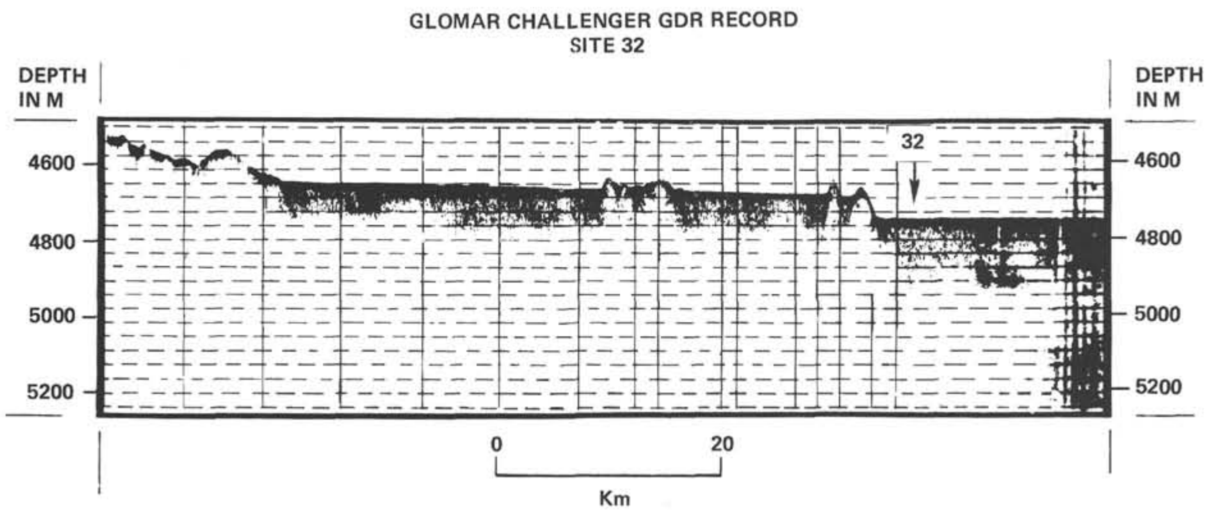

Figure 22. *Average organic-carbon content in pelagic and terrigenous sediments of Leg 5 holes.*

where both sediment types occur in the same hole, i.e., Holes 32 and 36. These differences substantiate the thesis put forth earlier, that the color differences between pelagic and terrigenous sediments are often related to organic content.

The organic carbon of the pelagic sediments is, no doubt, in a highly refractory form, since no indications of reducing conditions were found in any of these sediments.

Of greater stratigraphic significance are the microfossil tests which are present at all the pelagic sedimentation sites. Quantitatively they are more important there than in the terrigenous holes, comprising about three-fifths of the pelagic sediments.

As with the terrigenous deposits, the microfossils are divisible into three subgroups, which are listed below in their order of quantitative importance:

Siliceous microfossils:	Predominantly radiolarians, with few sponge spicules and only occasional diatoms.
Calcareous nannoplankton:	Mostly coccoliths, with important quantities of discoasters and lesser amounts of other nannoplankton.
Foraminifera:	Planktonic and benthonic forms.

The distribution of these subgroups in the pelagic sediments is complex, both in time and space.

Pelagic sediments at the nearshore sites, Holes 32 and 36, contain only Middle Cenozoic fossils. In Hole 36, which has a thin interval of pelagic sediments, most of the biogenous material is concentrated in the topmost portion of this interval (Core 12, Section 6). It is present in the form of a calcareous nannofossil ooze which, except for its color, is lithologically similar to that found in the overlying terrigenous section. The quantity of fossil material gradually diminishes with depth in this thin interval.

The same relationships prevail in Hole 32. The uppermost pelagic sediments in Core 8 have a fossil content not too dissimilar from that found in the overlying terrigenous sediments of Core 7. In these pelagic deposits, fossil tests are represented mostly by radiolarians, with some diatoms and silicoflagellates. Their numbers, except for a minor reoccurrence near basement, rapidly decrease with depth.

The more seaward holes (37 through 42) along the 140°W-meridian traverse have both Upper and Lower Cenozoic microfossils. The latter occur only in Holes 37 and 41, whereas the former are found in Holes 38 through 42.

In Hole 37, fossils are few in the upper sediments. Even this number diminishes with depth, disappearing completely below Core 2, Section 1. This differs from the fossil distributions in Holes 38 through 42. The largest fossil contents are always in the lower parts of these holes; and, where a decrease occurs (Holes 38 through 41), it is toward the top.

There is another pattern to the distribution of microfossil constituents in Holes 37 through 42. In traversing from north to south, there is an increase in the overall fossil content of these holes, as well as, an increase in the time spanned by their occurrence. Thus, Hole 38, near 39°N, has only minor amounts of Lower Eocene fossils which are all in the basal 9 meters of sediments; the overlying 39 meters of "red" clay are barren. Similarly, Hole 39, near 33°N, contains only a few Lower Eocene fossil remains, disseminated in the basal part of the lower core. Both Holes 38 and 39 have more fossils than Hole 37 (if a redeposited origin is accepted for the calcareous forms in this hole), but the amount is still fairly small. The fossil content in Holes 40 and 41 (20°N) has increased to where almost the entire Eocene interval is represented by biogenous oozes. Only in younger strata do the fossils occur as rare scattered individuals. Finally, at the southernmost site (14°N), Holes 42.0 and 42.1 contain abundant fossils—in the form of biogenous oozes—throughout their recorded history, that is, late Oligocene through middle Eocene time.

Both siliceous and calcareous microfossils are abundant along the meridian traverse. Calcareous forms (mostly nannofossils with some foraminifera) occur in all except Hole 41. They are dominant in Holes 37, 38 and 39.

In Holes 40, 41 and 42, the siliceous forms are dominant, and develop extensive oozes. They are present only in small amounts in Hole 37, and are absent from Holes 38 and 39. The siliceous fossils in the pelagic sediments consist mostly of radiolarians, with minor quantities of sponge spicules. This differs from the terrigenous sediments, where diatoms and silicoflagellates are more numerous than the radiolarians.

In the pelagic, as in the terrigenous sediments, microfossil abundances reflect the effects of (1) solution by sea-water, (2) diagenetic alteration, (3) dilution by other constituents, (4) surface productivity, and (5) processes of resedimentation. Again, the latter factor is treated under the sedimentation agents responsible.

Except for shallower regions, the corrosive effects of seawater on fossil tests is widespread in the North Pacific today. All sites, except Site 36, are located below the present-day compensation depth for calcareous tests; and, in some instances, they are below the compensation depth for siliceous tests as well.

Gradually—during successively earlier periods of late Cenozoic time—the soluble effects of seawater diminished and, correspondingly, the compensation depths deepened. Thus Arrhenius (1963, Figure 36), in his partial meridional section of the Pacific, graphically illustrates that the disappearance of calcareous fossils at 8°N in Plio-Pleistocene sediments had shifted to 17°N in Miocene strata. However, this shift was not enough to preserve calcareous fossils of these ages at the sites drilled along the 140°W traverse.

An even deeper compensation depth appears to have prevailed during early Cenozoic time. There is evidence that higher bottom-water temperatures (which lower the compensation depth of calcium carbonate) existed during at least part of early Cenozoic time (Emiliani, 1953). Arrhenius (*op. cit.*) feels that this may have displaced the compensation depth in the northern Pacific to a depth where dissolution occurred only north of 45°N. This would explain the presence of Eocene calcareous fossils in Holes 39 and 38 (33°N and 39°N, respectively).

Another possible explanation for the presence of calcareous tests in these holes is that, here, where they overlie basalt, their preservation coincides with a period when they were situated above a center of sea-floor spreading. This would have been a time when the depositional site was presumably in shallower water, possibly above the compensation depth for calcium carbonate. The same explanation may apply to the presence in Hole 32 of a basal nannofossil ooze on basement rocks.

The absence of a comparable basal ooze in Hole 37, which is but a short distance north of Hole 38, is somewhat anomalous. However, even though Site 37 may similarly have been at a shallower depth during its early history (late Oligocene time on the basis of the magnetic anomaly age), by then the compensation depth had probably also shallowed in this part of the Pacific. Consequently, Site 37 may have been below the calcium carbonate compensation depth during its entire history.

Amounts of biogenous constituents in the pelagic sediments also reflect the effects of diagenetic alteration. The silica-bearing solutions that formed the cherts in Holes 40 and 42 were probably at least partly derived from siliceous fossils. Particles of calcium carbonate, so prevalent in the terrigenous sediments and believed to be an alteration product of calcareous tests, were noted in Holes 36, 37 and 38. Their indicated absence in Holes 39 through 42 (Table 1) may simply be because they were not identified. Finally, the abundance of dolomite rhombs in the sediments overlying basalt in Hole 32 may partly be due to diagenetic alteration of calcareous fossils. The total alteration products encountered in the pelagic holes, nevertheless, is minor relative to the total biogenous material present.

Weakly-biogenous sediments were noted in some of the pelagic strata in Hole 32 and Holes 36 through 41. Unlike similar oocurrences in some terrigenous sediments, their dilute presence here does not reflect high influx rates of other lithologic constituents. Just the opposite is true, because in the realm of slow, deep-water deposition, the biogenous components become less plentiful the more slowly other constituents are deposited. A quickly deposited sediment cover inhibits solution by acting as a diffusion barrier between the fossil tests and the corrosive marine waters. The sporadic occurrence of siliceous fossil tests in only the upper, relatively more rapidly deposited, "red" clays in Hole 37 may be evidence of this. However, in the other cases the aforementioned factor of solution during settling was probably a more important reason for their scarcity.

The high rate of surface productivity was no doubt another factor in the observed distribution of biogenous constituents in the pelagic sediments. This is the best explanation for their prominence in the older sediments in Holes 40 to 42. These holes were located closest to the productive waters of the equatorial divergence during early Cenozoic time.

Maps showing present-day surface organic productivity indicate low biomass production near Holes 32 and 36. However, these holes have intervals of high microfossil content which extend from the uppermost pelagic sediments into overlying terrigenous sediments. One must therefore conclude that more productive surface waters were present here in the geologic past.

In sorting out the factors that influence the observed distribution of microfossil tests in the pelagic sediments, two others should be considered. One factor, whose effect is difficult to evaluate, is the ever-changing shape of the ocean basin. This probably had a greater bearing on biogenous productivity than on the other depositional agents. For example, uninterrupted equatorial flow between the Atlantic and Pacific Oceans is believed to have existed throughout much of Tertiary time. This could strongly distort patterns of surface water circulation and upwelling, which in turn influence biologic productivity.

Another factor is evolutionary changes in the resistance of fossil tests to solution, a subject about which relatively little has been published. It has been observed previously that Lower Cenozoic radiolarians generally have heavier test walls than Upper Cenozoic forms.

Recently, Moore (*op. cit.*) has shown that this is caused by a progressive evolution to more delicate species. This signifies that in any given water column the lighter-weight Upper Cenozoic radiolarians will dissolve more readily than their Lower Cenozoic ancestors. Although the reason for this evolutionary change is not clear, it may partially explain the diminished presence of Upper Cenozoic radiolarians in the Leg 5 pelagic sediments.

Volcanism

This mechanism contributed relatively more material to the pelagic than to the terrigenous sediments; however, because of authigenic changes, even a rough approximation of its importance cannot be made.

The volcanic constituents occur in diverse forms. There are the unaltered, easily recognized volcanic ash and pumice fragments. The former is found in thin beds or as disseminated glass particles. There are also ash and pumice fragments partially or completely replaced by zeolites, but still recognizable as being of volcanic origin. Finally, there are the zeolite-bearing "red" clays, whose origin is believed by some to be almost entirely volcanic. The inventory of volcanic contributions plus a discussion of the basaltic basement is found in Chapter 24.

Grain-by-Grain Settling

At the far-offshore sites (37 through 42), surface currents–because they are far from any source of suspended matter–transport only clay-sized particles; therefore, their products would be largely in the clay fraction of the "red" clays. The same would be true of Sites 32 and 36 which may have been even farther removed from the distributive flow of the California Current during the periods they accumulated pelagic sediments.

As defined in the section on terrigenous sediments, grain-by-grain settling refers only to the seaborne transfer of continentally-derived detritus. This rules out eolian and extraterrestrial clay-sized minerals settling through the water column, as well as the authigenic clays. The latter clays are derived mostly from the alteration of volcanics, which generally develop into montmorillonite.

Recognizing which agent is responsible for the "red" clays in Holes 32 and 36 through 41 is impossible with the data now available. Griffin *et al.* (1968), in analyzing oceanic clays, were able to distinguish some transport agents and sediment sources by the types of clay minerals present. They noted that a high illite content occurs in a band of North Pacific clays between 20° and 40°N, which they attribute to eolian transport. However, one might question whether some of the illite which is believed derived from the Asiatic mainland might not entrain by fluvial discharge into the Kuroshio Current, and be spread eastward in the midlatitudes by the North Pacific Current. In any event, grain-by-grain settling was probably a minor contributor to the "red" clays along the 140° traverse and to Sites 32 and 36.

Its greatest importance may have been during Pleistocene time when larger portions of the continental land masses were subject to erosion. Also, the more intense atmospheric circulatory patterns assumed to have been present at that time are believed to have been reflected by a similar intensification of flow of the oceanic currents. Such conditions would favor a larger suspensoid in the water column, one better able to influence distant pelagic depositional sites. Therefore, grain-by-grain settling, though still a minor contributor, may have played a more important role during Pleistocene time.

Several facts lead one to suspect that progressively less suspensoid was being transported in this manner during earlier parts of Cenozoic time. First, larger epicontinental seas during the early Cenozoic diminished the total landmass subject to erosion. Second, the theory of moving sea-floor plates suggests that the Pacific Ocean was larger during the geologic past, placing the Leg 5 depositional sites even farther from continental sediment sources. Finally, the increasing abundance of zeolites in the older, darker "red" clays indicates an authigenic origin was more prominent.

Answers to some of the above questions should be provided by the shore-based clay mineral determinations.

Bottom Currents

As in the discussion of terrigenous sediments, a short summary will be made of the sketchy data available concerning present-day bottom-current flow near the pelagic sites; then evidence of their former activity will be given.

The conditions of bottom-current flow near Sites 32 and 36 have already been described in the section on terrigenous sediments and will not be repeated in detail here. Suffice to say, slow-flowing Antarctic Bottom Water (AABW) transporting a nepheloid layer of *weak-to-moderate* intensity flows near Site 32. A *strong* nepheloid layer seems to be present at Site 36; however, the bottom current responsible for its transport is undefined.

The flow of AABW probably affects Sites 40, 41 and 42 as it flows eastward towards western North America, from the gap south of the Hawaiian Islands. No flow-velocity data are available near these sites. There are nephelometer measurements in this region (Ewing and Connary, in press) indicating the presence of a nepheloid layer of *moderate* intensity in the AABW.

The flow of AABW in the mid-latitude regions of the Central North Pacific had been assumed to be generally northward. However, if the North Pacific bottom flow is characterized by two large counterclockwise gyres, as suggested by Ewing and Connary (*op. cit.*), then the flow directions may be more complex. Ewing (personal communication) has data from several bottom-current stations in this region (although he feels their data may have a large degree of uncertainty). These data indicate a southwesterly flow of bottom water near Site 39, but show varying directions of flow at stations some distance from Sites 37 and 38. Surprisingly, average flow velocities of 3 to 6 cm/sec at these stations are as high or higher than they are along the continental margin. Connary (personal communication) feels that these velocities may largely reflect tidal forces. If so, most of the bottom-current motions are transient, and the steady-state component is probably low.

There are no nepheloid layer measurements near the mid-latitude Leg 5 sites (Sites 37, 38 and 39). However, a north-south line of stations in the mid-Pacific near 160°W registered a nepheloid layer of *moderate* intensity (Ewing and Connary). Also, an individual station several hundred kilometers north of Site 37 recorded a nepheloid layer of *strong* intensity. The above data and that given in the discussion of terrigenous sediments show how widespread the nepheloid layer is in the Northeast Pacific.

It is difficult to extrapolate back in time to determine the effects of bottom flow conditions on older sediments. This difficulty is compounded at Sites 32 and 36, where the pelagic deposits are overlain by other sediments. At Site 32, the general paucity of burrow-mottles in the sediments plus weak transient current motion there today suggest that transient currents may have also been ineffectual in the past. This is borne out by the seismic profiler records, which show only minor sediment ponding in those areas where the abyssal plain cover is lacking (Figure 4).

Steady-state currents transporting sediments in a nepheloid layer apparently were also unimportant during the period of pelagic sedimentation. This is suggested by the absence of redeposited fossils in the sediments. The low rate of sediment accumulation at Site 32 also shows that such transport could have been, at best, a slow contributor.

The seismic profiler records closest to Site 36 indicate that sediment ponding in the troughs is absent (Figure 18). Therefore, in spite of the presence of a moderate amount of burrow-mottles in the sediments, transient currents probably were of no consequence in redistributing sediments at this site. Paleontological evidence indicates a gap in the depositional record between the pelagic and terrigenous deposits in Hole 36. As was mentioned in the section on terrigenous sediments, this gap is suggestive of steady-state bottom current activity.

As at Site 32, the slow depositional rate and the absence of redeposited fossils indicate that fallout from steady-state current transport of nepheloid-layer material had little effect on sedimentation at Site 36.

Burrow-mottles are uncommon at Hole 37. Whether this is due to an inability to detect them, particularly in the dark brown "red" clays, or whether it indicates a low-level development of infaunas is not known. The *Argo* Site Survey does reveal a certain degree of sediment ponding, especially near the drill site (Figure 20). Although some ponding no doubt was caused by slumping, transient bottom currents are active in this region today. Very likely these currents were largely responsible for the redistribution of sediments at this site in the past.

As was described in a previous section, reworked Pliocene calcareous fossils occur in the Pleistocene light brown "red" clays at this site (Core 1 and the upper part of Section 1, Core 2). Here they constitute no more than 3 per cent of this 5-meter[1] interval. It has also been shown that turbidity currents do not seem to be able to account for these fossils. The dual nature of their occurrence (i.e., as disseminated individuals in the "red" clays and as thin laminae and streaks having gradational contacts) is better explained by deposition from a slow-moving nepheloid layer.

That a nepheloid layer of *strong* intensity now flows near Site 37 has already been demonstrated. During Pleistocene time such a layer could have accompanied the flow of a deep countercurrent or deeper portions of the North Pacific Current. At that time flow velocities would have been stronger, because of the intensification of zonal flow which is believed to have occurred during the Pleistocene. Either current, its velocity amplified locally by the topographic effects of the larger abyssal hills, might easily erode their sediment cover. As has been previously suggested, this cover very likely consisted of calcareous ooze over the more prominent hills.

Such erosion might have taken place either close to or at some distance from Site 37. In either event, after being resuspended, this material could have been spread over a wide area by a nepheloid layer entrained in steady-state currents.

[1]Two meters are believed to be duplicated by the coring process.

The eroding power of these currents would vary through time, as their flow paths migrated or the effects of transient current motions varied. Consequently, the amounts of biogenous material carried in suspension would also vary. This could result in streaks of fairly pure ooze being deposited during some periods, while disseminated individual fossils accumulated at other times.

A bottom-current nepheloid layer may also have transported varying amounts of "red" clay to Site 37. Menard's map (*loc. cit.*) shows a large abyssal plain north of this site. Presumably constructed by turbidity currents, such flows could periodically introduce clouds of fine suspensoid into the northeast Pacific bottom water where it would be incorporated into the steady-state bottom current flow.

Although this model of nepheloid layer sedimentation is based on several assumptions, it is not at variance with facts known about this mechanism. This model seems to offer the best explanation for the manner in which the biogenous constituents occur at Site 37.

However, this mechanism does not seem applicable to the yellow "red" clays, which also appear to be displaced sediments. Their sharp upper and lower contacts plus their presence in thicker beds (1 to 20 centimeters) suggest deposition by another mechanism.

Bottom currents, as a whole, appear to have had a moderate influence on sedimentation at Site 37.

The effects of bottom currents on the sediments at Sites 38 and 39 are difficult to evaluate. The 3 to 6 cm/sec average current velocities recorded near these sites are believed to represent mostly transient current motions. These velocities, if present during earlier times would not have been capable of eroding sediments although they would be able to redeposit sediments resuspended by burrowing organisms. Again, the past presence of such a fauna is not easy to establish, because of the problem of recognizing burrow-mottles in "red" clays.

Near Site 38 the less extensive profiling records of the *Glomar Challenger* show uniform sediment thicknesses over the abyssal hills and troughs, and no sediment removal from the hill-flank locale of this site is indicated. That some erosion has occurred at Site 39 is indicated by the *Argo* seismic records. They show (Figure 23) sediment thinning at Site 39 and at other abyssal hilltop areas, and local ponding of sediments in the intervening troughs.

Erosion at Site 39 is also suggested by comparing the thicknesses of "red" clay at Sites 37, 38 and 39. This thickness is appreciably less at Site 39 than at either Sites 37 or 38 (after allowing for the probable interval of Pleistocene sediments at the tops of the three holes). Assuming a complete section is present at Site 39, the depositional rate for the pre-Pleistocene interval would be 0.3 m/m.y. This is lower than the rates for Sites 37 and 38 (see Chapter 31) or the 0.4 to 0.7 m/m.y. rate generally ascribed to this region by Menard (1964, p. 169) and Dymond (1966). However, until the depositional rates of sediments, particularly of older Cenozoic strata, are better documented in this region, the value of this line of evidence remains speculative.

Although the flow of bottom water may have caused some sediment removal, it may also have contributed to its deposition. Ewing and Connary's (*loc. cit.*) data reveal the presence of a slow-flowing bottom current with a *moderately* intense nepheloid layer in this region. As at Site 37, if such a layer also existed in the past it could have contributed to some of the "red" clays at Sites 38 and 39.

Holes 40 and 41 are only 15 kilometers apart in comparable water depths (5183 and 5339 meters, respectively), and far from any local sediment sources. Under these circumstances most depositional agents should have a similar effect on them. However, the earlier depositional records of these sites differ greatly, possibly because of the variable effects of bottom currents, which in turn are related to differences in topographic setting.

Hole 40 was drilled on a broad, ponded site at the base of a prominent hill, the same or similar to the one shown in Figure 24. Site 40 could therefore be expected to have been protected from any steady-state bottom currents, as well as from any current velocity fluctuations that develop on topographic prominences. At this site, it appears likely that most of the Lower Cenozoic section (whose presence is predicted by extrapolating from known paleontological data) is present. The seismic records indicate that approximately 300 meters or more of Lower Cenozoic section are present at Site 40.

Hole 41, drilled on the upper flank of a low abyssal hill, penetrated only the upper 34 meters of this section before reaching basalt. Sediments at this site would be more subject to erosion by both steady-state and transient currents, which may explain the absence of the lower portion of the section. The *Argo* seismic profiler records indicate that the sediment ponding at Site 40 is regionally anomalous; consequently, the absence of this lower sediment interval is widespread.

The interpretation of sediment removal at the base of the section by currents appears reasonable, if one assumes that the oceanic crust developed at approximately the same time throughout this region. As this has not yet been established, ascribing the absence of older sediments at Site 41 to current erosion must be viewed as a tentative conclusion.

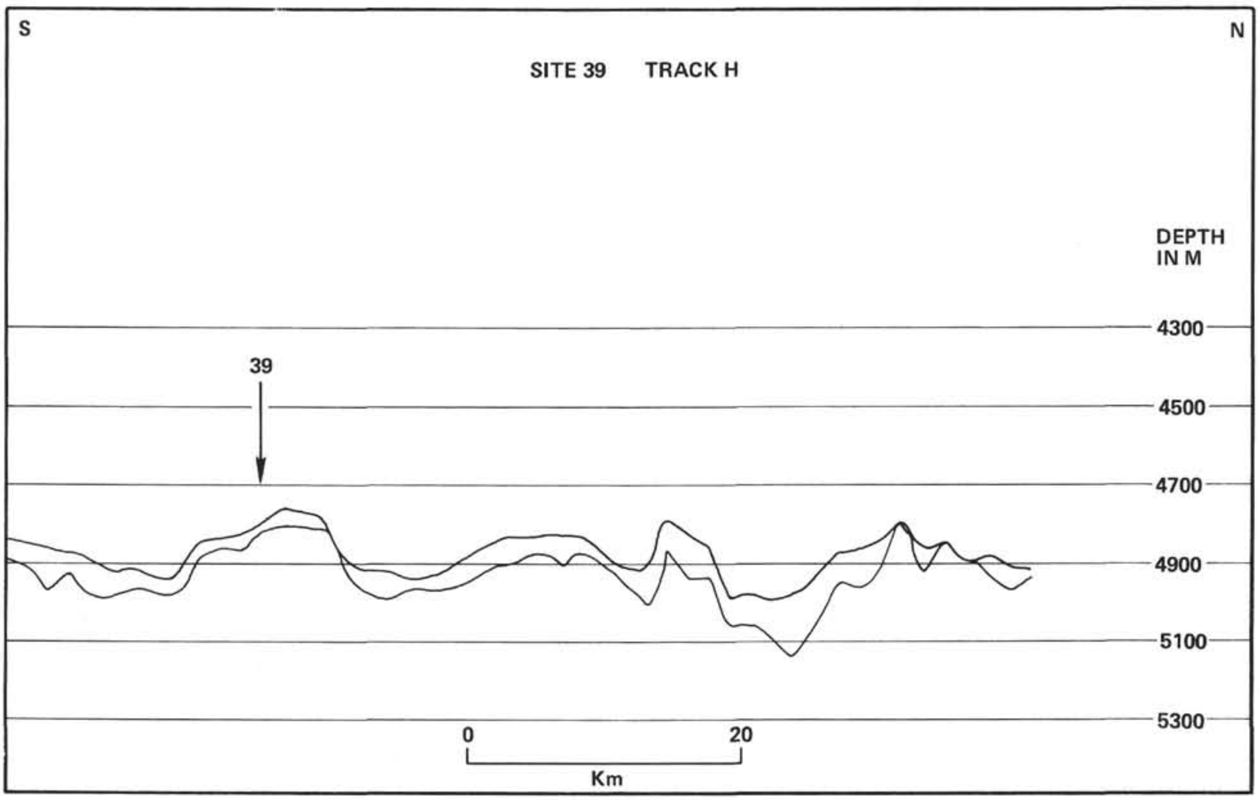

Figure 23. *Line drawing of seismic profile, Site 39, located high on flank of hill. Sediment cover thins over abyssal hills, and ponds in trough areas. Drill site projected 4 kilometers west onto line of traverse. (From* Argo *seismic profile, 25 March, 1969, 0825-1230.)*

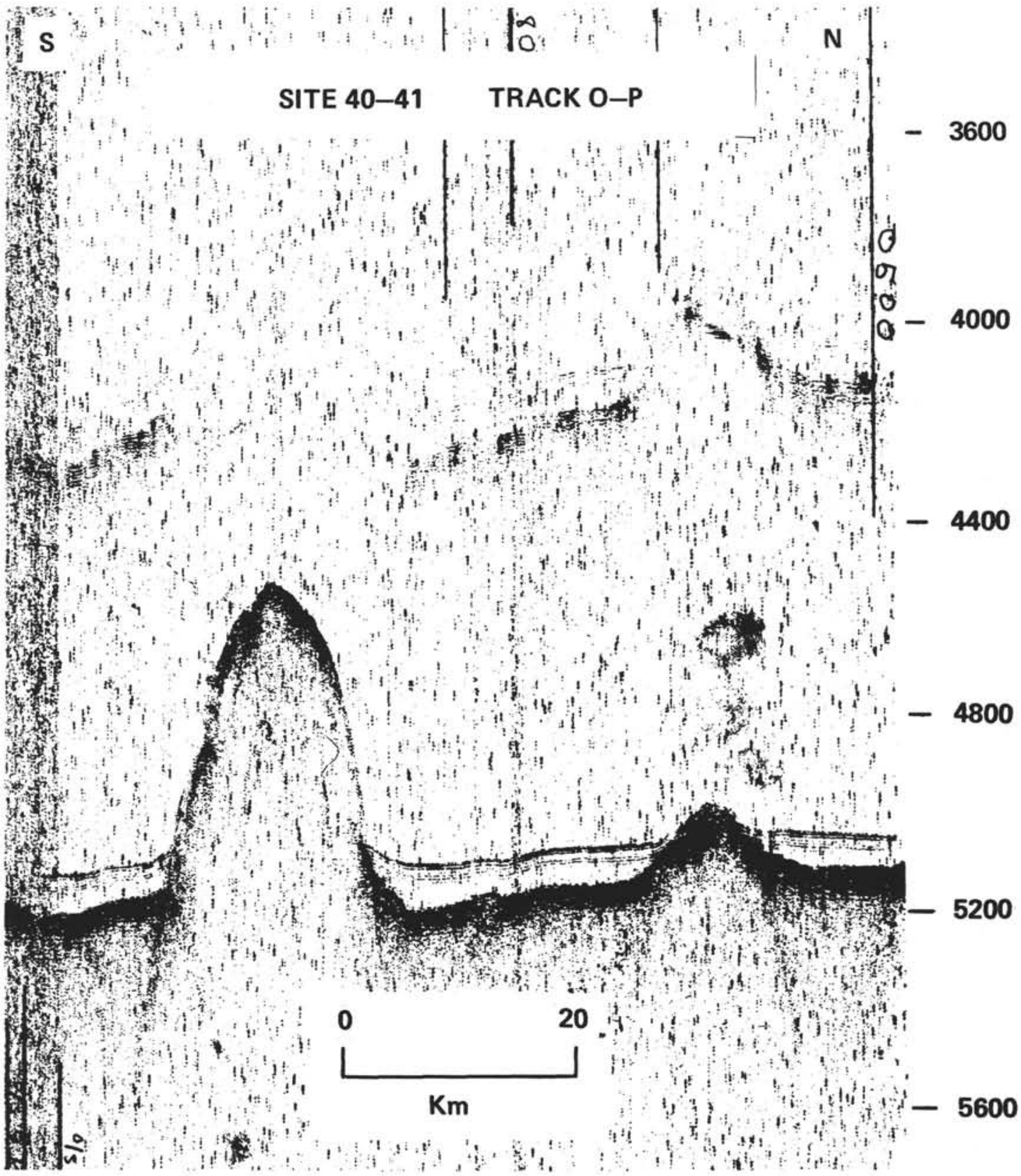

Figure 24. *Seismic profile near Site 40. Interval of ponded, acoustically-transparent sediment at base of large hill is seen to be conformable with most of underlying basement reflector. Hole 40 is similarly situated on ponded surface near large (possibly same) abyssal hill. There acoustically-transparent sediment interval is represented by Eocene radiolarian oozes capped by thin "red" clay interval, and basement reflector is basal Eocene chert. Distance from Track O-P to drill site unknown. (*Argo *seismic profile, 19 April, 1969.)*

Both sites have poor representation of either sediments or fossil remains for the post-late Eocene period. Overlying the Eocene radiolarian oozes are 10 meters of nonfossiliferous "red" clays at Site 40 and 6 meters of weakly fossiliferous "red" clays at Site 41. At the latter sites, the fossils consist of a mixture of Eocene and Upper Miocene or younger radiolarian tests. As has already been pointed out, the decrease or absence of radiolarians may reflect a shallowing compensation depth due to evolutionary changes in the test walls.

The lack of diagnostic fossils in the upper sediments makes it difficult to detect whether all of post-Eocene time is represented in the sedimentary section, or whether one or more hiatuses, occasioned by current erosion, are present. The two "red" clay intervals are similar in color and general composition, and they may therefore represent comparable depositional periods. They represent approximately 36 million years of geologic time; and, if continuous deposition had occurred, their rate of deposition must have been extremely slow.

At Site 41 somewhat nondefinitive paleontological data indicate Upper Miocene or younger strata, overlie Upper Eocene sediments. If valid, such data indicate approximately 30 million years of time are unrepresented by sediments, which is definite evidence of a hiatus.

Steady-state bottom currents very likely influenced sedimentation at Sites 40 and 41. Such a current in the form of AABW flows over these sites today, transporting a nepheloid layer of *moderate* intensity. During periods of higher flow velocity there may have been a net movement of sediment out of the area. At other times this steady-state current may have deposited "red" clays or any biogenous sediments which had been resuspended. This sedimentation mechanism could explain the presence of the mixed Upper Miocene or younger and Eocene radiolarians at Site 41. (The mixing is probably not due to infaunas, as burrow-mottles were not seen at this site.) Why this mechanism did not deposit similar mixed fossil assemblages at Site 40 is hard to explain.

In summary, steady-state bottom currents were no doubt a factor at these two sites. Present-day information concerning these currents, however, is too sketchy to make even a good qualitative estimate of their importance in the past.

Ewing and Connary's data indicate that the same flow of AABW, transporting a nepheloid layer of *moderate* intensity, is present at Site 42 and at Sites 40 and 41. Current velocities, whether due to steady-state or transient motions, may be higher at Site 42, as current ripples were recorded there by the *Argo* Site Survey photographs.

It is surprising that the seismic profiler records indicate an absence of sediment-ponding in the troughs near Site 42 (Figure 25). This is particularly odd because the biogenous oozes in Hole 42 have light-to-moderate burrow mottling throughout. Furthermore, sediment mounds were noted on the *Argo* presite photographs. Apparently any detritus resuspended by bottom-dwellers has been transported out of the area.

This may indicate that the nepheloid layer in this region is experiencing a net gain rather than a loss of suspended particles. This conclusion is supported by the sedimentary record of Hole 42 which was drilled on the upper flank of an abyssal hill. There are no post-Oligocene sediments here, not even nonfossiliferous "red" clays, such as, those which occur at Sites 40 and 41.

Magmatic Exhalation

There is one other depositional agent or process which contributed to the formation of the pelagic sediments. This can be referred to as "magmatic exhalation", a process described by Boström and Peterson (1969). Deposits of this origin have been identified by C. von der Borch at Sites 37, 38 and 39, and are described in detail in Chapter 26.

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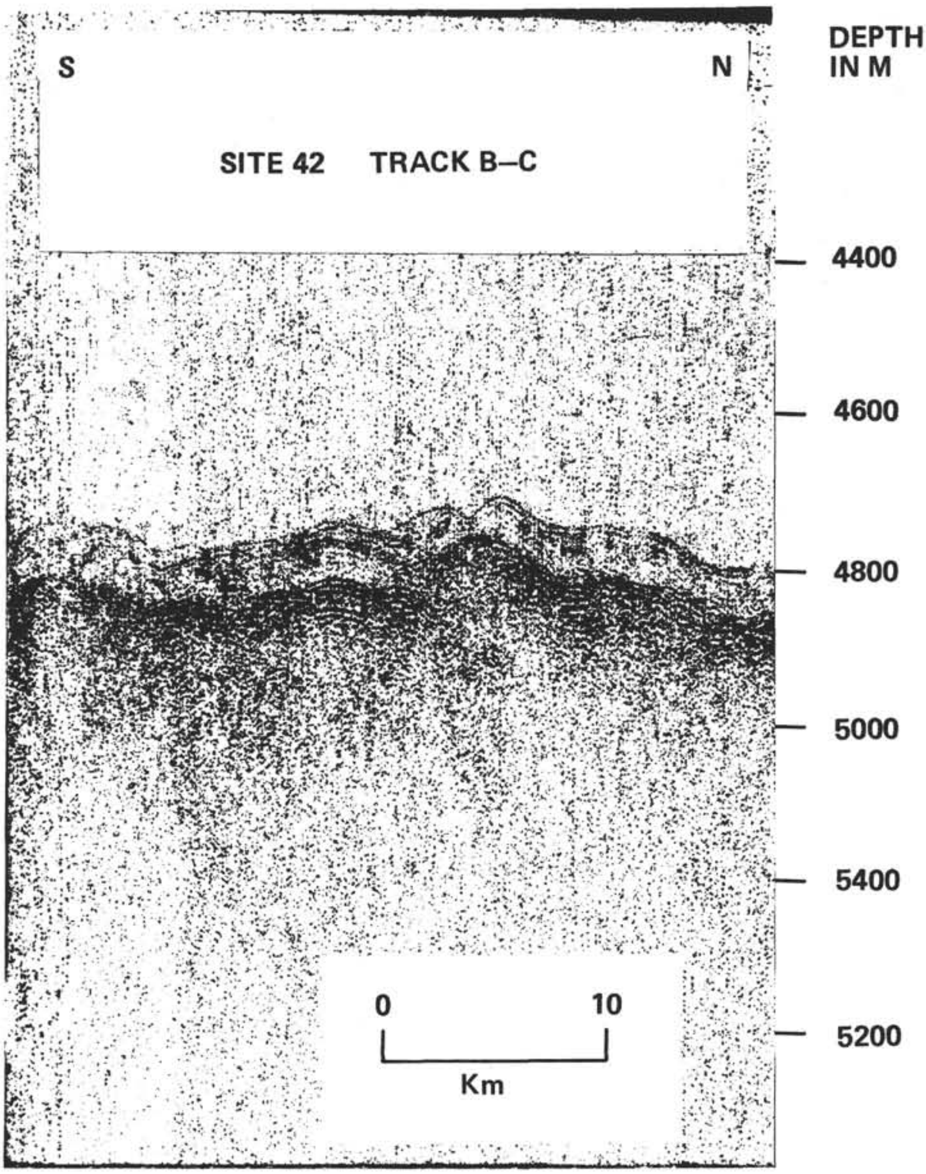

Figure 25. *Typical profile near Site 42 showing uniformly thick sediment layer mantling basement in area of low-relief abyssal hills. No ponding evident anywhere in this region. Distance from Track B-C to drill site unknown. (*Argo *seismic profile, 20 April, 1969, 1930-2110.)*

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