Foraminiferal and Sedimentological Evidence for Uplift of the Deep-sea Floor, Gorda Rise, Northeastern Pacific[1]

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ABSTRACT

Displaced benthic Foraminifera in semiconsolidated clayey sandstone from the Gorda Rise provide evidence for uplift of the deep-sea floor. The sediment was deposited by turbidity currents on the floor of the Escanaba Trough (the axial valley of the Gorda Rise) from a sublittoral source on the continental margin to the east. Subsequent tectonism has lifted the sediment 1000 m up the flanks of the axial valley in approximately the last million years. For the coarse fraction, heavy-mineral data indicate a Klamath Mountain provenance; for the fine fraction, clay mineralogy indicates a probable derivation from the lower Columbia River and the Snake River sub-basins and from the Klamath Mountains.

Introduction. Knowledge gained from studies of Foraminifera, principally planktonic types, has been very useful in the interpretation of geologic processes operating within the oceanic crust. Most of the published observations have reported work performed in establishing the age of rocks dredged from outcrops or the age of unconsolidated to semiconsoldiated sediments in cores (see, for example, Burckle et al., 1967, Cifelli et al. 1968, Saito et al. 1966).

The greater emphasis placed upon studies of planktonic Foraminifera as opposed to benthic forms is a natural result of the relatively greater abundance of the planktonic Foraminifera in many deep-sea deposits and of their greater potential for dating and correlation. In certain areas, however, benthic Foraminifera may be particularly useful, not so much for chronology but for quantitative estimates of vertical sea-floor motion.

The Gorda Rise (McManus 1967), immediately adjacent to the continent off southern Oregon and northern California (Fig. 1), is such an area. The Gorda Rise demonstrates all the characteristics of actively spreading deep-

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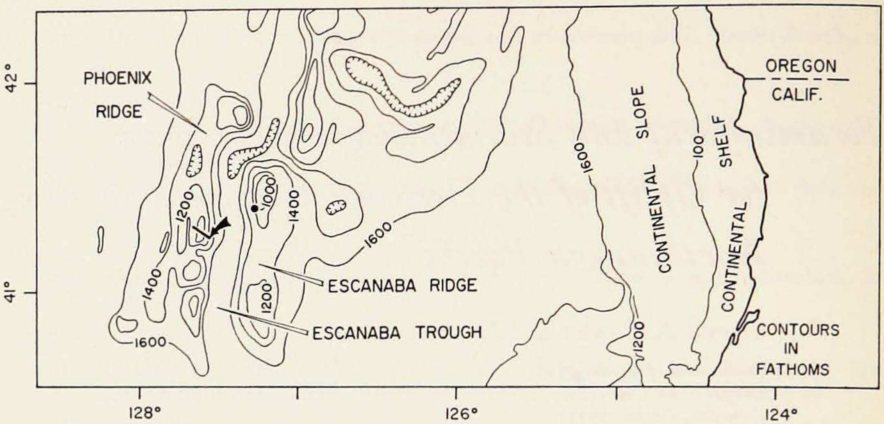

Figure 1. Location of dredge stations 6701F-8 (tip of solid arrow) and 6701F-5 (solid circle) and of deep-towed FISH profile (heavy line) on Gorda Rise. Physiography after McManus 1967.

sea ridge-rise systems (Atwater and Mudie 1968); these authors have described several tilted steplike topographic features on the walls of the Escanaba Trough—the axial rift valley of the Gorda Rise. This topography is believed to be the result of block faulting associated with sea-floor spreading. One interesting feature is that many of the steps are capped with planar acoustic-reflecting layers (Fig. 2). Atwater and Mudie, without the aid of samples, have speculated that these were sedimentary deposits, emplaced by turbidity currents on the floor of the axial valley at some time prior to the block faulting. In the present paper we confirm and expand upon their interpretations through a study of the faunal and sedimentological data.

Dredge hauls taken over the Gorda Rise from Oregon State University's R/V YAQUINA in January and February 1967 have yielded several pieces (up to 30 cm across) of semiconsolidated massive-to-laminated yellowish-gray (5Y8/1, Geological Society of America color code) to light-olive-gray (5Y6/1) mudstone and silty and clayey sandstone along with large quantities of basalt. The pieces of sedimentary rock are subrounded to subangular, contain organism borings up to one cm in diameter, and are variously coated with manganese oxide. Several pieces display freshly broken surfaces as if they were torn from outcrops. All of the samples contain varying quantities of Foraminifera.

K. S. Deffeyes (personal communication), using data from a bathykymograph mounted on the tow cable a short distance ahead of the dredge, estimated that the dredge was located in 2200 m of water at 41°15.9′N, 127°32.9′W; this depth can probably be considered reliable to within a few hundred meters. Heinrichs (1970) has estimated that the uncertainty in the ship's position, using Loran A for navigation, during a December 1966 cruise to the same area was of the order of ± 2 km.

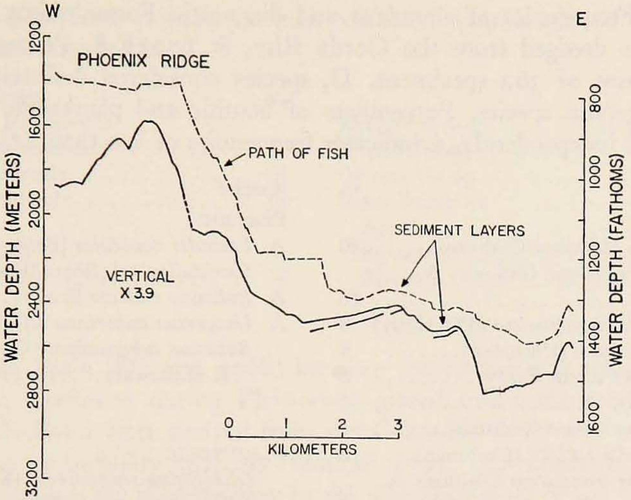

Figure 2. Continuous seismic-penetration record from 3.5 kHz System on deep-towed FISH.

Paleontology. A sample of massive light-olive-gray (5Y6/1) clayey sandstone, from dredge 6701F-8 (Fig. 1), contains a particularly interesting and useful fauna (Table I). At least 76% of the benthic foraminiferal assemblage is composed of typical sublittoral forms. The most abundant species (*Elphidium clavatum*, *E. microgranulosum*, and *Buliminella elegantissima*) are rarely found alive below 100 m. Very few of the species—notably *Bulimina rostrata*, *Eponides tumidulus*, and *Uvigerina auberiana*—are confined when alive to depths below 2000 m and are to be considered definitely indigenous. The sublittoral Foraminifera and perhaps several others that have not been assigned to a bathymetric zone undoubtedly were displaced from their natural habitat to the sample site.

Samples of claystone and mudstone from 6701F-8 and from several other dredge sites contain only typical abyssal benthic Foraminifera and very high percentages of planktonic Foraminifera. These lithologies may have originated through hemipelagic and pelagic processes.

The semiconsolidated sediments from the Gorda Rise cannot be dated precisely by using foraminiferal evidence. All recognized species presently live in the area and range back at least into the Pliocene. The planktonic Foraminifera represent a typical subarctic assemblage for the Pacific Ocean (Bradshaw 1959). Although they are abundant (59% of the total Foraminifera in the clayey sand from 6701F-8), none of the planktonic species lends itself to a precise age determination. In 6701F-8, *Globigerina pachyderma* makes up 69% of the planktonic Foraminifera; 97% of the specimens observed coil to the left. According to the known stratigraphic distribution of this species in the northeastern Pacific, this evidence indicates either a late Miocene, middle

Table I. Frequencies of abundant and diagnostic Foraminifera in a clayey sandstone dredged from the Gorda Rise, St. 6701F-8. Percentages based on a count of 362 specimens. D, species considered defintely displaced; A, indigenous species. Percentages of benthic and planktonic species determined independently. x indicates frequencies of less than 1 %.

	Species	%
	BENTHIC	
D	*Elphidium clavatum* Cushman	30
D	*E. micrograrulosum* Galloway & Wissler	26
D	*Buliminella elegantissima* (d'Orbigny)	9
D	*Buccella frigida* (Cushman)	8
	Bolivina decussata Brady	6
	Eponides sp.	5
	Cassidulina minuta Cushman	4
	Epistominella pacifica (Cushman)	3
	Cassidulina translucens Cushman & Hughes	3
	Eilohedra levicula (Resig)	2
D	*Cibicides lobatulus* (Walker & Jacob)	1
	Trifarina angulosa (Williamson)	1
A	*Eponides tumidulus* (Brady)	x
	Cassidulina subglobosa Brady	x
A	*Bulimina rostrata* Brady	x
A	*Uvigerina auberiana* d'Orbigny	x
	Bulimina subacuminata Cushman & R. E. Stewart	x
	PLANKTONIC	
	Globigerina pachyderma (Ehrenberg)	69
	Globigerinita uvula (Ehrenberg)	16
	Globigerina quingueloba Natland	11
	Globigerinita glutinata (Egger)	3
	Globigerina bulloides d'Orbigny	1

Pliocene, or Pleistocene age (Bandy 1964). The last is the most likely age based upon geophysical evidence. An estimate of probably less than one million years for the age of the oceanic crust beneath the sediment layer at 6701F-8 has been obtained by using the magnetic anomaly pattern presented by Raff and Mason (1961) and from the ages of the anomalies estimated by Vine (1966).

Sedimentology. The heavy-mineral compositions of the silty sandstones in 6701F-5 and -8 are similar and are characterized by an amphibole assemblage that consists primarily of blue-green and green hornblende, with lesser amounts of actinolite-tremolite (Table II). Epidote, clinozoisite-zoisite, clinopyroxene, and garnet also are common constituents. The extremely low pyroxene/amphibole ratios (< 0.1) are typical of the modern sands derived from the Klamath Mountain provenance of southwestern Oregon and northwestern California (Kulm et al. 1968).

Metamorphic constituents, such as blue-green hornblende, actinolite-tremolite, kyanite, and the epidote group, in the Gorda Rise sedimentary rocks reflect a significant contribution from a continental metamorphic provenance. A similar heavy-mineral assemblage is derived from the Klamath-South Coast basins (Kulm et al. 1968), which lie on the western flanks of the Klamath Mountains and of the southern Oregon Coast Range. This suite of minerals also is dominant in the sands and coarse silts on the adjacent continental shelf (Chambers 1968) as well as in the Holocene deep-sea deposits

Table II. Composite nonopaque heavy-mineral assemblages of the Gorda Rise sedimentary rocks.

Amphibole Group	%		%
Blue-green hornblende		Epidote Group	7
and actinolite-tremolite	50	Garnet Group	5
Green hornblende	25	Olivine Group	1
Brown hornblende	3	Other Minerals	
		Apatite	1
Pyroxene Group		Kyanite	2
Clinopyroxene	6	Zircon	1

in the Gorda Basin (Duncan 1968) between the continental margin and the Gorda Rise. However, during Pleistocene glacial times, the sand-silt layers in the Gorda Basin were derived from the Columbia River and were carried to the Basin by turbidity currents (Duncan 1968). Although there are two possible sources for the sand fraction in the silty sandstones of the Gorda Rise, the heavy-mineral suite indicates that they were derived principally from the Klamath Mountain provenance.

The clay-mineral composition of the sedimentary rocks from Gorda Rise dredge haul 6701F-8 is montmorillonite-rich, with lesser amounts of illite and chlorite, respectively (Fig. 3). Mean values for four subsamples from 6701F-8 are: montmorillonite 52%, illite 33% and chlorite 15%. This clay-mineral suite demonstrates some similarity to that found by Duncan et al. (1970) for the unconsolidated sediments of the Cascadia Basin, the Blanco Fracture Zone, and the northern end of the Gorda Rise. These two suites differ in that the former has a considerably higher montmorillonite content, with illite being more abundant than chlorite. A similar montmorillonite-rich clay-mineral assemblage is found in the deep-sea deposits immediately adjacent to the Columbia River (mean values: montmorillonite 52%, illite 23%, and chlorite 25%) (Duncan et al. 1970). These deposits were derived largely from the lower Columbia River and Snake River subbasins.

In contrast, the principal clay-mineral composition of sample 6701F-5 is 27% illite and 73% chlorite. Montmorillonite was not detected in the one sample analyzed. This clay-mineral suite probably was derived from the Klamath Mountains, which apparently have a rather low montmorillonite content and a high chlorite content. For example, the Rogue River produces a clay-mineral suite that contains 23% montmorillonite, 26% illite, and 51% chlorite (Duncan et al. 1970).

Although the sediment source for the sands in the Gorda Rise sedimentary rocks appears to be the Klamath Mountains, the clay-mineral constituents apparently were derived from two sources, probably the Columbia River and the Klamath Mountains.

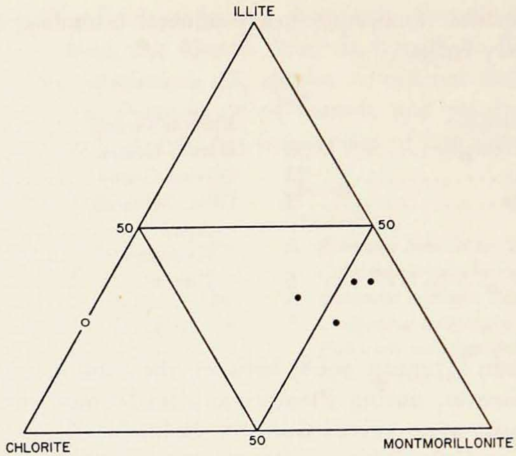

Figure 3. Clay-mineral composition of four samples of sedimentary rock from 6701F-8 (solid circles) and one from 6701F-5 (open circle). Data are from an x-ray diffraction study of the < 2-μ size fraction using techniques outlined by Heath (1968) and Biscaye (1965).

Discussion. By a fortunate coincidence, one of the tracks on a S.I.O. survey —using a deep-towed geophysical vehicle (FISH)—(Atwater and Mudie 1968) passed almost directly over the site of dredge station 6701F-8. The continuous 3.5 kHz seismic-penetration record taken along the track displays one prominent and one less-prominent sediment-covered block-like step between 2400 and 2600 m (Fig. 2). It is significant that the depth of 2200 m estimated by Deffeyes for the dredge haul differs by only 10 to 20% from the depths of the steps. The estimated bottom position for 6701F-8 is near the east end of the FISH track, where no sediment layers have been evident; however, considering the probable uncertainty regarding the ship's position, the dredge could easily have sampled one of the prominent steps to the west.

Atwater and Mudie (1968) have argued convincingly that the shapes of the sediment bodies do not indicate a predominantly pelagic origin. The faunal and textural characteristics of the dredge samples bear this out. These characteristics are typical of the turbidity-current deposits of Cascadia Basin to the north (Duncan 1968). There is no known mechanism of sedimentation that could reasonably account for the deposition of the silty sandstone at the site of dredge 6701F-8 approximately 1000 m above the floor of the Escanaba Trough. The only plausible explanation for the origin of the sediments is that they were deposited in a depression by a turbidity current that originated in an inner sublittoral environment to the east off northern California or off southern Oregon.

Late Pleistocene and Holocene sediments of the Blanco Fracture Zone troughs and the northern end of the Escanaba Trough consist chiefly of basaltic glass lutite. The fine-grained portion of the deposit is largely terrigenous and represents particle by particle sedimentation whereas the coarse-grained portion is a by-product of local submarine volcanic activity (Duncan 1968). There is no sedimentary evidence to indicate that the turbidity-current deposits of the Cascadia Basin have entered the Escanaba Trough through the fracture zone from the north.

On the other hand, the thick (at least 400 m) Pleistocene sedimentary section in the southern portion of the Escanaba Trough (McManus and Burns 1969) and the available route to the Trough from the south suggest that most of the bottom-transported sediments entered the Escanaba Trough through its southern extremity. The dominance of a Klamath Mountain heavy-mineral suite over a Columbia River suite further indicates a southern source.

Using an estimate of 1000 m of uplift and a maximum age of one million years for the sedimentary rocks in 6701F-8, we obtain a minimum rate of uplift of 0.1 cm/year for the Gorda Rise. This estimate could easily be low by a factor of five or more. Duncan and Kulm (1970), on the other hand, have calculated an average rate of uplift of 1.5 cm/year for portions of the Blanco Fracture Zone during approximately the last 30,000 years. A similar rate has been suggested for the Mid-Atlantic Ridge in the vicinity of the Vema Fracture Zone (van Andel 1969).

It is interesting to note that, of the five dredge hauls that recovered sedimentary rocks from the Gorda Rise, two contained coarse-grained sediment (6701F-5 and 6701F-8). The sediments from these two sites are very similar in terms of composition, texture, and gross characteristics. Site 6701F-5 is at a depth of approximately 2200 m on the east wall of the Escanaba Trough, opposite site 6701F-8 (Fig. 1). The depths at these sites are similar and correspond favorably with the depth of the prominent block-like step illustrated in Fig. 2 and with the 2400-m depth at one of the bathymetric benches that appears consistently on either side of the Escanaba Trough (Heinrichs 1970). It is tempting to speculate that the coarse-grained sediment at sites 6701F-5 and 6701F-8 was deposited at the same time.

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