Reports

Spreading of the Ocean Floor: Undeformed Sediments in the Peru-Chile Trench

Abstract. *None of the expected stratigraphic and structural effects of a spreading sea floor have been imposed on the sedimentary fill of the Peru-Chile Trench. During at least the last several million years, and perhaps during much of the Cenozoic, the trench has not been affected by an oceanic crust thrusting under the continent.*

During April and May 1967, 28 continuous seismic-reflection profiles were made across the Peru-Chile Trench between Antofagasta (23°S) and Isla Chiloé (44°S), Chile (Fig. 1). The trench contains little or no sedimentary fill north of Valparaiso (33°S), but southward the fill is as thick as 2.5 km. Deformation of the sedimentary fill, and the lack of fill to the north, are examined in relation to expected effects of spreading of the sea floor from the East Pacific Rise.

The concept of a spreading ocean floor (SOF) was formally proposed by Dietz (*1*) and Hess (*2*) to reconcile proposed models of mantle convection with the crustal structure and topography of ocean basins. The validity of the general model for spreading is strongly fortified by the symmetric configuration of magnetic anomalies about the axes of oceanic ridges and rises (*3*); the anomalies are thought to represent linear belts of volcanic rock of opposing polarity. Comparison of the sequence of reversals to the established chronology of geomagnetic reversals enables the computation of spreading rates ranging from 1 to 4.5 cm/year. The sense of displacement indicated by first-motion studies of earthquakes along oceanic fracture zones is additional strong evidence of crustal spreading, as the relative movement accords with that predicted by transform faults (*4*). Less convincingly, the age and thickness distribution of sediments flanking oceanic ridges have been cited to support a model of SOF (*5, 6*).

A basic premise of the spreading concept is that the upper volcanic layer of the oceanic crust (second layer) is generated principally at or near the sea floor along the medial axes of major ridges and rises. Once formed, the crustal material spreads or moves laterally toward adjacent continental blocks, carrying with it, like a conveyor belt, any superjacent pelagic or terrigenous sedimentary blanket. Near the base of continental margins the spreading crust descends below the sialic continental block. If a marginal trench is present, the continent is presumed to be a relatively immobile mass, with simatic crust shearing below its oceanic margin (*1*), possibly along a steeply dipping Benioff fault plane.

The work of Pitman and Heirtzler (*3*) suggests that the rate of spreading from the southern portion of the East Pacific Rise (Fig. 1) toward the South American continent has averaged about 4.5 cm/year during the last 10 million years—450 km of movement. Data on the age distribution of sediments overlying the rise suggest spreading rates as high as 10 cm/year since late-Pliocene time (*5*). Other ridges (Fig. 1) that may be or may have been sources of crustal spreading toward the Peru-Chile Trench are the Nasca and South Chile ridges. We now examine the consequences of this proposed spreading in terms of the structural relations it should impose on the Peru-Chile Trench.

1) The general spreading model stipulates that pelagic sediments are swept against the continental block along with down-welling oceanic crust (*1, 2*), and are either added to or stuffed beneath the continental crust. Seaward of the Peru-Chile Trench the basaltic second layer is overlaid by 130 to 150 m of pelagic sediment (Fig. 2, profile A–A′). Because we are unaware of a mechanism (one could allude to some sort of repetitive tectonic "swallowing") whereby low-strength pelagic sediments can be steadily inserted below the continental crust, and thereby hidden from "acoustic" view, we reason that, had spreading taken place, a crumpled fill of allochthonous pelagic scrapings should occupy the axis of the trench (Fig. 3A). However, from north of Valparaiso to near the Peruvian border the trench is devoid of a sedimentary fill, except for isolated pockets of undisturbed (that is, flat-lying) sediments a few hundred meters thick (Fig. 2, profile *A–A′*). Thus the absence of even a small portion of

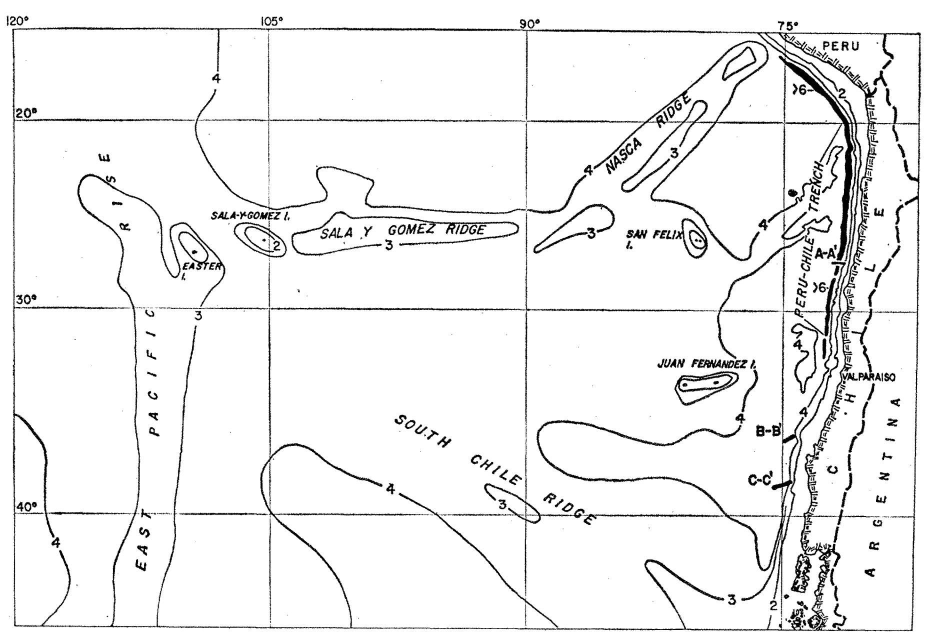

Fig. 1. Relation of Peru-Chile Trench to East Pacific Rise and other oceanic ridges that may be or have been centers of spreading; depths are in kilometers. *A–A′*, *B–B′*, and *C–C′* locate acoustic-reflection profiles shown in Fig. 2.

the expected pelagic scrapings points to the absence of SOF for some distance seaward of the trench since its formation. Later we provide evidence that the trench is at least as old as the Pliocene.

Pelagic sediments west of the trench are largely or partly composed of calcareous oozes (*7–9*). Thus one may argue that they would have been lost by solution soon after they were carried below the 3500-m carbonate-compensation depth for this area (*8*), so that the pelagic sediments would not have tectonically accumulated in the trench. However, a relatively thick sequence of calcareous sediments would have been only partially dissolved, because it would have been soon covered by a protective blanket of solution-concentrated residual pelagic clays, or a newly deposited layer of noncalcareous terrigenous sediment derived from the nearby continent. Occurrences of calcareous ooze well below the regional compensation depth, but beneath a protective layer of noncalcareous sediment, are widely known over the southeastern Pacific (*5*) as well as on the flanks of the Peru-Chile Trench itself (*9*).

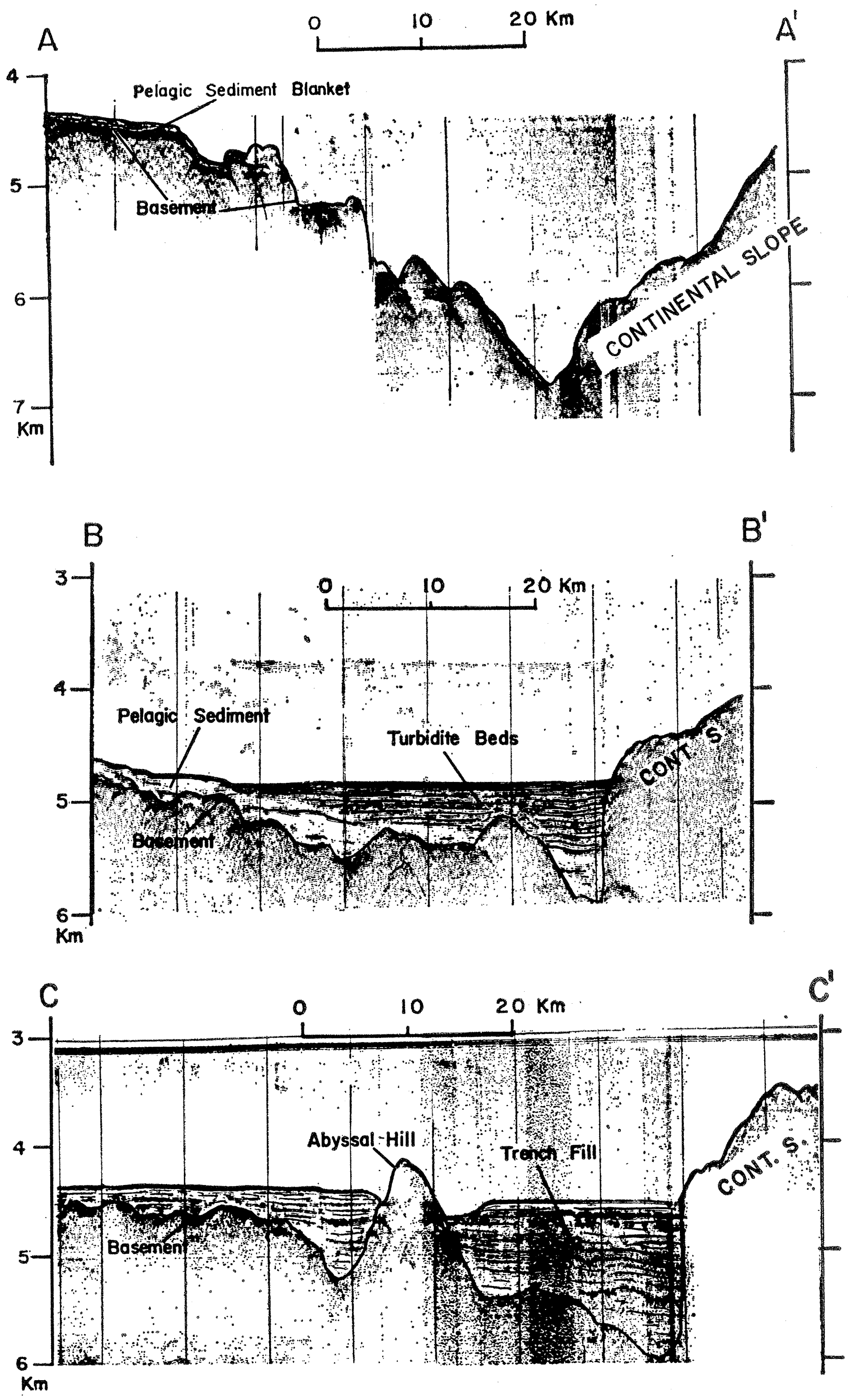

Fig. 2. Seismic-reflection profile *A–A'* is across a sediment-barren segment of the trench; pelagic sediments overlie the surface of the second layer, west (left) of the trench. Profile *B–B'* shows a segment of the trench fill consisting of turbidite beds overlying pre- or early-trench pelagic sediments; the separating unconformity is thought to reflect a change in depositional dynamics rather than trench tectonics. Profile *C–C'* shows the effects of a topographic protuberance on the deposition of turbidites, which here have overfilled the trench to the west (left). See Fig. 1 for locations of profiles; vertical exaggeration is about 11:1.

2) South of Valparaiso the trench is partially filled, or filled to a depth of westward overflow, with turbidity beds (Fig. 2, profiles *B–B'* and *C–C'*); their identification is based on their horizontal attitude, the internally reflective nature of the fill, the presence of leveed channels, and the occurrence of graded sandy and silty beds (*9*) in cored sediment from the trench. The turbidite section sharply abuts an extremely steep scarp, possibly exceeding 45 deg, forming the landward flank of the trench. In many areas 500 to 700 m of turbidite fill unconformably overlies several hundred meters of weakly reflecting beds that dip landward and parallel to the surface of the basement rock (second crustal layer) underlying the seaward flank of the trench. The latter sediments can be traced westward from the trench axis to the adjacent oceanic floor, where bottom samples (*7*) and the topography-conforming geometry of the deposits (*10*) identify them as pelagic sediments. Thus the thick turbidite fill in the trench overlies early- or pre-trench pelagic sediments (doubtless some nonturbidite terrigenous or hemipelagic sediments also are involved). The correlation of contemporary and Pleistocene terrestrial sources of sediment with the thickness and distribution of the turbidite fill implies that this sequence cannot be much older than the Miocene-to-Pleistocene uplift that formed the Andes (*11, 12*). We suspect that the turbidite sequence is in fact largely of Pleistocene age and reflects a high rate of sediment offloading from the adjacent continent in response to low stands of sea level, pluvial periods, and growth of alpine and coastal glaciers (*11*). The age of the underlying pre- or early-trench pelagic and hemipelagic sediments cannot be estimated with much accuracy. However, if rea-

sonable sedimentation rates (1 to 5 mm/1000 years) are applied to the thickness of these deposits (130 to 150 m) immediately seaward of the trench, it seems apparent that at least they represent much of the Tertiary.

If the compound sedimentary fill of the Peru-Chile Trench south of Valparaiso accumulated during a period of active SOF, the rate of filling obviously far exceeded any rate of loss by way of continental underthrusting. The eastward-moving floor and the incoming pelagic blanket would therefore be expected to have deformed compressionally the entire sedimentary fill by driving it against the steep landward wall (that is the continental slope) of the trench (Fig. 3B). However, profile B–B' (Fig. 2), a typical acoustic-reflection profile over the southern or filled segment of the trench, clearly shows that the expected deformation is absent. In addition, the contact between the pelagic and turbidite sequences directly abuts the steep landward wall of the trench, indicating the absence of compressional features even in close proximity to the base of the continental slope. These structural relations unequivocally attest that the sedimentary sequences occupying the trench are not, and have not been, involved in continental underthrusting. Unless the landward wall of the trench is moving eastward, these same relations eliminate the possibility that SOF has taken place for some distance seaward of the trench during the time required for accumulation of the fill.

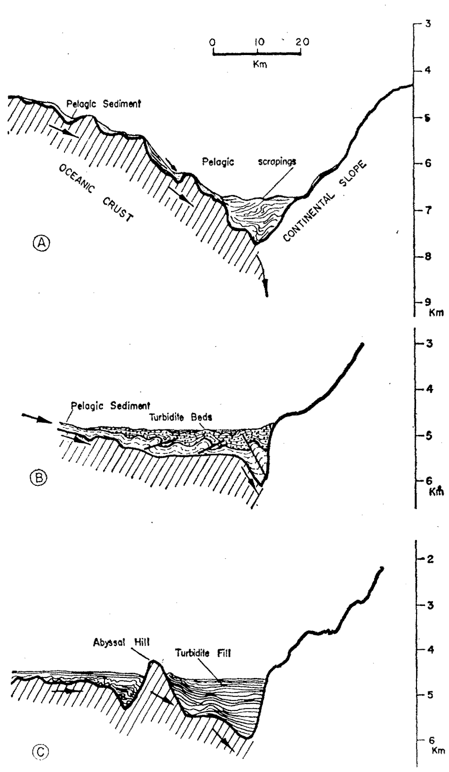

Fig. 3. (A) An illustration showing that a portion of the pelagic sediments swept into the trench by way of SOF should be left behind as scrapings from an oceanic crust thrusting under a continent; compare with A–A' in Fig. 2. (B) An illustration showing the style of deformation that SOF may have imposed on the sedimentary fill of a marginal trench. The mild deformation indicates that spreading did not begin until most of the fill had accumulated; compare with profile B–B' in Fig. 2. (C) An illustration showing that large topographic features, entering the trench along with SOF, must compressionally deform a turbidite fill of the trench because these sediments have obviously accumulated in the trench at a rate greatly exceeding any possible loss by thrust under the continent; compare with C–C' in Fig. 2.

3) If the turbidite sequence of the trench fill accumulated during SOF, one may conclude that this fill would have been repeatedly deformed by features of basement relief entering the trench from the west. Relief features would have been dragged "plow-like" through the accumulating sediment on their way to obliteration at the base of the trench (Fig. 3C). Profile C–C' (Fig. 2), however, shows that the expected deformation does not appear, even in association with large topographic features. The partially buried abyssal hill shown along this profile has had little deformative effect on the surrounding sediment, although it has profoundly affected the depositional geometry of flanking turbidite beds, much as has Kodiak Seamount in the Aleutian Trench (*13*).

Spreading from the East Pacific Rise has not produced the expected stratigraphic and structural relations within the sedimentary fill of the Peru-Chile Trench off central Chile; this is also true for the Middle America Trench west of Mexico and Central America (*14*). If correct, our assessment of the age of the undeformed turbidite fill in the Peru-Chile Trench may mean that SOF has not taken place since late-Pliocene time. The older pre- or early-trench pelagic and hemipelagic sediments underlying the turbidite fill also are undeformed and may attest to an absence of spreading during most of the Cenozoic.

The possibility that the floor did not in fact spread during late-Cenozoic time in the vicinity of the East Pacific Rise is doubted by us considering the strength of supporting magnetic, seismologic, and sedimentologic evidence. However, we are equally convinced that a spreading floor has not slid beneath Central and South America along the axis of their nearly contiguous trenches at least since late-Pliocene time and perhaps during most of the Cenozoic.

A solution to this paradox appears to require modification of the basic SOF model already proposed (*1, 2*). Possibly the lateral motion of the crust, away from the rise, is taken up by crustal deformation before it reaches the trench; or perhaps the spreading crust begins its continental underthrusting at an unrecognized area seaward of the trench. More difficult solutions may involve (i) eastward sliding of the South American continent, along with spreading, which is the reverse of the motion stipulated by the hypothesis of continental drift; or (ii) SOF during a period of global expansion, essentially the unwieldy concept previously advanced (*15*).

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References and Notes

R. S. Dietz, *Nature* **190**, 854 (1961).
2. H. H. Hess, *Petrologic Studies: A Volume in Honor of A. F. Buddington* (Geol. Soc. Amer., New York, 1962), p. 260.
F. J. Vine and D. H. Matthews, *Nature* **199**, 947 (1963); F. J. Vine and J. T. Wilson, *Science* **150**, 485 (1965); W. C. Pitman III and J. R. Heirtzler, *ibid.* **154**, 1164 (1966).
L. R. Sykes, *J. Geophys. Res.* **72**, 2131 (1967).
5. L. H. Burckle, J. Ewing, T. Saito, R. Leyden, *Science* **157**, 537 (1967).
6. J. Ewing and M. Ewing, *ibid.* **156**, 1590 (1967); W. R. Riedel, *ibid.* **157**, 540 (1967).
7. M. N. Bramlette, *Oceanography*, M. Sears, Ed. (AAAS, Washington, D.C., 1961), p. 345.
8. O. L. Bandy and K. S. Rodolfo, *Deep-Sea Res.* **11**, 817 (1964).
9. E.-A. Zen, *Amer. Mineral.* **42**, 889 (1957); *J. Sediment. Petrol.* **29**, 513 (1959).
E. L. Hamilton, *J. Geophys. Res.* **72**, 4189 (1967).
11. R. L. Fisher and R. W. Raitt, *Deep-Sea Res.* **9**, 423 (1962); J. M. Zeigler, N. D. Athearn, H. Small, *ibid.* **4**, 238 (1957); R. F. Schmalz, dissertation, Harvard Univ. (1958); D. E. Hayes, *Marine Geol.* **4**, 309 (1966); R. von Huene, D. W. Scholl, J. B. Ridlon, in *Abstr. Geol. Soc. Amer. Ann. Meeting New Orleans* (1967); D. W. Scholl, R. von Huene, J. B. Ridlon, *ibid.*
12. R. W. R. Rutland, J. E. Guest, R. L. Grasty, *Nature* **208**, 677 (1965); C. Galli-Olivier, *Science* **158**, 653 (1967).
13. E. L. Hamilton and R. von Huene, *Science* **154**, 1323 (1966).
14. D. A. Ross and G. G. Shor, Jr., *J. Geophys. Res.* **70**, 5551 (1965).
15. B. C. Heezen, in *Preprints Intern. Oceanog. Congress 1st* (AAAS, Washington, D.C., 1959), p. 26; R. H. Dicke, *Science* **138**, 653 (1962); J. Hospers and S. I. van Andel, *Tectonophysics* **5**, 5 (1967).
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