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MECHANICAL OBSTACLES TO THE MOVEMENT OF CONTINENT-BEARING PLATES

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Abstract. Recent studies indicate three problems with the concept of continental drift as an incidental corollary of plate movemement: (1) Slab pull can not drive plates with continental leading edges, (2) There is no low velocity zone under shields, and (3) Continents have "roots" 400 to 700 km deep. These problems imply that if continental drift occurs, it must use mechanisms not now understood, or that it may not occur at all, plate movement being confined to ocean basins.

Introduction

Plate movement is generally assumed to involve continental drift, the continents being carried as incidental parts of lithospheric plates moving on the low-velocity zone (LVZ). However, recent work in geophysics and geochemistry suggests three problems with this concept, specifically mechanical obstacles to the movement of continent-bearing plates.

Absence of a Suitable Plate-driving Mechanism

Several recent studies (Forsyth and Uyeda, 1975; Chapple and Tullis, 1977; Carlson et al., 1983) indicate that slab pull is the dominant plate-driving mechanism, as distinguished from ridge push and other forces. Slab pull includes gravitational subsidence of oceanic lithosphere and subduction promoted by the gabbro-eclogite inversion (Ahrens and Schubert, 1975) and phase changes such as the olivine-spinel transition. Neither of these would appear to be effective for continental crust, and especially not for plates whose nominally leading edges consist of continental crust such as the American and Eurasian plates. The apparent northward movement of peninsular India has been explained by Bird (1978) by "delamination" that began with subduction of mafic crust. This mechanism is not applicable to the three continent-bearing plates just mentioned because their leading edges are not being subducted.

Absence of the Low-Velocity Zone under Shields

All schematic mantle cross-sections illustrating sea-floor spreading and continental drift show the low-velocity zone (LVZ), the supposed bearing surface on which plates move, as existing under continents and ocean basins alike. However, there is increasingly strong evidence from two independent approaches that the LVZ is not of global extent. First, seismic studies (Alexander and Sammis, 1975; Goncz and Cleary, 1976) show that the LVZ does not exist under shields. Second, the low heat flow of shields implies thermal gradients in the mantle that do not intersect the solidus (Knopoff, 1983). Since the LVZ is generally interpreted as a zone of partial melting (eg., Lambert and Wyllie, 1970), this evidence independently argues against its existence under shields. There is good evidence for the sub-continental LVZ under areas of current or recent tectonism, such as the Basin and Range Province. However, all large continents have high proportions of exposed or covered shield, and presumably substantial parts of unmelted mantle with no low-velocity zone.

Deep Continental Roots

Several independent lines of evidence (Alexander, 1974; Jordan, 1975) indicate that continents have roots, so to speak, extending to depths of at least 400 km in the mantle, as proposed by MacDonald (1963). Jordan's treatment, the most comprehensive, shows that the characteristically subcontinental seismic properties, thermal gradients, and chemical composition of the mantle extend to 400 to 700 km depths, although he interprets this as meaning the deep layers must translate with the continents, not that the continents are stationary. Anderson (1979) has challenged the seismic evidence for such deep roots, but the weight of several independent lines of evidence clearly favors them.

Discussion

Plate tectonic theory was originally developed on the basis of evidence from the ocean basins, and this evidence has always been remarkably clear-cut and objective in contrast to the evidence for plate tectonics in continents. For example, Wilson's (1965) transform fault concept permitted a definitive test (first motions of transform fault earthquakes), and was confirmed quickly by Sykes (1967). Recent high-precision geodesy using satellite laser ranging, very long baseline interferometry (VLBI), and Doppler tracking (Anderle and Malyevac, 1983; Christodoulidis and Smith, 1983) has begun to detect plate motions around the Pacific Basin generally agreeing in sense and magnitude with the Minster and Jordan (1978) model. On the other hand, trans-Atlantic VLBI measurements (Ryan and Mallama, 1984) have at this writing not demonstrated continuing separation of North America and Eurasia. It will of course be objected that continental drift is episodic and may not be happening now, but since sea-floor spreading is demonstrably occurring in the North Atlantic, plate tectonic theory taken

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at face value requires that drift should also be occurring. Furthermore, laser ranging across the San Andreas fault system (Christodoulidis and Smith, 1984) shows that the movement between the North American and Pacific plates (though not necessarily local movement on the San Andreas itself) is steady, within measurement errors, over at least the 1974-83 period.

We see here an interesting and hitherto-overlooked dichotomy. For oceanic crust, the plate-driving mechanisms are both adequate and reasonably well-understood, and there is a low-strength bearing surface (the LVZ) on which oceanic plates can move. Correspondingly, the evidence for plate tectonic processes in and around ocean basins is extremely strong. In contrast, for continent-bearing plates, there are severe mechanical obstacles, summarized here, and the evidence for continental drift, considered by itself, is so far indirect, subjective, and debatable if not refutable.

The meaning of this dichotomy may be that continent-bearing plates simply move with difficulty, as the Minster and Jordan (1978) model implies. But if carried further, as I have done elsewhere (Lowman, 1981, 1983, and in press), it may also mean that large continents do not move, and that plate tectonic processes are effective only in and near ocean basins. Unless and until VLBI or satellite laser ranging clearly demonstrates trans-Atlantic continental drift, it appears that the possibility of fixed continents should be kept as a working hypothesis. Even if drift is finally confirmed, the problems raised here suggest that it occurs by means of mechanisms considerably more complicated than those widely expounded today in textbooks and popular science writing.

This paper has discussed only selected geophysical problems of continental drift. Other problems, chiefly geological, are covered in a longer paper in press for the Journal of Petroleum Geology. That paper also treats questions not covered here, such as non-drift causes for the parallelism of opposing continental margins and the apparent absence of passive margin subduction required by the hypothesis of "plate tectonics with fixed continents" (Lowman, in press).

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