

Seismology and the New Global Tectonics¹

BRYAN ISACKS AND JACK OLIVER

Lamont Geological Observatory, Columbia University, Palisades, New York 10964

LYNN R. SYKES²

Earth Sciences Laboratories, ESSA

Lamont Geological Observatory, Columbia University, Palisades, New York 10964

A comprehensive study of the observations of seismology provides widely based strong support for the new global tectonics which is founded on the hypotheses of continental drift, sea-floor spreading, transform faults, and underthrusting of the lithosphere at island arcs. Although further developments will be required to explain certain part of the seismological data, at present within the entire field of seismology there appear to be no serious obstacles to the new tectonics. Seismic phenomena are generally explained as the result of interactions and other processes at or near the edges of a few large mobile plates of lithosphere that spread apart at the ocean ridges where new surficial materials arise, slide past one another along the large strike-slip faults, and converge at the island arcs and arc-like structures where surficial materials descend. Study of world seismicity shows that most earthquakes are confined to narrow continuous belts that bound large stable areas. In the zones of divergence and strike-slip motion, the activity is moderate and shallow and consistent with the transform fault hypothesis; in the zones of convergence, activity is normally at shallow depths and includes intermediate and deep shocks that grossly define the present configuration of the down-going slabs of lithosphere. Seismic data on focal mechanisms give the relative direction of motion of adjoining plates of lithosphere throughout the active belts. The focal mechanisms of about a hundred widely distributed shocks give relative motions that agree remarkably well with Le Pichon's simplified model in which relative motions of six large, rigid blocks of lithosphere covering the entire earth were determined from magnetic and topographic data associated with the zones of divergence. In the zones of convergence the seismic data provide the only geophysical information on such movements.

Two principal types of mechanisms are found for shallow earthquakes in island arcs: The extremely active zone of seismicity under the inner margin of the ocean trench is characterized by a predominance of thrust faulting, which is interpreted as the relative motion of two converging plates of lithosphere; a less active zone in the trench and on the outer wall of the trench is characterized by normal faulting and is thought to be a surficial manifestation of the abrupt bending of the down-going slab of lithosphere. Graben-like structures along the outer walls of trenches may provide a mechanism for including and transporting sediments to depth in quantities that may be very significant petrologically. Large volumes of sediments beneath the inner slopes of many trenches may correspond, at least in part, to sediments scraped from the crust and deformed in the thrusting.

Simple underthrusting typical of the main zone of shallow earthquakes in island arcs does not, in general, persist at great depth. The most striking regularity in the mechanisms of intermediate and deep earthquakes in several arcs is the tendency of the compressional axis to parallel the local dip of the seismic zone. These events appear to reflect stresses in the relatively strong slab of down-going lithosphere, whereas shearing deformations parallel to the motion of the slab are presumably accommodated by flow or creep in the adjoining ductile parts of the mantle. Several different methods yield average rates of underthrusting as high as 5 to 15 cm/yr for some of the more active arcs. These rates suggest that temperatures low enough to permit dehydration of hydrous minerals and hence shear fracture may persist even to depths of 700 km. The thickness of the seismic zone in a part of the Tonga arc where very precise hypocentral locations are available is less than about 20 km for a wide range of depths. Lateral variations in thickness of the lithosphere seem to occur, and in some areas the lithosphere may not include a significant thickness of the uppermost mantle.

¹Lamont Geological Observatory Contribution 1234.

²Order of authors determined by lot.

The lengths of the deep seismic zones appear to be a measure of the amount of under thrusting during about the last 10 m.y. Hence, these lengths constitute another 'yardstick' for investigations of global tectonics. The presence of volcanism, the generation of many tsunamis (seismic sea waves), and the frequency of occurrence of large earthquakes also seem to be related to underthrusting or rates of underthrusting in island arcs. Many island arcs exhibit a secondary maximum in activity which varies considerably in depth among the various arcs. These depths appear, however, to correlate with the rate of underthrusting, and the deep maxima appear to be located near the leading (bottom) part of the down-going slab. In some cases the down-going plates appear to be contorted, possibly because they are encountering a more resistant layer in the mantle. The interaction of plates of lithosphere appears to be more complex when all the plates involved are continents or pieces of continents than when at least one plate is an oceanic plate. The new global tectonics suggests new approaches to a variety of topics in seismology including earthquake prediction, the detection and accurate location of seismic events, and the general problem of earth structure.

INTRODUCTION

This paper relates observations from the field of seismology and allied disciplines to what is here termed the 'new global tectonics.' This term is used to refer in a general way to current concepts of large-scale tectonic movements and processes within the earth, concepts that are based on the hypotheses of continental drift [Wegener, 1966], sea-floor spreading [Hess, 1962; Dietz, 1961], and transform faults [Wilson, 1965a] and that include various refinements and developments of these ideas. A comprehensive view of the relationship between seismology and the new global tectonics is attempted, but there is emphasis on data from earthquake seismology, as opposed to explosion seismology, and on a particular version of the sea-floor spreading hypothesis in which a mobile, near-surface layer of strength, the lithosphere, plays a key role. Two basic questions are considered. First, do the observations of seismology support the new global tectonics in some form? To summarize briefly, they do, in general, give remarkable support to the new tectonics. Second, what new approaches to the problems of seismology are suggested by the new global tectonics? There are many; at the very least the new global tectonics is a highly stimulating influence on the field of seismology; very likely the effect will be one of revolutionary proportions.

The mobile lithosphere concept is based partly on an earlier study [Oliver and Isacks, 1967], but, as presented here, it incorporates ideas from Elsasser [1967], who independently developed a model with many similar features based on entirely different considerations, and ideas from Morgan [1968] and Le Pichon

[1968], who pursued this concept further by investigating the relative motion in plan of large blocks of lithosphere.

Figure 1 is a block diagram illustrating some of the principal points of the mobile lithosphere hypothesis. In a relatively undisturbed section, three flat-lying layers are distinguished: (1) the *lithosphere*, which generally includes the crust and uppermost mantle, has significant strength, and is of the order of 100 km in thickness; (2) the *asthenosphere*, which is a layer of effectively no strength on the appropriate time scale and which extends from the base of the lithosphere to a depth of several hundred kilometers; and (3) the *mesosphere*, which may have strength and which makes up the lower remaining portion of the mantle and is relatively passive, perhaps inert, at present, in tectonic processes. (Elsasser refers to the lithosphere as the tectosphere and defines some other terms somewhat differently, but the terminology of Daly [1940] is retained here. The term 'strength,' which has many definitions and connotations, is used here, following Daly, in a general sense to denote enduring resistance to a shearing stress with a limiting value.) The boundaries between the layers may be gradational within the earth. The asthenosphere corresponds more or less to the low-velocity layer of seismology; it strongly attenuates seismic waves, particularly high-frequency shear waves. The lithosphere and the mesosphere have relatively high seismic velocities and propagate seismic waves without great attenuation.

At the principal zones of tectonic activity within the earth (the ocean ridges, the island arc or island-arc-like structures, and the major

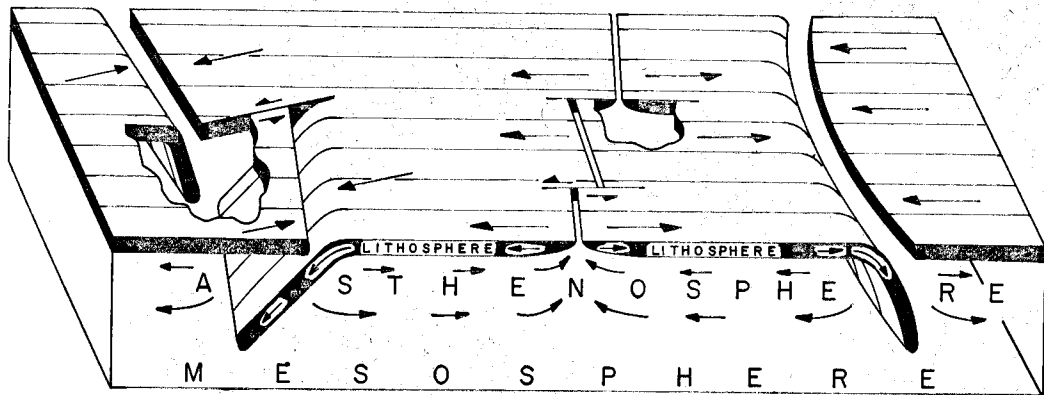


Fig. 1. Block diagram illustrating schematically the configurations and roles of the lithosphere, asthenosphere, and mesosphere in a version of the new global tectonics in which the lithosphere, a layer of strength, plays a key role. Arrows on lithosphere indicate relative movements of adjoining blocks. Arrows in asthenosphere represent possible compensating flow in response to downward movement of segments of lithosphere. One arc-to-arc transform fault appears at left between oppositely facing zones of convergence (island arcs), two ridge-to-ridge transform faults along ocean ridge at center, simple arc structure at right.