How Thick is the Lithosphere?

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The hypotheses of seafloor spreading and plate tectonics have received much attention lately because they explain in a consistent manner the pattern of magnetic anomalies on the seafloor, the distribution of earthquake belts and the thickness and ages of deep-sea sediments. According to these hypotheses the lithosphere (composed of the crust and the rigid cap of the upper mantle) is divided into a number of rigid plates in constant motion. The plates are created along mid-ocean ridges and are destroyed in the process of sinking back into the mantle in the vicinity of deep-sea trenches. The lithosphere is underlain by the asthenosphere—a weak zone coincident with the seismic low velocity layer, and probably the source region of basaltic magmas.

This article is concerned with the problem of determining the thickness of the suboceanic mantle. Thickness is an important parameter which enters discussions of the mechanism of plate tectonics and the thermal regime in the lithosphere.

The thickness of the lithosphere may be estimated in several different ways. For example, seismic focal depths under Hayes generally coincide with the zone that the base of the lithosphere where magma enters the fissure system which ultimately leads to the surface. A value of 60 km was found. Seismic focal depths at mid-ocean ridges extend to 60 km, this limiting depth presumably marking the base of the lithosphere. The most direct indication of the thickness of the lithosphere is the shear velocity distribution with depth. A reversal in shear velocity in the suboceanic mantle now seems to be uniquely established although the determination of the velocity-depth curve is still uncertain. Presumably the high velocity lid to the low velocity zone coincides with the lithosphere and the base of the lithosphere is marked by a rapid decrease in shear velocity. This method has been used by several investigators and values ranging from 40 to 70 km have been reported. Unfortunately these determinations are subject to the well known lack of uniqueness of surface wave methods, especially when density and shear velocity are both allowed to vary.

In this article we use new and highly precise group velocity data to test models found by F. P. using a Monte Carlo procedure and reported in an earlier paper. In the previous work randomly selected models were required to fit Love and Rayleigh wave phase velocities pertinent to oceanic paths, eigenperiod data, mass and moment of inertia of the Earth. In the new test, group velocities

A rapid decrease in shear velocity in the suboceanic mantle is used to infer the thickness of the lithosphere. It is proposed that new and highly precise group velocity data constrain the solutions and imply a thickness near 70 km.
are calculated for each model and compared with the new group velocity values of H. K., which are based on thirty sets of data from predominantly oceanic paths. These are more data than previously available, leading to good estimates of the errors. This is a stringent test because group velocity is associated with the derivative of phase velocity with respect to period and a slight difference in slopes of phase velocity shows up more clearly in the group velocity curve.

The results for Rayleigh waves are shown in Fig. 1. H. K.'s experimental group velocities together with error indications (+s) are shown with group velocities calculated for various models. Also shown are the early data of Ewing and F. P. The Haddon–Bullen model HBl (ref. 6) fails to fit the data between 150 and 200 s. The Gutenberg–Bullen A model (ref. 7) fits the data somewhat better, but this model must be rejected because of its failure to fit the Love wave observations (not shown here). The well known models 8099 (ref. 8) and CIT 11A (ref. 9) do not fit the new Rayleigh wave group velocity data. All twenty-eight models of F. P. fit the Love wave group velocities but only seven fit the Rayleigh wave data within ±2σ. Two of these are shown in Fig. 1 (5-06, 9-71) together with two models which fail (6-21, 7-77).

![Fig. 1. Rayleigh wave group velocity data compared with several theoretical models. Vertical bars indicate ±σ.](image1)

The seven successful models are illustrated in Fig. 2. All show a large decrease in shear velocity beginning at 70 km. In the absence of an analytical method for establishing uniqueness with the data used, we interpret the narrow envelope formed by the models between 70 and 145 km as strong evidence that the data highly constrain the solutions. Numerical experiments were made in which the models were varied over smaller steps than with the Monte Carlo solutions. What seems to be required to find solutions which fit the group velocity data to ±1σ is an almost abrupt velocity drop at a depth of 70 km as shown by model 5-08 M in Fig. 3. The fit of this model to the data is shown in Fig. 1. From these results we conclude that the base of the lithosphere is at a depth not much different from 70 km.

![Fig. 2. Shear velocity distributions in the Earth's mantle which fit new group velocity data.](image2)

![Fig. 3. Modification of model 5-08 to 5-08 M to obtain better fit to group velocity data.](image3)

Although several previous investigators (see ref. 10, for example) found similar results, we believe that our procedures remove the uncertainties which accompany surface wave studies. This is based on the agreement between models in which density and shear velocity were randomly selected and subjected to tests against data of known precision.

The sharp decrease in rigidity near 70 km supports the notion that the lower boundary of the lithosphere is determined by the solidus.

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