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The heterogeneous upper mantle low velocity zone

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Abstract

The upper mantle low velocity zone (LVZ) is a depth interval with slightly reduced seismic velocity compared to the surrounding depth intervals. The zone is present below a relatively constant depth of 100 km in most continental parts of the world, both in cratonic areas with high average velocity and tectonically active areas with low average velocity. Evidence for the low velocity zone arises from controlled and natural source seismology, including studies of surface waves and of primary and multiple reflections of body waves from the bounding interfaces, calculations of receiver functions, and absolute velocity tomography. The available data indicates a more pronounced reduction in seismic velocity and *Q*-value for S-waves than P-waves as well as high electrical conductivity in the LVZ. Seismic waves are strongly scattered by the zone, which demonstrates the existence of small-scale heterogeneity. The depth to the base of the LVZ is systematically shallower in cold, stable cratonic areas than in hot, active regions of the world. Because of its global occurrence below a relative constant depth of 100 km, the LVZ cannot be explained by metamorphic or compositional variation and rheological changes. Calculated upper mantle temperatures indicate that the rocks are close to the solidus in an interval with variable thickness below 100 km depth, provided that the rocks contain water and carbon dioxide. The presence of, even small amounts of such fluids in the mantle rocks will lower the solidus by several hundred degrees and introduce a characteristic kink on the solidus curve around 80–100 km depth. The seismic velocities and *Q*-values are significantly reduced of rocks, which are close to the solidus or contain small amounts of partial melt. Hence, the LVZ may be explained by upper mantle temperatures being close to the solidus in a depth interval below 100 km. Assuming that the rocks contain only limited amounts of fluids, this mechanism may explain the low velocities, *Q*-values, and resistivity, as well as the intrinsic scattering, and the characteristic variation in thickness of the low velocity zone.

Keywords: Mantle; Seismic velocity; Low velocity zone; Scattering; Attenuation; 8° discontinuity; Lehmann discontinuity

1. Introduction

The existence and potential causes of the upper mantle low velocity zone (LVZ) have been debated during most of the latter half of the last century. It was proposed as a general feature of the Earth's mantle in the fifties by Gutenberg who interpreted "a shadow zone caused by an LVZ centred at 100–150 km depth" (Anderson, 1989). About the same time, Lehmann (1961, 1964) proposed the existence of a general discontinuity in the upper mantle, the Lehmann Discontinuity, at a depth of ca. 220 km based on data from North America and Europe. It appears that there was a strong discussion in the sixties whether one or the other model was correct. Later studies of long-range explosion seismic profiles provided evidence for several intermixed high- and low-velocity layers in the lithospheric mantle (e.g. Ansorge and Mueller, 1973;

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Hirn et al., 1973), which directed attention away from the possible existence of a general LVZ below a relatively constant depth of 100 km.

Low velocity zones may be caused by the existence of partial melt. As such it is expected that the rheologically weak zone, the asthenosphere, should be an LVZ. However, interpretations of surface wave data (e.g. Suhadolc et al., 1990) and also very long-range explosion seismic data (Guggisberg and Berthelsen, 1987), have shown that high seismic velocities may extend to deep levels of the continental mantle such that a thick zone of low velocity may be encountered only at depths exceeding 200–300 km in cold cratonic regions with low heat flow. This has been interpreted as evidence for the lithosphere–asthenosphere boundary (LAB).

The existence of the LVZ is still being debated, whereas the stronger main interfaces in the inner Earth are well established as concentric shells, where abrupt discontinuous changes in physical parameters take place: The Moho (Mohorovicic, 1909), the 410 km discontinuity (Jeffreys, 1936) and the 660 km discontinuity (Niazi and Anderson, 1965) marking the mantle transition zone, the Core–Mantle Boundary, which exhibits the strongest contrast in physical parameters in any part of the inner Earth, and the transition between the outer and inner core, which has been named the Lehmann discontinuity between the inner and outer core after Lehmann (1936). Compared to these main seismic boundaries in the Earth, the LVZ has very weak contrasts in seismic parameters to the surrounding intervals, and its detection requires high-resolution seismic data with a high signal-to-noise ratio.

The main advance in mantle geophysics over recent years has been in the field of seismic tomography at global, regional and local scales (e.g. Bijwaard et al., 1998). The tomographic principle has been applied to body and surface waves, and has provided spectacular images of structure in the mantle that may be directly linked to plate tectonic processes, such as subduction of young and old oceanic plates (Fukao and al., 2001) and rifting, which by some authors has been coupled to the existence of mantle plumes that originate from the Core–Mantle Boundary (Romanowicz and Gung, 2002; Montelli et al., 2004). The tomographic images are usually derived and displayed as perturbations from a background velocity structure, which has to be close to the average structure of the study area. The background structures are therefore based on the average structure of the Earth, e.g. on a model of the Earth, which consists of

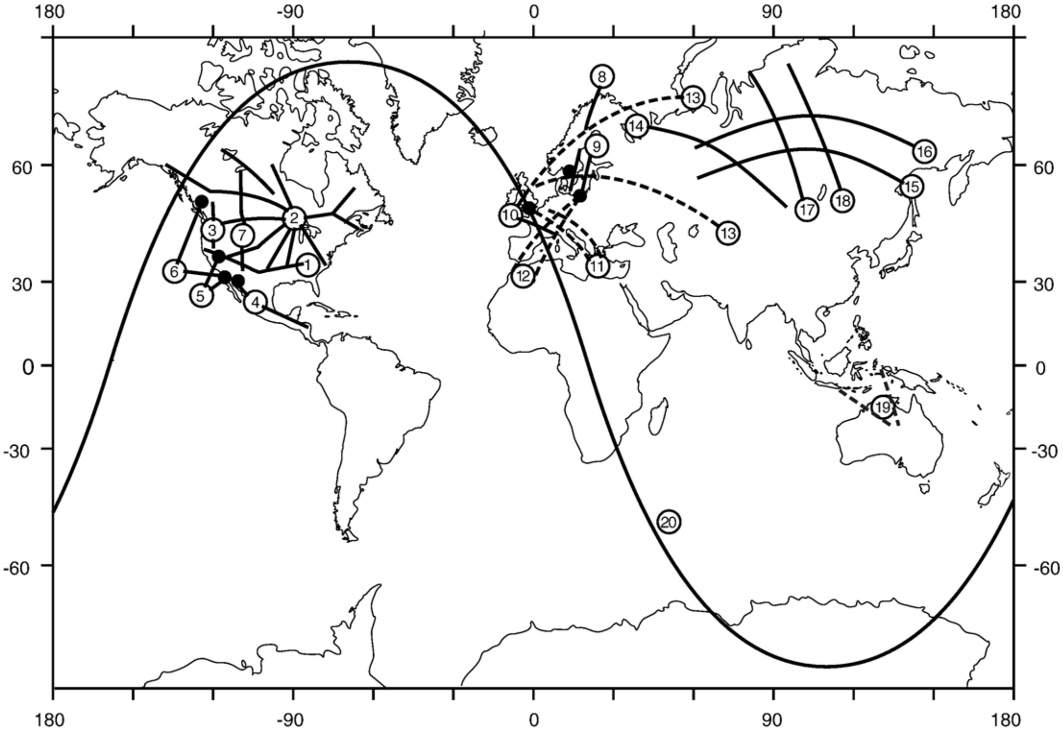

Fig. 1. Location of the high-resolution seismic profiles, which were recorded to sufficient offset to show the existence of the upper mantle low velocity zone. Numbers refer to the lines listed in Table 1. The profile line of the tomographic model in Fig. 10 (No. 20) is also shown.