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Coincident seismic reflection/refraction studies of the continental lithosphere: a global review

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Summary Vertical-incidence reflection profiling has identified several characteristic features of the continental lithosphere including a generally transparent upper crust, a reflective lower crust, reflections from the crust-mantle boundary, and a commonly transparent upper mantle. The underlying physical causes of these characteristic features remain poorly understood. This review summarizes additional information brought to bear on the physical properties of these characteristic crustal structures through the use of coincident wide-angle refraction profiling.

1. Transparent upper crust

Seismic reflection profiling often reveals few reflectors in the upper 4 to 5 s two-way time (TWT) of the crust beneath the sediment cover. Important exceptions include reflections from the upper crust from inferred low-angle faults, from highly-extended terranes within core complexes, and from the base of exposed plutons. Our global compilation of coincident seismic experiments (Fig. 1) shown in Figs 2 and 3 reveals no systematic relationship between the velocity-depth functions and the apparent transparency of the upper crust as observed on seismic reflection profiles.

Many authors have shown that relatively small perturbations in a well laminated velocity structure at length scales of tens of meters, as observed in well-logs from the crystalline portion of the upper crust, produce large amplitude reflections. Why then is the upper crust apparently transparent?

The best explanation is that the reflection strength is strongly dependent on a reflector's geometry and scale length as well as the reflector's impedance contrast. The velocity perturbations in the upper crust are probably neither well-laminated nor of long scale length because in this portion of the crust extension and compression are accomplished by brittle cataclasis and folding, producing short features with steep dips not well-imaged using conventional seismic profiling methods.

2. Reflective lower crust

In contrast to the upper crust, most seismic reflection profiles reveal that the lower 5 s of the crust is strongly reflective over a large depth range (Figs 2 and 3). The depth to the top of

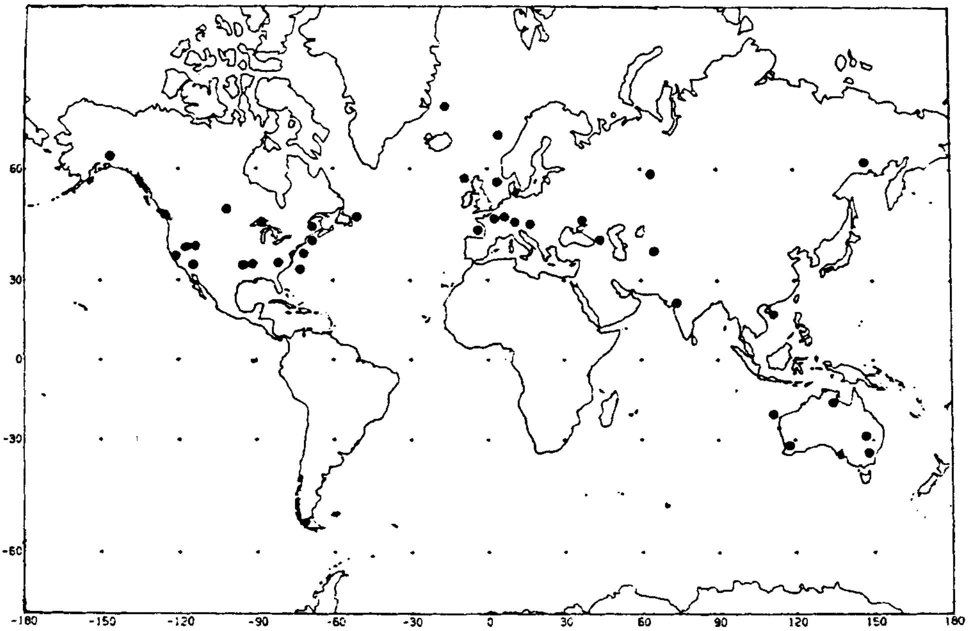

Figure 1. World-map showing locations of coincident seismic reflection/refraction experiments (large solid dots) performed as of the end of 1986.

the reflective lower crust is typically found between 5 to 7 s TWT (15 and 21 km depth) (Fig. 2).

Wide angle reflections provide more information regarding the physical properties of lower-crustal reflectors than do near-vertical incidence reflections. Energetic wide-angle reflections from the lower crust on the flank of the Rhinegraben were best modeled as being generated by solid-solid laminations having thicknesses of approximately 100 m (Sandmeier & Wenzel 1986; Fuchs *et al.* 1986); near-vertical incidence data could not distinguish between solid-solid and liquid-solid models. In the Mojave Desert, California, Louie & Clayton (1986) provide evidence from the dependence on the angle of incidence of reflection spectra that many reflectors in the lower crust are produced by such thin lamellae.

3. Landward dipping reflectors

In several convergent zones of western North America landward dipping reflectors are identified which are presumably the product of the accretionary process at these presently or recently active margins. Coincident seismic data sets from British Columbia, Alaska, and central California (Fig. 1) provide the best information on the interpretation of the structures responsible for these reflections.

The coincident seismic data from Vancouver Island have been correlated by Clowes *et al.* (1986) as follows: 1) seismically transparent zones with high seismic velocity are identified as mantle material; 2) highly reflective zones with intermediate velocities are identified as subducted sedimentary and igneous rocks. Clowes *et al.* (1986) interpret these paired landward-dipping zones as obducted oceanic slabs accreted during an earlier phase of subduction.

In central California, seismic refraction data, interpreted independently by Mereu (1986) and Trehu & Wheeler (1986), indicate a pronounced seismic low velocity zone at the base of the crust, at the same depth as landward-dipping reflections. Trehu & Wheeler (1986)

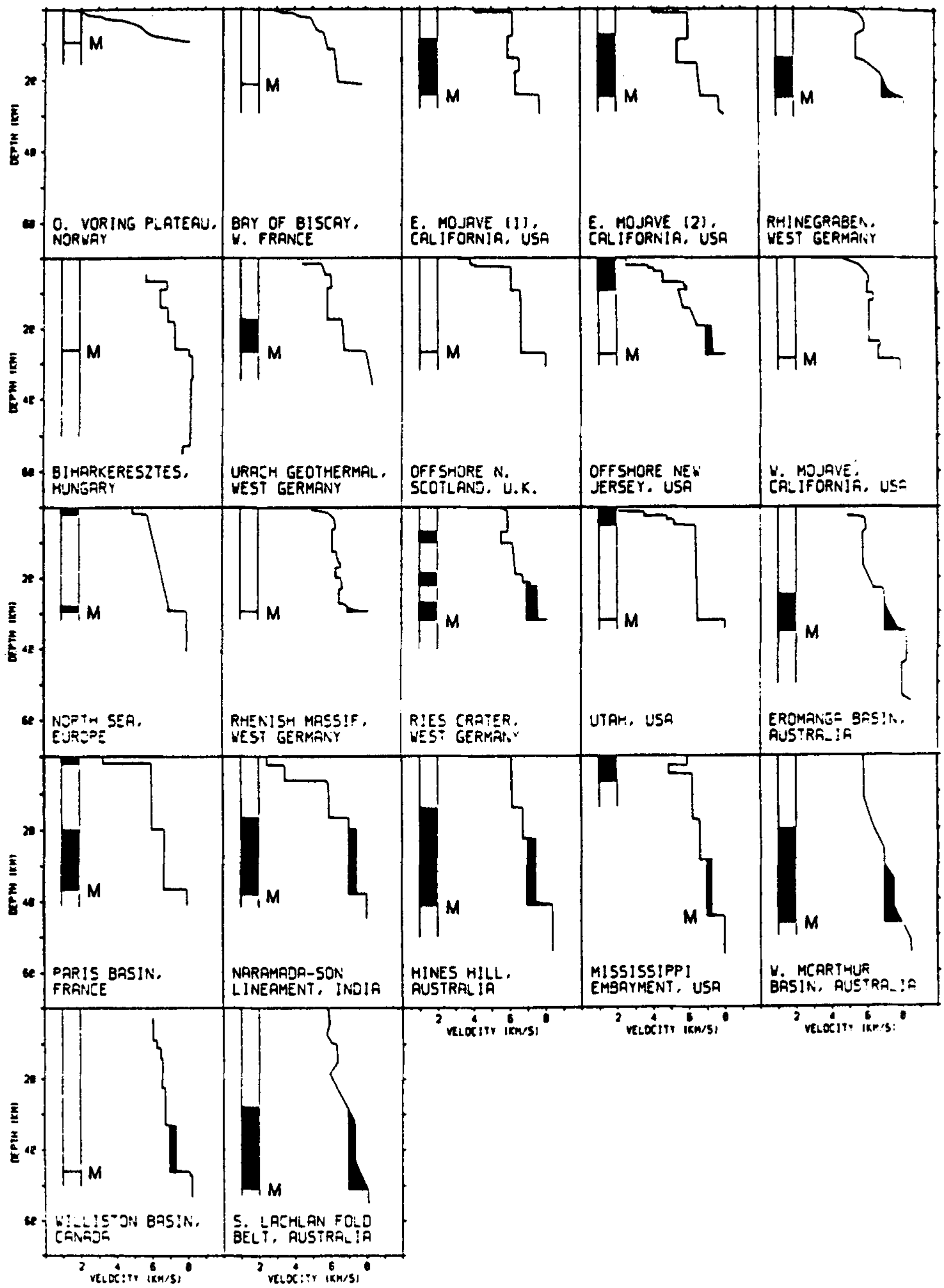

Figure 2. Comparison of the velocity-depth functions and zones of crustal reflectivity for extensional terranes. For each experiment the V-Z function is shown, with crustal velocities greater than 7 km s^{-1} shown as black. The refraction Moho is indicated by a M. On the left of each V-Z is a column indicating reflective zones in the crust as black. Transparent zones are shown as white. Complete references for this figure provided in Mooney & Brocher (1986)

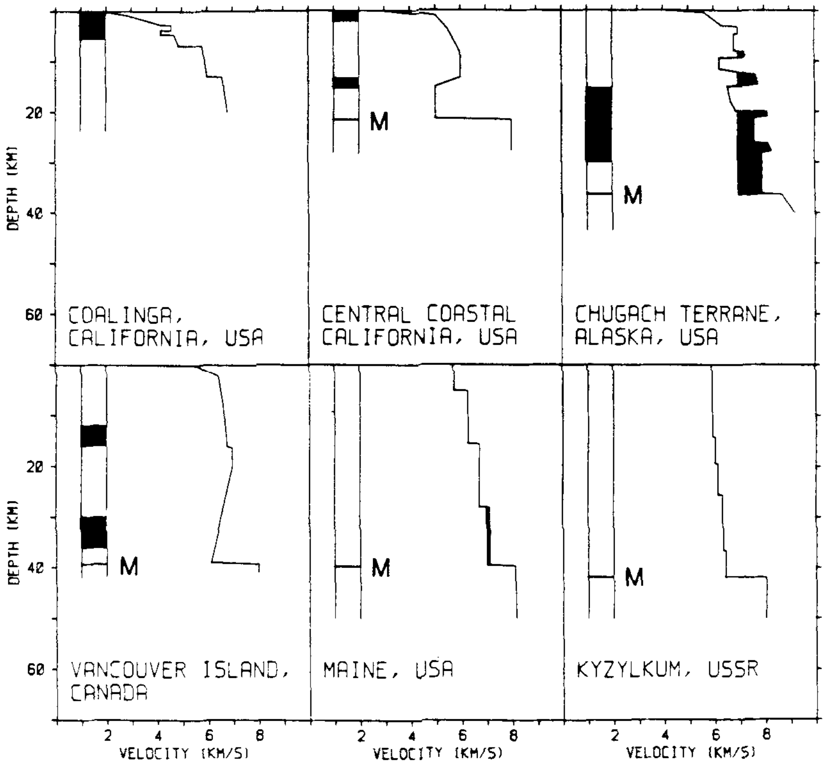

Figure 3. Comparison of the velocity-depth functions and zones of crustal reflectivity for convergent terranes. The format of the figure is the same as that for Fig. 2. Complete references for this figure are provided in Mooney & Brocher (1986).

interpret the coincident seismic data as indicating that the lower crust contains a package of deeply buried sediments subducted at the presently inactive trench.

4. The crust-mantle boundary

There is increasing interest in defining a seismic reflection Moho (Braile & Chiang 1986). A consensus emerged from the comparison of seismic reflection data with proximal refraction data that the "reflection Moho" consists of a package of nearly-continuous reflections at a TWT of 8-12 s that are underlain by a seismically transparent zone. The base of the reflective zone is correlated with the "refraction Moho", although the case is certainly not proved.

The coincident seismic transect in Quebec, Canada, and Maine (Fig. 1), provides strong evidence that the base of the reflective zone corresponds to the refraction Moho in that area (Stewart *et al.* 1986; Luetgert 1985). Gajewski & Prodehl (1986) determined that the reflection and refraction Moho on the east flank of the Rhinegraben in southwestern Germany are in excellent agreement. While Klemperer *et al.* (1986) present evidence for the close correspondence between the reflection and refraction Moho across Nevada, USA, a discrepancy of 3 km is still possible and points to the need to retain separate definitions of the Moho for vertical and wide-incidence data.

5. Transparent upper mantle

Unequivocal wide-angle reflections from the upper mantle are reported in a number of long-range refraction experiments (Prodehl 1984; Fuchs 1986). Encouraged by these wide-angle experiments, reflection seismologists have attempted to identify near-vertical reflections from the continental upper mantle. The BIRPS' MOIST and DRUM profiles, which presently lack coincident wide-angle reflection coverage, reveal prominent upper-mantle near-vertical reflections at 15-24 s, which do not migrate into the crust (Peddy *et al.* 1986; Warner & McGeary, this issue).

Elsewhere, the evidence for unequivocal upper mantle reflections at near-vertical incidence is less conclusive. Dipping upper mantle reflection events in CDP data from the Gulf of Maine and Maine migrate into the crust during line segment migration (D.R. Hutchinson, pers. comm. 1986; D.B. Stewart, pers. comm. 1986). Wide-angle reflection events with TWT of 15 s and greater observed from onshore Maine are converted crustal phases and their multiples (Luetgert *et al.*, this issue).

6. Convergent vs extensional terranes

Figs 2 and 3 indicate possible systematic differences between convergent and extensional terranes. In convergent terranes the lower crust is typically reflective with weak velocity gradients (Fig. 3). The lower crustal reflectors appear to be discrete; they are inferred to be generated by horizons well-separated (by over a wavelength) in depth. In extensional terranes, the lower crust is usually highly reflective with a strongly laminated appearance; this reflective zone is frequently correlated to velocities between 6.5 and 7.3 km s^{-1} (Fig. 2), thought to correspond to a mixture of mafic and ultramafic rocks.

7. Summary

Coincident seismic reflection/refraction studies provide an improved understanding of the continental lithosphere. Major conclusions include: 1) Although a transparent upper crust is a common observation on reflection profiles, wide-angle data show no strong correlation with velocities suggesting that the transparent upper crust may be best explained by short-scale length of reflectors in the brittle upper crust. 2) The reflective lower crust is characterized by a high average seismic velocity (6.6 - 7.3 km s^{-1}), consisting of laminated high- and low-velocity layers. 3) Landward-dipping reflectors observed in convergent zones are identified as paired high- and low-velocity slabs which represent oceanic crust and mantle accreted via underplating to the continental margin. 4) Possible discrepancies in observations of Moho from vertical-incidence and wide-angle profiling justify retaining, for the present, separate definitions for the reflection and refraction Moho. There is evidence that these features are physically the same in several regions. 5) Upper mantle vertical reflections which cannot be migrated into the lower crust remain rare, despite isolated unequivocal examples. The wide-angle method appears likely to provide the most reliable information on the velocity structure and physical state of this portion of the lithosphere for some years to come. 6) There are clear and consistent basic differences between convergent and extensional terranes as identified from coincident experiments.

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