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Discussion

Glacial isostasy and long-term crustal movements in Fennoscandia with respect to lithospheric and asthenospheric processes and properties—comment

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Recently, Mörner discussed his model of glacio-isostatic compensation in the light of new seismological models of the upper mantle below Fennoscandia (Mörner, 1990). He concluded that the P-wave velocity distribution is in "full agreement" with his estimate of the viscosity distribution as inferred from glacio-isostatic relaxation. Whereas the consistency of seismological and geodynamical earth models is a necessary condition for their soundness, the particular type of agreement sought by Mörner is not required or expected, nor can his method of attaining such agreement be approved.

For easier understanding of my criticism, I briefly recall the type of information provided by the seismological and by the glacio-isostatic evidence:

(1) The propagation of high-frequency compressional waves admits an inference of the P-wave velocity distribution, which, in turn, provides basic information on the elastic properties of the earth. In certain tectonic provinces, a high-velocity lid superimposes one or several upper mantle low-velocity channels. The high-velocity lid, sometimes referred to as the *seismological* lithosphere, is therefore a manifestation of radial heterogeneity in *elasticity*.

(2) The relaxation of low-frequency, glacio-isostatic disturbances provides basic information on the creep properties of the earth. The transition from a surface layer of long-term strength to a more ductile region of viscous creep underneath crudely defines the *mechanical* lithosphere–asthenosphere boundary. The mechanical lithosphere can thus be regarded as a manifestation of radial heterogeneity in *viscosity*.

Mörner's whole argument rests on the assumption that the seismological and mechanical lithospheres are necessarily coincident. Since the viscosity distribution strongly reflects the temperature distribution, this assumption can obviously be only satisfied if a similar type of temperature dependence applies to the velocity distribution. However, below old shields the velocity distribution may not be thermally controlled at all but be largely due to compositional heterogeneity (e.g. Jordan, 1981), in which case the velocity and viscosity patterns will differ.

Whatever applies to Fennoscandia, the utility of information on the distribution of either property for confirming or inferring the distribution of the other is clearly limited. Two examples of Mörner's disregard of these restrictions are given here:

(1) Mörner formally converts the thickness of the high-velocity lid into the flexural rigidity of the mechanical lithosphere. As an alternative, he also estimates flexural rigidities using signatures of the relaxation process itself (the method applied by him is not without problems, see below).

The closeness of the two estimates he then interprets as "mutual confirmation".

(2) Mörner identifies the basal low-velocity channel with the mechanical asthenosphere and regards the horizontality of the base of the low-velocity channel as indicating that the asthenospheric "mass flow" has not reached this level.

If the second argument were valid, its logical consequence would be that the downwarping of the top of the basal low-velocity channel by more than 100 km *may* be produced by compensatory material flow. As it stands, Mörner's second argument strongly suggests that he regards viscous relaxation as a finite-amplitude flow process capable of producing substantial boundary deflections. In fact, viscous relaxation involves only *small perturbations* of a hydrostatic equilibrium state, which admits the linearization of the governing field equations (for details see, for example, Peltier, 1982, pp. 38–59, and Wolf, 1991). The solutions to the linearized equations for given surface tractions in particular show that the degree of disequilibrium decreases with depth, resulting in subsurface deflections that are far too small to be resolved by current seismological techniques.

In view of the problems with indirect methods of estimating the viscosity and, in particular, the thickness of the mechanical lithosphere, any method of inferring these parameters must continue to rely on signatures of the relaxation process itself. Several investigators have estimated the thickness of the Fennoscandian lithosphere on this basis (McConnell, 1968; Cathles, 1975; Fjeldskaar, 1987; Wolf, 1987). Although their approaches differ to some extent, the resulting values agree reasonably well, the highest estimate being close to 120 km.

Mörner's own estimate of the thickness of the Fennoscandian lithosphere on the basis of the relaxation process uses two supposed indicators of lithosphere thickness:

(1) Mörner uses the "straightness" of (partially extrapolated) paleo-shorelines as one indicator and interprets it in terms of a mechanical lithosphere much thicker than 120 km. This conclusion conflicts with numerous calculations showing that the shape and relaxation of a glacially induced depression is a complicated function of several parameters including load distribution, deglaciation history, viscosity distribution and lithosphere thickness (for results relevant to Fennoscandia see, for example, Wolf, 1985).

(2) Mörner takes land uplift as an additional indicator of lithosphere thickness; in particular, he expects that the corresponding "curves" are of similar "shape". This is certainly an unusual expectation, and no simple explanation for the lithosphere being thick where the uplift is high can be conceived of.

We conclude that Mörner's two methods of estimating the viscosity distribution and, in particular, the thickness of the mechanical lithosphere below Fennoscandia, i.e. using the seismological evidence and using the glacio-isostatic evidence, have serious flaws. The significance of the agreement arrived at is therefore not clear—in fact, we usually would not expect the type of agreement sought at all.

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