Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Journal of Geodynamics 39 (2005) 143–163
JOURNAL OF GEODYNAMICS
http://www.elsevier.com/locate/jog

Inverting the Fennoscandian relaxation-time spectrum in terms of an axisymmetric viscosity distribution with a lithospheric root

Zdeněk Martinec*, Detlef Wolf

GeoForschungsZentrum Potsdam, Department 1: Geodesy and Remote Sensing, Telegrafenberg, D-14473 Potsdam, Germany

Received 23 March 2004; accepted 8 April 2004

Abstract

The Fennoscandian relaxation-time spectrum is an observational data set representing post-glacial land uplift and employed in interpretations of glacial-isostatic adjustment. We invert this data set by adapting the spectral finite-element method, originally developed for a 3D self-gravitating spherical earth model [Martinec, Z., 2000. Spectral–finite element approach to three-dimensional viscoelastic relaxation in a spherical earth. Geophys. J. Int. 142, 117–142], to an axisymmetric viscosity distribution. The free parameters used in the inversion are either the central-lithosphere thickness (below the former Fennoscandian ice sheet) and the upper-mantle viscosity or the peripheral-lithosphere thickness and the peripheral-asthenosphere viscosity (surrounding the former Fennoscandian ice sheet). We demonstrate that a model featuring a central lithosphere with a thickness of 200 km and a peripheral lithosphere with a thickness of 80 km underlain by an asthenosphere satisfies the relaxation-time spectrum. We also show that the spectrum can be explained on the basis of a spherically symmetric model featuring a 100-km thick lithosphere, but no asthenosphere. Whereas this result is essentially consistent with previous interpretations of glacial-isostatic adjustment, the result obtained for the axisymmetric viscosity model also agrees with a large number of interpretations based on seismic, geomagnetic, thermal or rheological evidence for Fennoscandia.

Keywords: Fennoscandia; Glacial-isostatic adjustment; Lateral heterogeneity; Lithospheric root; Mantle viscosity

* Corresponding author. Tel.: +49 331 288 1140; fax: +49 331 288 1163.
E-mail address: dasca@fgz-potsdam.de (Z. Martinec).

0264-3707/$ – see front matter © 2004 Published by Elsevier Ltd.
doi:10.1016/j.jog.2004.08.007

1. Introduction

1.1. Estimates of lithosphere thickness

The Fennoscandian lithosphere is the result of a series of tectonothermal processes that started in the Archean about 3.5 Ga ago and continued during the Proterozoic until the early Phanerozoic about 0.5 Ga ago. Geophysical studies of the properties of the lithosphere have been progressing steadily for several decades and, according to the method employed, particular types of lithosphere have been sampled. An important result is that all types of lithosphere seem to be rather thick below the Archean part of the Fennoscandian Shield. Such lithospheric roots are also typical of other Archean terrains and must be closely related to the tectonothermal evolution of the latter. In principle, lithospheric roots could be indications of dynamic downwellings of colder material into the hotter mantle. The majority of studies, however, suggests that they represent static features that are either thermally (e.g. Crough and Thompson, 1976) or petrologically (e.g. Jordan, 1978) stabilized over geologically long periods.

The definition of the lithosphere goes back to Barrell, Daly and others at the beginning of the 20th century, who recognized that the response of the earth's outer shell to surface loading can be understood by the concept of a *mechanically strong* lithosphere (supporting deviatoric stress over geologically long periods) overlying a *mechanically weak* asthenosphere (allowing mass flow associated with isostatic adjustment) (for reviews, see Wolf, 1993; Watts, 2001). Today, the concept of the lithosphere has become more sophisticated, and several types of lithosphere need to be distinguished.

In seismic studies, the lithosphere is defined as the outer shell with higher seismic velocities than in the underlying upper-mantle shell, the asthenosphere. The thickness of this *seismic lithosphere* below Fennoscandia has been estimated by Sacks et al. (1979), Husebye and Hovland (1982), Babuška et al. (1988), Plomerová et al. (2002), and Gregersen et al. (2002), who analysed body-wave travel time residuals for teleseismic events, by Guggisberg and Berthelsen (1987), who analysed the data from the FENNOLORA seismic refraction profile, and by Calcagnile (1982, 1991), who analysed Rayleigh-wave dispersion data. These studies indicate that, down to depths of about 250–300 km, the central part of the Fennoscandian Shield is characterized by higher seismic velocities than the surrounding Caledonides and Barents Sea, where the thickness of seismic lithosphere is less than 100 km. They also show that the seismic asthenosphere is almost absent below the central region, but clearly developed elsewhere.

In geomagnetic induction and magnetotelluric deep-sounding studies, the lithosphere is defined as the resistive outer shell overlying a highly conducting shell in the upper mantle, also called the electrical asthenosphere. Beneath the central part of the Fennoscandian Shield, an *electrical lithosphere* of at least 160–200 km in thickness was detected by Jones (1982, 1983), Hjelt (1991), Rasmussen et al. (1987), Korja (1993) and Balling (1995).

The *thermal lithosphere* is usually regarded as the thermal boundary layer in which heat transfer is conductive and the temperature is below the solidus temperature. Assuming that its base is isothermal, the instantaneous thickness of the thermal lithosphere is determined by the constraint that the heat carried upward by conduction balances the heat advected to its base from below. Pasquale et al. (1990, 1991), Balling (1995), Čermák and Bodri (1995), Kukkonen and Peltonen (1999) and Jokinen and Kukkonen (2000) applied this concept to heat-flow data from the Fennoscandian Shield and adjacent areas and found that the thickness of the thermal lithosphere varies from 85 to 110 km beneath northern Germany, Denmark and the southern shield margin to about 150 km in the central shield areas and exceeds 200 km in the northern shield. Recently, Artemieva and Mooney (2001) have modelled the thermal-lithosphere