Ofioliti, 1999, 24 (1a), 93-94

EMPLACEMENT OF DEEP MANTLE ROCKS INTO CRATONIC LITHOSPHERE BY CONVECTION AND DIAPIRIC UPWELLING

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ABSTRACT

It is now established that some mantle xenoliths (Sautter et al., 1991) and orogenic peridotite bodies (Davies et al., 1992; Dobrzhinetskaya et al., 1996; Van Roermund and Drury, 1998; Bozhilov et al., 1999) are derived from the deep upper mantle (200-410 km) or possibly even the transition zone (410-670 km) (Sauter., et al 1991; Green et al 1997). Several mechanisms have been proposed for the exhumation of deep mantle peridotites. Mantle peridotites may be emplaced into crust which has been subducted to great depth (Green et al., 1997). Buoyant uprise of the crustal material will transport deep mantle peridotite bodies up to the base of the crust. Alternative mechanisms involve transport of deep mantle peridotites to lithospheric depths by asthenosphere upwelling either in association with slab detachment (Davies et al., 1992) or simply by diapiric upwelling of asthenosphere (Nicolas 1986; de Smet 1998, 1999).

In this contribution we will investigate the role of asthenosphere diapirism and mantle convection in the emplacement of deep mantle peridotites into the lithosphere. We will compare PT paths obtained for cratonic peridotites with those obtained from numerical models of mantle convection and asthenosphere diapirism beneath a cratonic root (De Smet et al., 1998; 1999). We will concentrate on cratonic peridotites from kimberlites and the two peridotite bodies on the island of Otrøy in the Western Gneiss terrane, Norway. The Otrøy peridotites contain relicts of super-silicic garnets (Van Roermund and Drury, 1998) which indicate a depth of origin of more than 185 km. The Otrøy peridotites are similar in many ways to kimberlite xenoliths from the Kaapvaal craton (Sautter et al., 1991).

Both rock suites are dominated by depleted compositions. The Otrøy rocks have a banded (harzburgite - dunite) composition. The dominant microstructure is an equi-granular olivine mosaic. The PT conditions estimated from mineral chemistry fall along an array consistent with a cratonic geotherm. Megacrysts occur in both rock suites. PT conditions for the megacrysts suggest higher temperatures and/or higher pressures than the matrix phases. Differences between the Otrøy peridotites and kimberlite xenoliths are; the lack of hot sheared peridotites, lower modal orthopyroxene, and later metamorphic reactions in the Otrøy rocks. The similarities and other evidence suggest that the Otrøy peridotites are fragments of Precambrian cratonic lithosphere similar to the Kaapvaal craton (Van Roermund et al., 1999).

The most plausible PT path for the Otrøy peridotites involves adiabatic ascent from 6 to 3 GPa at temperatures of 1400-1600°C followed by cooling down to 800°C at pressure of 3 GPa. Similar PT paths have been deduced for cold cratonic harzburgites by Cox et al. (1987) who recognised that garnet, cpx and opx exsolved from a high Ca-Al pyroxene precursor. For hot sheared kimberlite xenoliths an unusual PT path involving cooling and increasing pressure is implied if the garnets and pyroxenes were also derived by exsolution from high Ca-Al pyroxene (Canil, 1991). The PT paths derived for the Otrøy peridotites and kimberlite xenoliths are qualitatively consistent with upwelling of hot asthenosphere up to lithospheric depths. This type of PT path has also been observed in a numerical model for continental formation by De Smet et al. (1999). We will now describe the results obtained from the numerical modelling study of De Smet et al. (1998; 1999) and compare the PT and depletion history predicted from the models with the data from the Otrøy peridotites and kimberlite xenoliths.

De Smet et al. (1998; 1999) studied the evolution of the Precambrian continental lithosphere using a thermo-chemical convection model of the upper mantle which included the effects of melt extraction on the density of the residue; various descriptions of the solidus and liquidus; and a temperature and pressure dependent viscosity. The model shows that a stable depleted root develops beneath continental cratons. Lithosphere growth occurs by accretion of small diapirs (50-100 km diameter) which originate from instabilities near the base of the cratonic root. Diapiric instabilities can develop over a hot upwelling limb of a larger scale mantle convection cell so material can rise from the transition zone, become included in a small scale diapir and then rise into the lithospheric root. As the diapirs rise, melting occurs and continues until the diapirs stop at a depth of 60-100km beneath the high viscosity mechanical boundary layer. A relatively buoyant depleted harzburgite root around 200km thick is formed in this way. Derivation of the PTt depletion history for individual tracers in the model shows some remarkable histories.

A variety of PT paths are obtained for material tracers starting in the deep mantle (d>350 km). Some tracers have PT paths similar to the Otrøy peridotites and cratonic kimberlite xenoliths. With this type of PT path deep upper mantle material becomes incorporated into the cratonic lithosphere at depths of 70-100 km. The impingement of diapirs within the cratonic root sets up circulation in the root below the mechanical boundary layer. In consequence, material which has ascended to depths as shallow as 60 km can slowly descend to deeper levels in the root. The PT path produced are qualitatively similar to those suggested for hot deformed kimberlite xenoliths. Continued circulation in the root can produce a remarkable spiral PT path. Flow in the continental root will result in strong mixing of material with different degrees of depletion. This could explain the presence of small scale (cm- metres) compositional banding in the Otrøy peridotites. The model shows that after some time delamination occurs and depleted lithosphere can sink to the base of the upper mantle. After reheating this material may become involved in convective upwellings and could be transported back into the cratonic root. Thus, melting and depletion of a peridotite body may occur in an earlier stage of evolution than the upwelling event that resulted in emplacement in the lithosphere.

In summary, PT paths derived for kimberlite xenoliths and the Otrøy peridotites suggest that deep upper mantle peridotites are transported to shallow depths by convection and asthenosphere diapirism. Numerical models of this process show that cratonic peridotites will have a variety of PT histories which can involve several stages of diaprism, upwelling and melting in the dynamic cratonic root.

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