Results of the Eifel Plume Project and Geodynamic Interpretations

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Volcanic eruptions occurred in the Eifel mountains in the western part of Germany since Mesozoic time. Two new volcanic fields evolved in the last 600 ka and the last eruptions occurred only 11-12 ka B.P. At the same time strong uplift (up to 250 m in 600 ka) occurred in the region. To study the deep structure of the Eifel region 10 European institutions shared their facilities to operate a seismological network with 84 permanent and 158 mobile stations including 32 broadband instruments during an 8 months field experiment. The network had a 500 km by 500 km aperture and the mobile stations were deployed between 3. Nov. 1997 to 23. June 1998. Details on the seismological network, data and first results were presented in 6 contributions in the Comptes-Rendus of the 87th session of the Journées Luxembourgeoises de Géodynamique (March 2000).

In the following the latest results of the seismological project are summarized and interpreted. Details on the teleseismic P- and S-wave travel time tomography and the teleseismic P-wave attenuation tomography can be found in Jordan et al. (this volume). The P-wave model contains a column-like low-velocity anomaly (LVA, -1% to –3%) in the upper mantle underneath the Eifel volcanic fields, reaching down to at least 410 km depth. The radius of the plume-like structure is about 50-60 km. The S-wave model has a prominent LVA of up to –5% in the upper 100 km of the mantle. At 200 $\pm$ 50 km depth there is no clear S-wave velocity anomaly. Below, the S-wave velocity reduction is about –1%, and it extends at least downwards to the transition zone at 410 km depth. The teleseismic P-wave attenuation shows a strong absorption anomaly in the lithosphere and a weaker absorption anomaly in the deeper upper mantle. The lithospheric anomaly is interpreted as scattering attenuation at a magmatic intrusion zone. In the asthenosphere temperature-induced solid-state anelastic attenuation is assumed.

The seismic P-wave and S-wave velocity anomalies in the lithosphere and upper asthenosphere can be explained by an increase of temperature by about 100-150 K plus 1% melt. In the lower asthenosphere, above the transition zone, the excess temperature of the plume is at least 70 K. Because the velocity anomalies in the tomographic models are underestimated, the actual positive temperature anomaly may reach up to 200 K in the lower asthenosphere which is in better agreement with the observed 15-20 km downwarping of the

410 km phase discontinuity below the Eifel region (Grunewald et al., 2001). These temperature variations are derived from published pressure and temperature derivatives of the seismic velocity as obtained from mantle minerals and rocks in laboratory measurements (e.g. Duffy & Anderson, 1989; Karato, 1993; Faul et al., 1994; Jackson et al., 2002). The determined temperature anomaly can be interpreted as the excess temperature of the plume material relative to the surrounding mantle.

Based on an excess temperature of 100-150 K and a radius of 50-60 km I try to estimate the flux in the Eifel plume. As physical model I take the volume flux Q_p as a function of the rise velocity v_{pl} which can be estimated e.g. from Poiseuille's equation for flow inside a tube adopted to a buoyant viscous fluid. The buoyancy is determined by the excess temperature and the associated thermal expansion of the material: The buoyancy flow B of a rising mantle plume can be estimated by the density contrast $\Delta\rho$ of the rising material and the volume flux Q_p (Sleep, 1990):

$$B = \Delta\rho_m \, Q_p = \rho_m \, \alpha \; \Delta T \; Q_P \qquad (1)$$

with ρ_m mean mantle density, α thermal expansion coefficient of the mantle rock, and ΔT excess temperature of the plume. The volume flux is a function of the radius r of the plume conduit and the rise velocity v_{pl} after Poiseuille's equation for flow inside a tube:

$$v_{pl} = \frac{3\,\rho_m \,\alpha \,\Delta T \,g\, r^2}{8\,\eta} \qquad (2)$$

g is Earth's gravity acceleration, and η is the viscosity of the flowing material. A factor 3/4 is included in equation (2) because it is assumed that the temperature anomaly inside the plume conduit decreases from the maximum excess temperature in the centre to the ambient mantle temperature at the rim of the plume. The buoyancy flux

$$B = \frac{9\,\pi\, g}{64} \frac{(\rho_m \,\alpha \;\Delta T)^2 \, r^4}{\eta} \qquad (3)$$

depends on relatively constant and known parameters in the mantle such as g, ρ_m and α as well as plume-dependent parameters such as ΔT, r and η. $B(r,\Delta T)$ is highly non-linear because it depends on the radius in fourth order and the excess temperature in second order. The temperature-dependent viscosity of the plume material is calculated with an Arrhenius law following Karato and Wu (1993). Further details can be found in Ritter (2003).

In Figure 1 the buoyancy flux of mantle plumes as function of radius and excess temperature is shown in megagramm (metric ton) per second. For the Eifel a value of 0.05-0.1 Mg/s is reasonable based on the tomographic results and the observed erupted material. For comparison the estimated flux of the Hawaiian plume is included. Based on seismological measurements (Li et al., 2000), the radius of the plume conduit in the upper mantle is about 70–80 km and the excess temperature is about 250-300 K. Using eq. (3) this gives a buoyancy flux of about 3-6 Mg/s which is similar to other estimates (e.g. Ribe & Christensen, 1999).

The small value of 0.05-0.1 Mg/s for the Eifel plume seems to indicate that the Eifel plume is at the lower end of a possible plume size, because even smaller plumes are thought to have not enough thermal buoyancy to overcome the resisting forces in the mantle, and thus would get stuck without reaching near-surface depths.

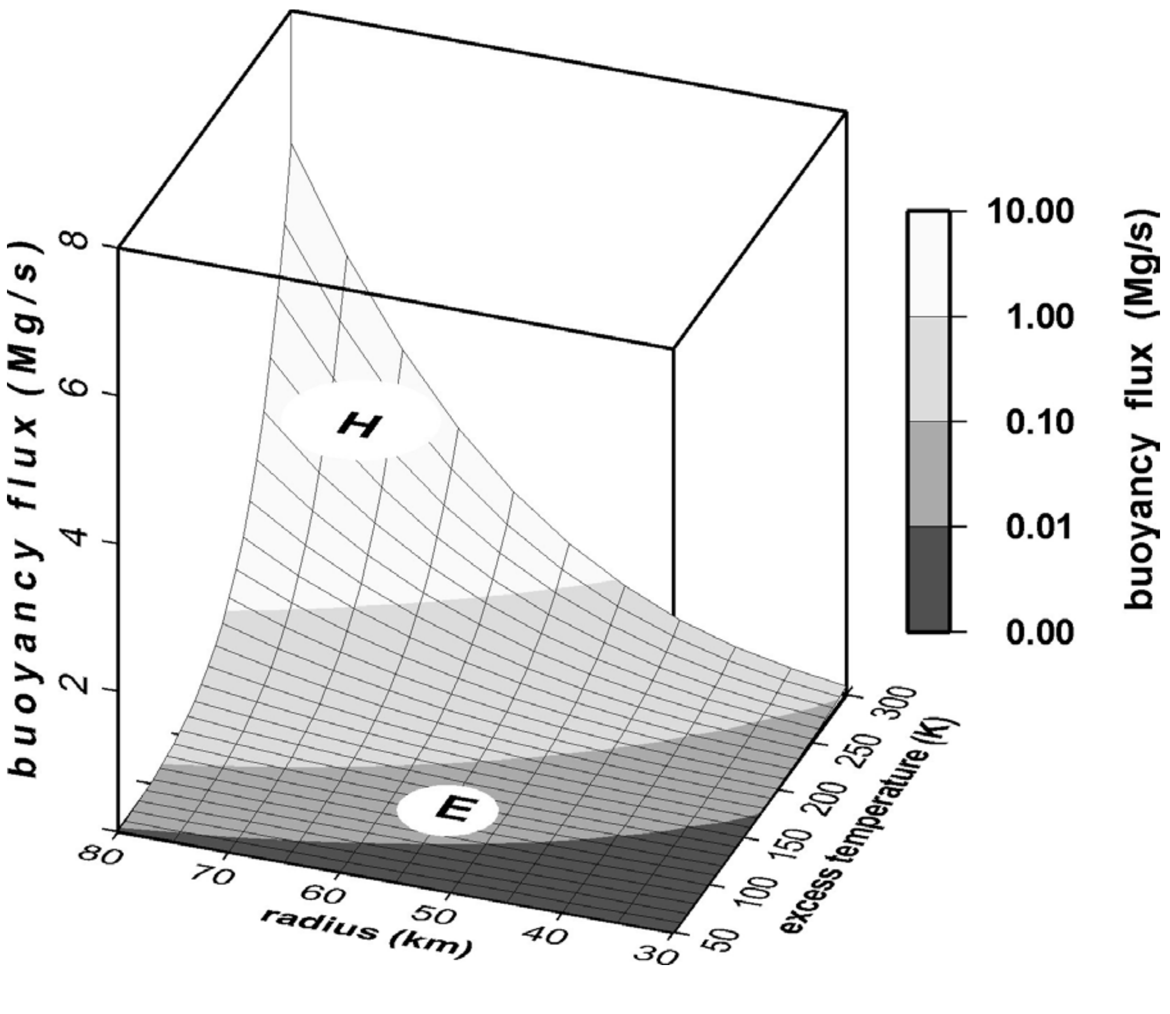

Figure 1:

Estimated buoyancy flux of a hot mantle plume as function of its radius and excess temperature. E: Eifel, H: Hawaii.

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This contribution is dedicated to Dr. Günter Bock (GFZ Potsdam) who died on his way to Muensbach castle, Luxembourg, in an airplane crash on 6. November 2002. As member of the Eifel Plume team Günter wanted to present his results at a Eifel meeting at Muensbach castle. We will always remember him as a friendly and well-experienced colleague.