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Teleseismic Evidence for Velocity Heterogeneity Beneath the Rhenish Massif *

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Abstract. Observations of teleseismic *P* wave residuals for 56 stations in the vicinity of the Rhenish Massif show that arrivals within the Massif may be up to 0.6 s later than those immediately outside. Stations within the Massif also tend to have delays which are strongly azimuthally dependent (up to 1 s variation) in marked contrast to those outside (maximum 0.3 s variation). The strongest variation and delays are associated with the area of the Massif west of the Rhine, and preliminary modelling suggests they are caused by a low velocity region in the uppermost mantle (ca. 50–150 km depth) centred beneath the West Eifel volcanic field. Delays of up to 0.8 s, but with little azimuthal variation, are also found within the Vogelsberg volcanics, and are attributed to a shallower ($\lesssim 60$ km) low velocity region.

Key words: Teleseismic *P* delays – Velocity heterogeneity – Upper mantle structure – Rhenish Massif.

Introduction

The Rhenish Massif is a relatively small (200×150 km^2) area of plateau uplift that has risen some 150 m during the Quaternary. The nature of this uplift and its causes are currently the subject of an intensive multidisciplinary research programme in Germany. As part of this, a detailed analysis of the variation of teleseismic *P* wave delays for stations in the area (Fig. 1) with azimuth and distance to the event is now in progress in order to obtain information about velocity variations within the lower crust and upper mantle beneath the Rhenish Massif. The technique has been described in detail elsewhere (e.g., Raikes 1976; Engdahl et al. 1977), and this paper only presents a summary of the observations, and their implications for the velocity structure.

Observations

Approximately 300 well-recorded events during the period 1976–1979 were chosen for this study, including 54 at distances over 120°; the azimuthal distribution is fairly good, except to the SE and NNW, although most events occur in the NE quadrant (Table 1). First arrivals were read with a precision of 0.1 s at most of the stations, and this data set was supplemented by bulletin times for a few extra stations (Fig. 1). Delays were calculated

Table 1. Distribution of events studied

Distance, degrees	Azimuth, degrees			
	0–90	90–180	180–270	270–360
0– 40	8	20	3	4
40– 80	59	12	21	12
80–105	64	–	12	25

Total 240+54 events at greater than 125°

with respect to the Jeffreys-Bullen arrival times, corrected for the earth's ellipticity and station elevation, using the U.S.G.S. hypocentral parameters. For the core phases Bolt's (1968) times were used since these gave a better fit to the observed $dT/d\Delta$. In order to minimise effects other than those arising from structure beneath the stations, the residuals were then normalised by subtracting the delays at BUH. For a given source region the scatter in relative residuals at a single station was ± 0.05 to ± 0.15 s, except for stations where bulletin data were used, where it was generally ± 0.15 to ± 0.4 s.

A contour map of the average relative residuals for PKP phases from events in the South Pacific is shown in Fig. 2. The values of these residuals reflect structure directly beneath each station, because the rays are essentially vertically incident, and they are thus of great value in fixing the horizontal location of any anomalies. The main features of this map are the late arrivals associated with the Rhenish Massif and the station GLS in the Vogelsberg. Outside the Massif the residuals lie largely between 0 and 0.3 s except for a small area in the southern Rhinegraben and stations such as WTS where sediment corrections are required. Observations for other source regions are similar to Fig. 2, although the late arrivals associated with the western Rhenish Massif appear to be shifted directly away from the source, giving rise to large azimuthal variation of residuals (e.g. BNS -0.1 to $+0.9$ s, STB 0.02 to 0.92 s, BIR 0.1 to 0.9 s, ELG -0.09 to $+0.81$ s). There is a marked contrast between the western Massif and the eastern half which has earlier arrivals with less azimuthal variation (e.g. TNS 0.16 to 0.56 s). Outside the Rhenish Massif the residuals vary little with azimuth (e.g. CLZ -0.01 to $+0.23$ s, WTS 0.37 to 0.63 s, BFO -0.15 to $+0.07$ s, WLS -0.2 to $+0.1$ s) implying that the large variations in the western Massif are not simply the result of changes in the level of residuals at the reference station BUH. One exception is the station GRF which, as already

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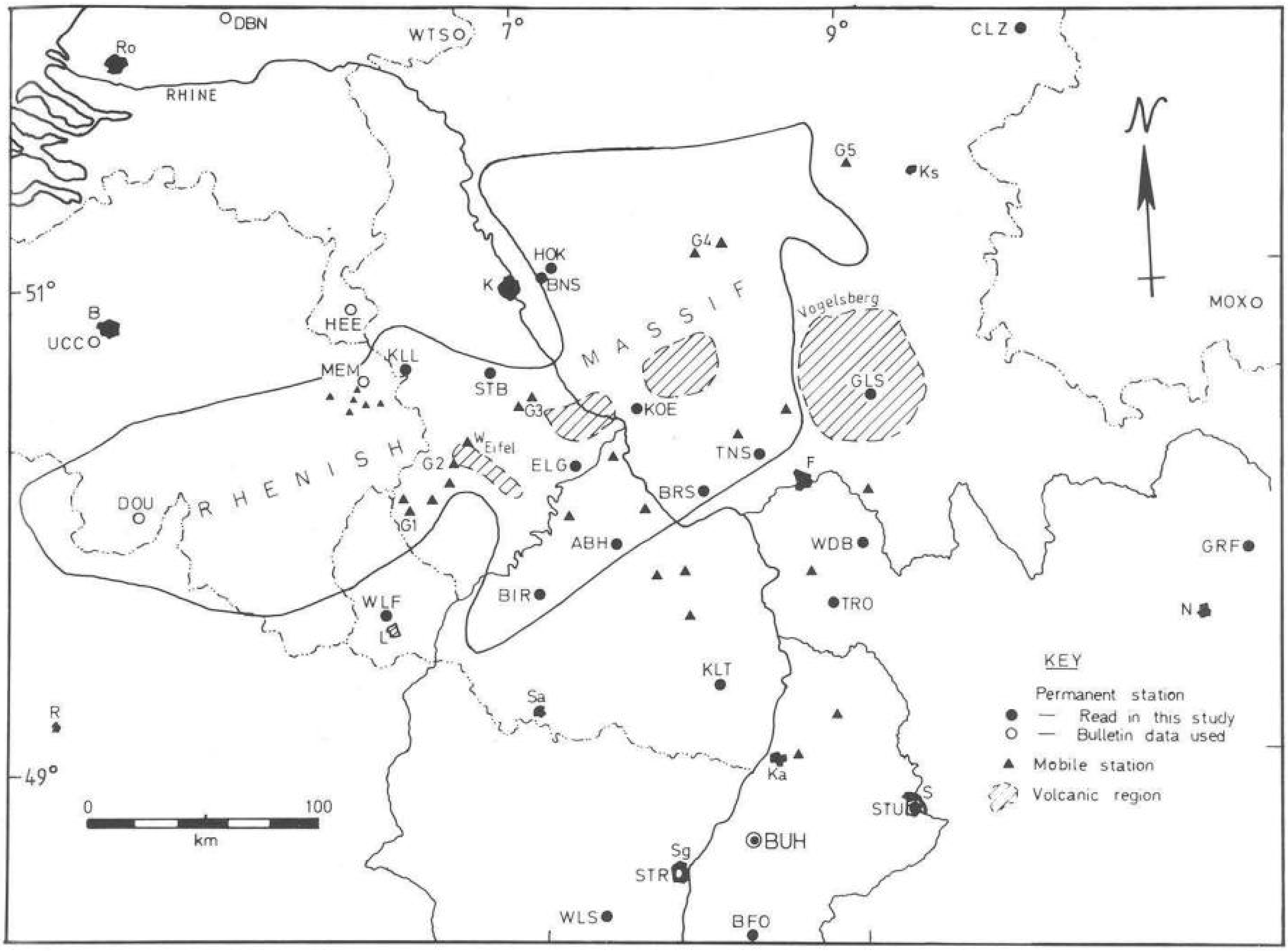

Fig. 1. Seismic stations used in this study

noted by Wenderoth (1978), has large positive residuals for events in the NE quadrant (0.6 to 1.2 s for azimuths 20° to 90° compared with 0.25 s for PKP and 0.3 to 0.5 s for azimuths 250° to 360°).

Implications

The observed pattern of teleseismic delays suggests that there are regions of low velocity beneath the Vogelsberg and the western half of the Rhenish Massif. The azimuthal variation (over 0.5 s) of residuals for stations in the latter area implies that they are caused by a velocity decrease in the upper mantle. Figure 3 shows a cross section through the Massif, with ray paths for events in the North Atlantic, Hindu Kush, and Sumatra regions, and the contours of residuals for the vertically incident PKP phases. The location of these ray paths and of those for other source regions suggests that the main low velocity regions lie at ca. 50 to 150 km depth beneath the western Massif, with the shallowest point beneath the West Eifel, and a shallower ($\lesssim 60$ km) region beneath the Vogelsberg. The velocity decrease depends on the depth extent of the low velocity region, but beneath the west Eifel it must be at least 3%. The residual variation is also compatible with a ca. 50 km thinning of the lithosphere beneath the western Rhenish Massif: a study of Rayleigh wave dispersion, which is more sensitive to S velocity variations, by Panza et al. (1979) indicates considerable variation in lithospheric thickness throughout Europe with thinning in the Rhinegraben – Rhenish Massif area.

More detailed modelling using automatic inversion procedures, and different normalisation schemes, plus increased mobile station coverage in the Belgian part of the Rhenish Massif, will allow better constraints to be placed on the anomalous regions. However, it is interesting that the should be great differences between the areas east and west of the Rhine. Low velocities are often associated with increased temperatures so it is perhaps reasonable that the major anomaly should be associated with the west Eifel, which is the area of most recent vulcanism. Currently available gravity data do not show a correspondingly strong anomaly in this area, so the velocity decrease is unlikely to be caused by a phase change (e.g. eclogite to garnet granulite, $\Delta\rho \sim 0.15$ gcm^{-3}). A more likely explanation appears to be the presence of partial melt ($\lesssim 1\%$, $\Delta\rho \sim 0.03$ gcm^{-3}) which would also be detected by deep electrical sounding techniques as it causes a marked increase in electrical conductivity.

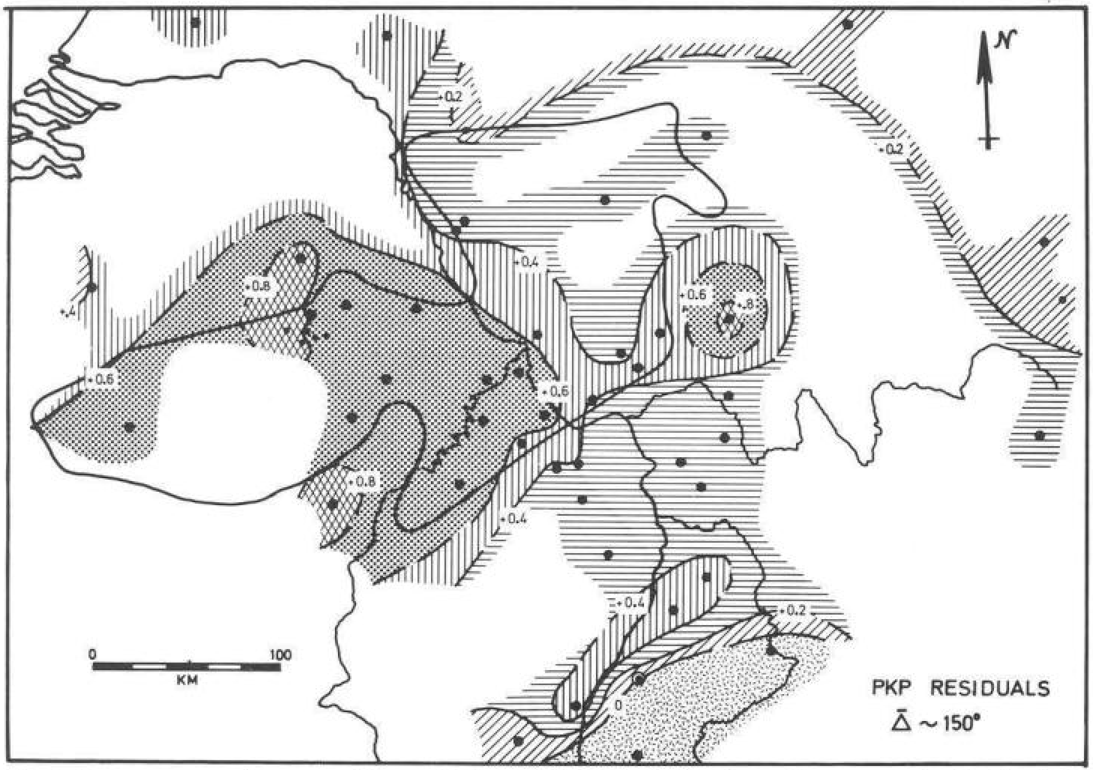

Fig. 2. Contour map of average delays, relative to BUH, for PKP phases from events in the South Pacific. The contour interval is 0.2 s; stations are indicated by *closed circles*

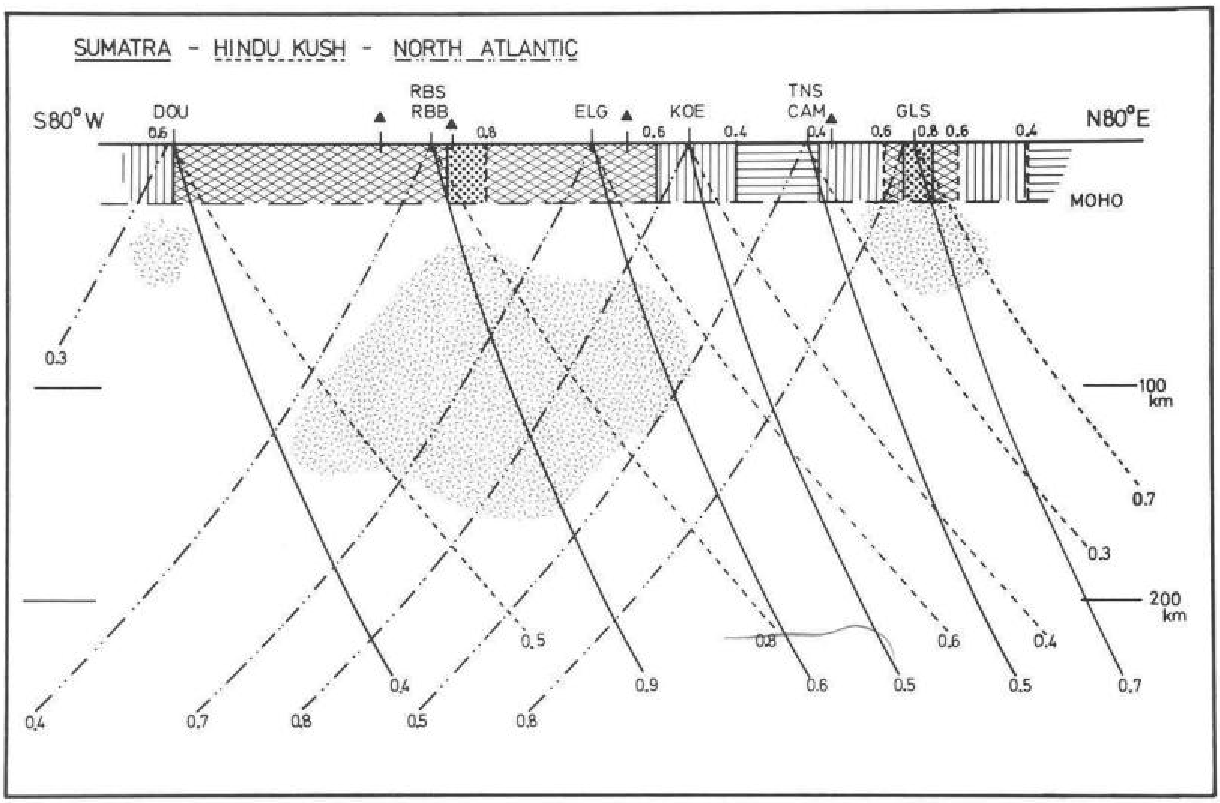

Fig. 3. Cross section through the Rhenish Massif showing ray paths to the named stations from events in the N. Atlantic (-··-··-), Hindu Kush (-----) and Sumatra (—) regions. Numbers at the end of each ray indicate the mean relative residual for that region, and the contours for PKP delays are projected on the crust. Further stations along the section, whose rays were omitted for clarity, are shown by *triangles*, and the inferred regions of low velacity are *hatched*

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