The geodynamic setting of Tertiary-Quaternary intra-plate magmatism in Europe: The role of asthenospheric diapirs or mantle "hot fingers"

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Despite significant advances in our understanding of the nature of mantle convection, we still have few constraints on the geometry of the thermal (and chemical anomalies) widely referred to as mantle plumes. Numerical and analogue modelling has indicated that several different scale lengths of convective instability are possible, with upwellings originating from boundary layers in the Earth's mantle such as the 650 km discontinuity or the core-mantle boundary. A variety of "evidence" has been used to argue for the existence of lower mantle plumes including teleseismic tomography, Sr-Nd-Pb-He isotope studies of oceanic island basalts and the existence of flood basalt provinces in the geological record, much of which is indicative but by no means conclusive. Far stronger evidence exists for the existence of plume-like convective instabilities in the upper mantle in geological settings in which magmatism is long-lived and plate motions relatively slow. The fundamental issue is whether these short-wavelength instabilities are a distinct mode of upper mantle convection, driven from below (perhaps by base heating of the 650 km discontinuity), or whether their locations are constrained by pre-existing lithospheric heterogeneities and the regional stress field.

Palaeocene-Recent volcanism within western and central Europe (Fig.1) is spatially and temporally linked to the development of a major intra-continental rift system and to domal uplift of Variscan basement massifs on a scale of 100s of km [1,2]. Mantle melting has been attributed to the diapiric upwelling of small-scale, finger-like, convective instabilities from the Transition Zone at the base of the upper mantle (Fig. 2), identified on the basis of local seismic tomography experiments in the Massif Central (France) and the Eifel (Germany) [3,4,5]. The local seismic tomographic studies indicate the existence of localised zones of mantle upwelling from depths of 400-650 km, 100-300 km across and up to 100-200 degrees Centigrade hotter than ambient mantle (if the velocity anomaly is attributed only to temperature). Global seismic tomographic studies also reveal the existence of broad zones of low velocity material in the upper mantle and, additionally, suggest the existence of a zone of low seismic velocities at depths of 900 to 1400 km in the lower mantle, extending from Iceland to the Eifel volcanic province of northern Germany, the Massif Central of France, the Hoggar massif in northern Africa and the Canary Islands [6,7]. We must therefore consider the possibility that the diapiric upper mantle upwellings inferred to have triggered the Tertiary-Quaternary volcanic activity within Europe could be linked dynamically to the upwelling and lateral spreading of the Iceland mantle plume. However, although Icelandic basalts are characterised by He isotope signatures ($R/R_A > 20$) consistent with a lower mantle source for the plume, detailed seismic tomography studies indicate that the Iceland plume itself may be an upper mantle phenomenon [8].

There is an interesting anti-correlation between the locations of the major volcanic fields, and the mantle diapirs which underlie them, and the location of a zone of seismically fast material in the base of the upper mantle (Fig.3) which has been interpreted as a zone of subducted oceanic lithosphere slabs [9]. The dynamics of mantle convection beneath Europe thus appears to be intimately linked to the closure of the Tethys ocean and the formation of the Alpine orogenic belt.

The spectrum of primitive mafic magma compositions within the European volcanic province ranges from melilite nephelinites and melilitites, through basanites and alkali basalts to subalkaline tholeiites; these are considered to be the products of variable degrees of partial melting of a relatively homogeneous HIMU-like reservoir within the upper mantle, the European Asthenospheric Reservoir or EAR [10]. Variations in the trace element and Sr-Nd-Pb isotopic characteristics of the magmas are consistent with mixing of partial melts from both lithospheric and asthenospheric mantle sources. A component geochemically similar to the EAR also exists within the Icelandic plume system; this is preferentially sampled by relatively rare, small degree, partial melts (nephelinites and alkali basalts). Thus both geophysical and geochemical data could be used to support a geodynamic link between the Palaeocene-Recent activity of the Icelandic mantle plume system and the magmatism much further to the south in western and central Europe.

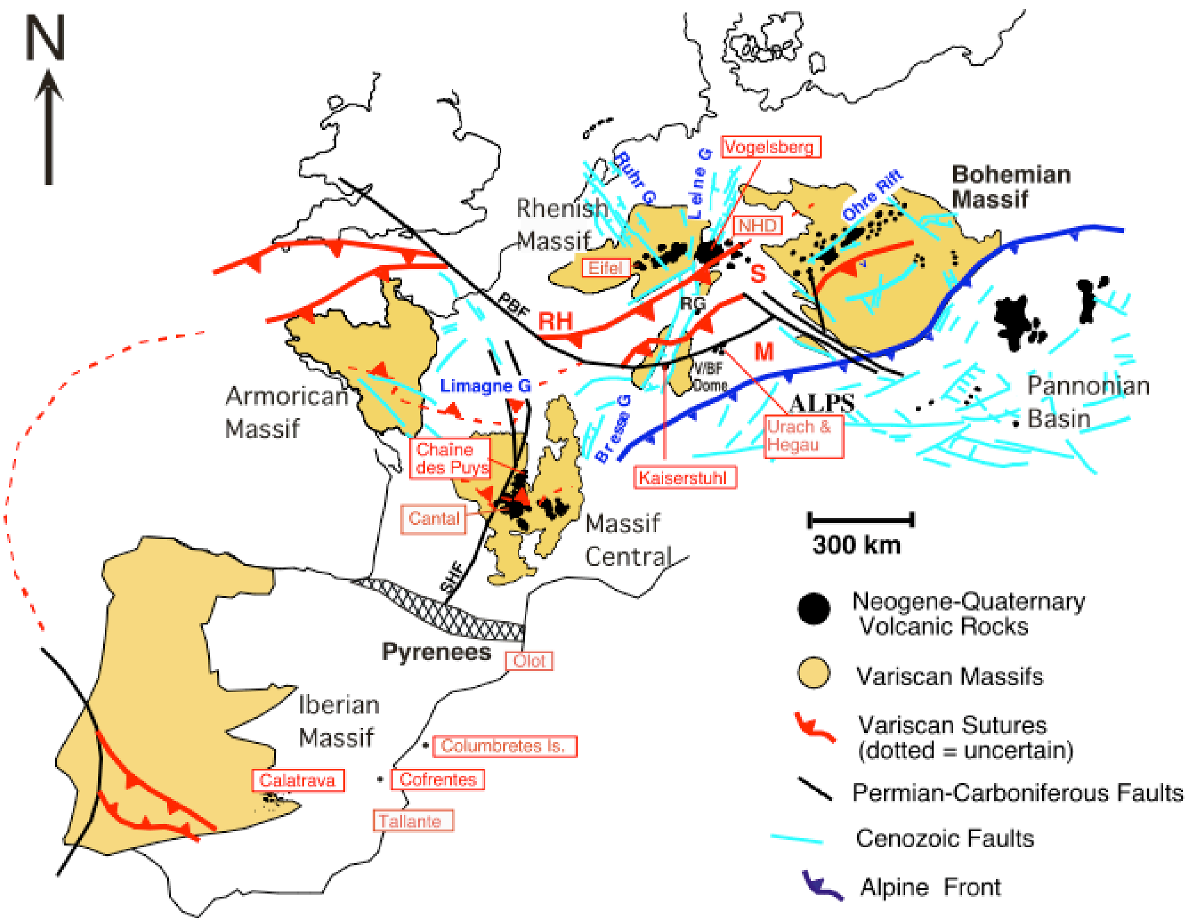

Fig.1 Location of Tertiary-Quaternary volcanic fields in Europe After: Wilson & Patterson [2]
Variscan terranes: RH – Rhenohercynian; S- Saxothuringian; M- Moldanubian
Abbreviations: RG- Rhinegraben; SHF – Sillon Houiller fault; PBF – Pas de Brays fault

The major Tertiary-Quaternary magmatic provinces within western and central Europe are located along tectonic sutures between micro-plates which collided during the Variscan orogeny some 300 Myr ago [1]. There is, however, little correlation between the zones of maximum lithospheric extension (e.g. the Rhinegraben rift system), which transect the Variscan lithospheric terrane boundaries at a high angle, and the location of the main volcanic fields (Fig.1).

Within the Massif Central of France the largest volcanic edifice, Cantal, is located at the intersection of three distinct lithospheric terrane blocks, Fig.4) [11]. This raises the question of whether the mantle diapirs beneath the Eifel and Massif Central volcanic fields really are upwellings from the Transition Zone or if they are tectonically induced zones of decompression melting which have propagated downwards from the base of the lithosphere.

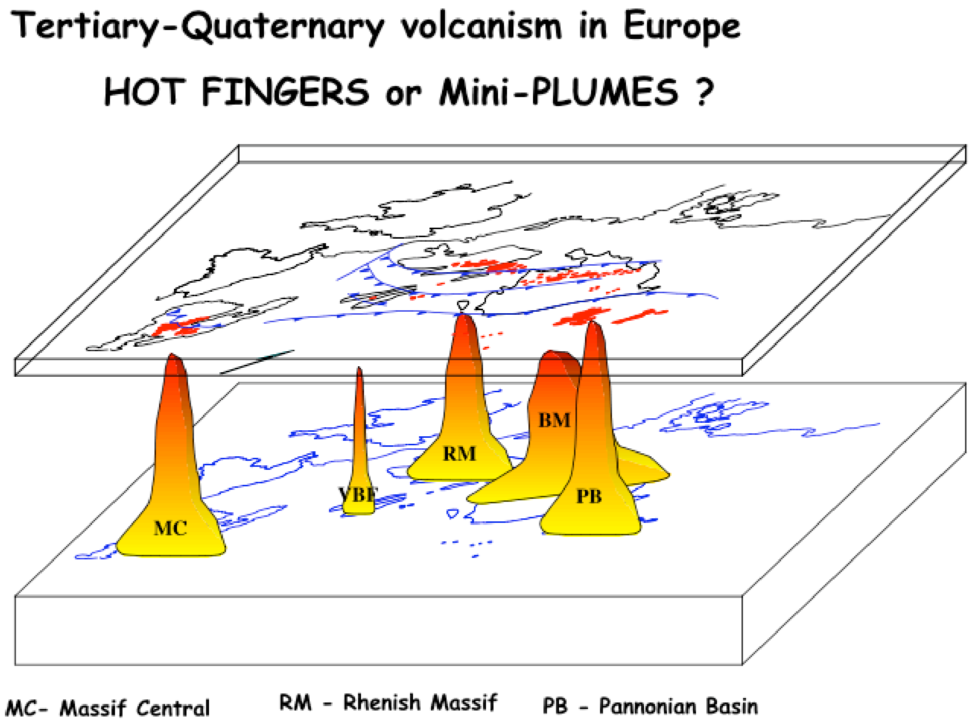

Fig. 2: The location of Tertiary-Quaternary volcanic fields in Europe and diapiric instabilities in the upper mantle. After Granet et al. [3]. (BM –Bohemian Massif; VBF- Vosges-Black Forest Dome)

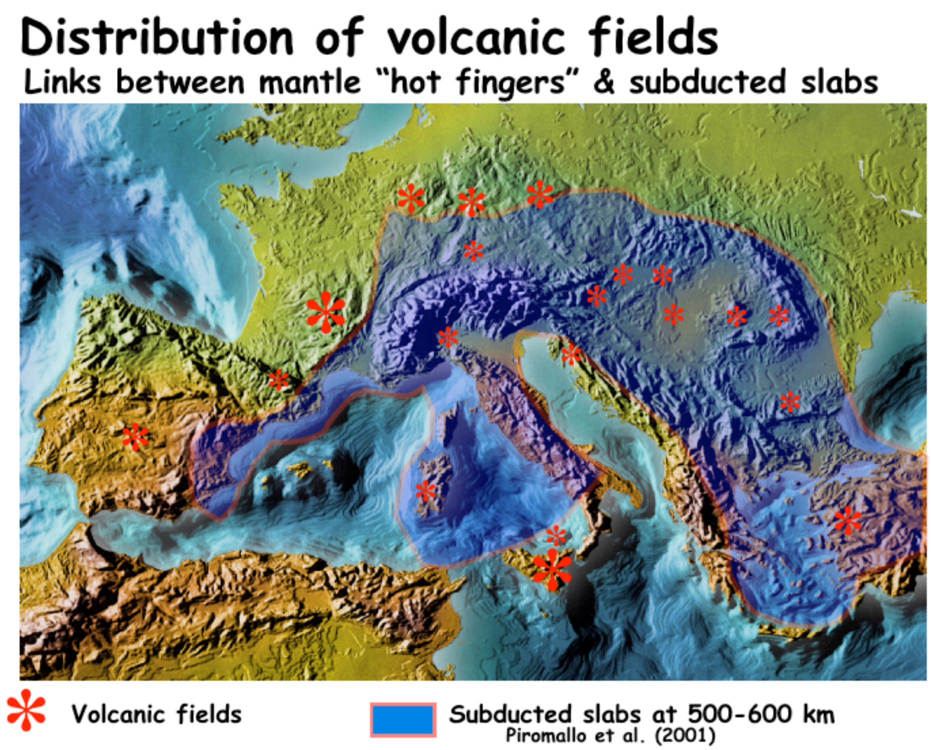

Fig.3 Location of Tertiary-Quaternary volcanic fields in relation to a zone of seismically fast material at the base of the upper mantle interpreted by Piromallo et al. [11] to be subducted oceanic lithosphere.

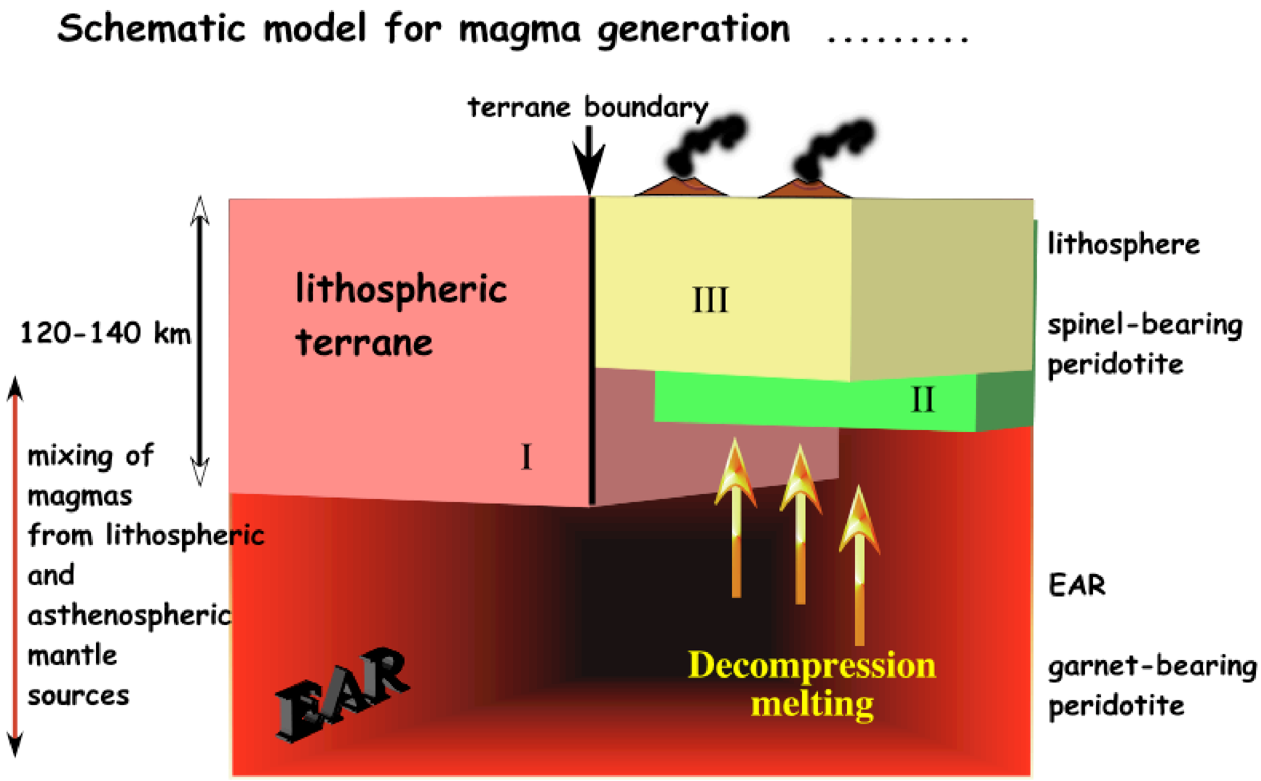

Fig. 4 Nucleation of diapiric upwelling at the intersection of lithospheric terrane boundaries in the French Massif Central. After Babuska et al. [11]

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