

EUG XI



Symposium MS07

Sub-Continental Mantle Plumes:
Origin, Evolution, Surface Expression and Fate;
What Do We Really Know?

Convenors

Marge Wilson
Ulrich Achauer

MS07 Sub-Continental Mantle Plumes

Wednesday PO Session

MS07 : WEpo01 : PO North Ladoga Early Proterozoic Plume: The Geology and Geochemical Evidences (Russia, Karelia)

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Geochemical particularity of some subalkaline diorites and tonalities within North-West Ladoga region may be explained as the effect of the mantled plume activity. The plutons of this are the located of Putsary sinclinary (Explanation map... 1996). The mean earth crust thickness this region is about 42 km (Sharov NV et al, 1990). Geophysical data evidence this elevation of M boundary up to 35 km (Orovetsky JP et al, 1988) under those plutons with the compensation depressions besides by the elevation. The base of consolidation core is 5-7 km. Hence, this deep crustal structure in the North-West Ladoga region can be interpreted as a "head" magmatic plum (diapire), which seems to be asymmetric shape and the most likely is bounded by deep fault zones. The irregular character of mantle/core boundary, may be originated by assimilation and interaction processes of the mantle magma in the way of its ascent in the crust. Diorites and tonalities are high Al, with the alkalinity varying from normal to subalkaline. Subalkaline trend and the enrichment in REE are typical features of the rocks. Metasomatic microcline is widely spread within this plutons. Wide variations of La/Yb ratio and really expressed Eu-maximum (Eu/Eu* varying from 1 to 2.9) anomaly are characteristic for micricline-bearing samples. The rocks feature are typical for rocks, which are formed by mantled fluids influence (Letnikov FP, Savelyeva VB et al, 1996). Partial melting of crust matter, and metasomatic granitization can be considered as the consequence of mantled plume evolution accompanied by regional heating and low-temperature metamorphism in andalusite-sillimanite facies.

Edited by Koistinen T, *Explanation to the Map of Precambrian Basement of the Gulf of Finland and surrounding area 1:1 million*, 141, (1996).

Letnikov FP, Savelyeva VB et al, *Geotectonica*, 5, 15-26, (1996).

Orovetsky JP & Golub VN, *Reports USSR*, 2, 9-15, (1988).
Sharov NV, Kosminskaya IP et al, *Geotectonica*, 1, 315-325, (1990).

MS07 : WEpo02 : PO Crust and Mantle Contributions to Anorogenic Magmatism: A Case Study of the Cretaceous Erongo Complex, Namibia

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The early Cretaceous igneous ring complexes in the Damaraland Province of NW-Namibia encompass an extreme range of compositions, from carbonatites to syenite-gabbro suites to granites. The Erongo is the largest of the Damaraland complexes and it includes components of both undoubted mantle origin (lamprophyre, basanite, alkali basalt) and those derived from felsic crust (peraluminous granite). Our study of the Erongo complex is aimed at defining the relationships among the mantle and crustally-derived units within it, and their implications for the igneous development of the Namibian margin as a whole. Three groups of basic units are distinguished: early basalt flows at the base of the complex, a ring dike of coarse grained tholeiitic dolerite surrounding the complex; and a group of basic alkaline plugs and dikes (basanite-tephrite and lamprophyre) which are the youngest units in the complex. The basalts at the base of the Erongo complex are tholeiitic and have a range of TiO₂ contents corresponding to the low-Ti group of Parana-Etendeka flood basalts. They show a wide range in isotopic and trace element composition, which is attributed in part to crustal contamination. The initial (calculated at 132 Ma) εNd-values and ⁸⁷Sr/⁸⁶Sr ratios vary from 0 to -7.3 and 0.70526 to 0.71428, resp. The tholeiitic ring dike dolerite is more homogeneous in composition than the basal basalts. Its geometric relationship to the complex indicates a local source but the present

chemical and isotopic data do not show significant differences between this source and that of the regional flood basalts. The basanite-tephrite plugs, on the other hand, are chemically and isotopically distinctive. Their εNd-values and ⁸⁷Sr/⁸⁶Sr ratios (+2 and 0.7045) are similar to those of carbonatites, nepheline syenites, lamprophyres and alkali gabbros reported from other ring complexes in NW-Namibia, which have been interpreted derived from plume mantle. The felsic units in the Erongo complex comprise rhyodacitic to rhyolitic lavas and tuffs as well as two intrusive series. The first of these (Ombu granodiorite) is compositionally identical to overlying volcanic unit and represents the intrusive equivalent of the intermediate magmas. The second intrusive unit (Erongo granite) occurs as sills, dikes and peripheral stocks of tourmaline-bearing biotite leucogranite. Our geochemical studies suggest that the intermediate volcanic and intrusive units and the Erongo granite could be derived from a common magma source. This is supported by preliminary isotopic data from the Ombu granodiorite and the Erongo granite. Both units cover a narrow range of values (εNd from -7 to -9 and ⁸⁷Sr/⁸⁶Sr(i) from 0.7263 to 0.7399), which overlaps completely with data from Damara metasediments and granites.

MS07 : WEpo03 : PO Palaeozoic Activation in the Northeastern Fennoscandian Shield: Rb-Sr and Sm-Nd Isotope Evidence for Evolution of Mantle Sources

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Preliminary Rb-Sr and Sm-Nd isotope studies were carried out in order to obtain time span of Palaeozoic magmatism in the northeastern Fennoscandian Shield. We focused on investigation of two rock series which belong to initial and final magmatic events within the northeastern Fennoscandia. The former are represented by alkaline and subalkaline volcanic series which occur in Lovozero, Kontozero and Ivanovka areas, whereas the latter appear as melanephelinitic pipes and dykes and phonolite dykes which cut the apatitic syenite and carbonatite intrusions. The obtained results are as follows: 1. Rb-Sr isochron age of the Lovozero alkaline picrite in volcanogenic pile gives the age estimation 446±56 Ma and initial ratio ISr=0.70300±9 with MSWD = 0.64 (N=5). 2. Rb-Sr isochron age of the Kontozero volcanogenic carbonatite - melanephelinitic suite gives the age estimation 380±8 Ma and initial ratio ISr=0.70318±8 with MSWD = 0.53 (N=4). 3. Rb-Sr isochron age of the olivine melanephelinitic from the pipe cutting the Khibina intrusion gives the age estimation 358±31 Ma and initial ratio ISr=0.70385±17 with MSWD = 4.0 (N=7). Sm-Nd isochron for the same rock gives 362±91 Ma (N=6, Initial ¹⁴³Nd/¹⁴⁴Nd = 0.512256±0.00062, MSWD = 0.58). The whole Rb-Sr isochron age dataset for the Kola Province show that the narrow age interval (380-360 Ma) of apatitic and carbonatitic complexes determined by Kramm et al., (1993) represent the maximum of the tectonic-magmatic reactivation in the NE Fennoscandia. Our new isotope measurements, due to the high errors also fall within the same age interval and provide no additional information to the previous age data (Beard et al., 1996; Arzamastsev et al., 1999) in order to expand time span of Palaeozoic magmatism. However, we can suggest that initial (volcanic) and final (dyke) stages of magmatic activity were not significantly separated from the main stage of alkaline magmatism in the Kola part of the Shield. The other output of the Rb-Sr and Sm-Nd isotope studies were relatively high epsilon Nd (+6.8 - +8.8) combined with epsilon Sr -11.8 - -13.2 (t=380 Ma) in the Kontozero volcanics. Lovozero picrites also exhibit high epsilon Nd (+3.6 - +8.3), whereas the adjacent Lovozero alkali basalts appear to be contaminated by crustal material (εNd = -0.3 - -1.7). On the other hand, Khibina melanephelinitic dykes fall within the range of εNd and εSr values close to that in Tersky kimberlites (Beard et al., 1998; Dunworth et al., unpublished). Thus, magma sources for initial, main and final magmatism in the northeastern Fennoscandia appear to exhibit the evolutionary trend expressed in decrease of the component of the depleted mantle.

MS07 : WEpo04 : PO The Influence of Hawaiian Hot-Spot on Deep Structure and Volcanism of Kamchatka

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According to the hypothesis of P.R. Vogt at al. the Hawaiian-Emperor Volcanic Seamount Chain, formed above Hawaiian Hot-Spot, defines the geometry of connection of Kurilo-Kamchatkan and Aleutian island arcs. The Obruchev rise is the finish part of the Hawaiian-Emperor Chain before its slip under Euroasian plate. It is shown that this rise has its extension under Kamchatka and it causes the bend of Eastern-Kamchatkan volcanic front in the north of Kamchatka. It is connected with the biggest Euroasian active volcanoes of Kluchevsky belt. By the data of seismic tomography it is characterized the velocity structure of lithosphere block of this region (till the depth 90 km). The zones of contrast velocity structures contact are obtained. The lowest for this peninsula of Vp and Vs velocities are established under Kluchevsky volcanoes, particularly, in lower crust. Evidently, the area of volcano magmfeeding is placed of this depth.

The appearance at Kamchatka the Late Neozoic volcanism of in-plate geochemical type together with typical island-arc volcanism, can not be explained by the presence of own plume under Kamchatka, but it can be explained by untypical condition of interaction of Pacific, Euroasian and north American lithosphere plates, connected with the Hawaiian-Emperor-Obruchev Volcanic Chain. Under such conditions it is possible to happen the break and slip of subducted Pacific plate under Kamchatka close to the place of Kurilo-Kamchatkan and Aleutian island arcs connection and intrusion of hotter mantle substance.

MS07 : WEpo05 : PO Wehrlite and Clinopyroxenite Xenoliths from Mt Cameroon: Implications for Lithospheric Processes

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Whereas spinel lherzolites and olivine websterites are common along both the oceanic and the continental sectors of the Cameroon Line (Déruelle et al., 1991; Lee et al., 1996), for the first time, wehrlite, olivine clinopyroxenite, and clinopyroxenite xenoliths have been sampled (conjointly with scarce lherzolite ones) in pyroclastic deposits from a monogenetic cone located on the eastern flank of Mt Cameroon.

Wehrlites (ol: 83; cpx: 10; plg: 3; sp: 2; amphibole: 2; vol%) have a poikilitic texture. Olivine clinopyroxenites and clinopyroxenites (ol: 10-3; cpx: 85-95; sp: 5-2; vol%) have an equigranular texture.

Clinopyroxene, olivine and spinel have the same respective compositions in wehrlites and clinopyroxenites. Olivine (Fo₆₂₋₈₅) is not as Mg-rich as that commonly found in spinel lherzolites (Fo₉₀) from the Cameroon Line (Lee et al., 1996) but is Ni-rich (NiO: 0.34%). Such characteristics observed in plagioclase wehrlites from oceanic domains were attributed (Girardeau & Francheteau, 1993) to reequilibrium through melt impregnation of peridotites by iron-rich liquids. Clinopyroxene is a Cr-rich diopside with high Al^{IV}/Al^{VI} ratios (1.4-8.0), high Ca-Tschermak's molecule (7%) and jadeite (2%) values, indicating pressure equilibrium between 5 and 10 kb. Spinel is Cr-, Fe- and Ti-rich and Mg- and Al-poor. Plagioclase (An₆₃) is less calcic than that in lherzolites from the Cameroon Line. Amphibole is a kaersutite which contains variable Mg amounts and is Cr-, K- and Ti-rich. No orthopyroxene has been found in the wehrlite and clinopyroxenite xenoliths.

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Low Fo values of olivine may result from reequilibrium due to mantle "Fe-Ti metasomatism" (Bodinier et al., 1991). Occurrence of kaersutite (with TiO₂ wt% up to 4.2) in the wehrlites favors the role of silicate melts rather than that of aqueous fluids during metasomatism.

Bodinier J-L, Menzies MA & Thirlwall MF, *J. Petrol. Spec. Vol.*, 191-210, (1991).

Déruelle B, Moreau C, Nkoumbou C, Kambou R, Lissom J, Njongfang E, Ghogomu RT & Nono A, *Migmatism in Extensional Structural Settings. The Phanerozoic African Plate*, Springer-Verlag, 274-327, (1991).

Girardeau J & Francheteau J, *Earth Planet. Sci. Lett.*, **115**, 137-149, (1993).

Lee D-C, Halliday AN, Davies GR, Essene EJ, Fitton JG, & Tendjim R, *J. Petrol.*, **37**, 415-441, (1996).

MS07 : WEpo06 : PO Geochemical Evolution and Ar-Ar Geochronology of the Emeishan Flood Basalt Province, SW China

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The 'Emeishan Volcanic Province' (EVP) is a Permo-Triassic continental flood basalt succession covering large areas in SW China. The EVP is considered as a 'Large Igneous Province' (Chung and Jahn, 1995). The EVP is virtually coeval with the Siberian flood basalt province. This near-coincidence raises a number of interesting questions on the causes of the Permo-Triassic extinction event. In contrast to many other flood basalt provinces, the EVP underwent a complex evolution. It has been covered by thick deposits of Triassic/Jurassic sediments, and has been considerably uplifted, deformed and segmented as a result of the Himalayan orogeny. The EVP has been systematically sampled during several field campaigns in 1998-2000 for Ar-Ar geochronology and geochemical/petrological studies. Ar-Ar dating of plagioclase separates from basalts sensu stricto turned out to be particularly difficult, as even the fresher samples have been affected by metamorphic and tectonic resetting. Reliable Ar-Ar plateau ages of 246±4.1 Ma and 254.4±0.3 Ma have been obtained for plagioclase and phlogopite separates from plutonic rocks associated with the EVP. Overall the EVP has the typical characteristics (e.g. REE patterns) of continental tholeiitic flood basalts. There are significant petrographic and geochemical differences between basalts from the western (western Yunnan province) and eastern side (eastern Yunnan and western Guizhou provinces) of the EVP. Picritic tholeiites are prominent among samples of the western side, but are absent in the eastern side. A remarkable geochemical homogeneity is observed for basalts from the eastern side. There is still major uncertainty about the tectonic environment in which the EVP was emplaced. Most likely the emplacement is coeval with an episode of rifting along a continental margin. Chung and Jahn (1995) proposed a now conventional plume head melting model. However, the spatial chemical dichotomy of the EVP requires a number of ad hoc assumptions for the plume model. Another problem with the plume hypothesis is the apparent short-lived nature of the plume, because there are very few indications for magmatic activity prior to or after the EVP emplacement. It appears as yet premature to exclude other models for the origin of massive magmatic events along rifting continental margins.

Chung SL & Jahn BM, *Geology*, **23**, 889-892, (1995).

MS07 : WEpo07 : PO Isotope Systematics of Cenozoic Intraplate Basalts: Evidence for Involvement of Common Mantle Sources beneath Africa, Western-Central Europe and Central Atlantic Islands

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The oceanic basalts display large variations in isotopic compositions. They show in isotopic 2-D, 3-D space diagrams strong correlations within elongate tube-like fields. These facts are interpreted as mixing or MET (Melt Extraction Theory, Morgan, 1999) between two distinct end-member components in which the deep reservoir labelled 'FOZO' (Hart et al., 1992, Hauri et al. 1994), probably represents an important signature. This interpretation is also available in Africa (except the East African rift) and Europe continental setting. In isotopic Sr-Nd-Pb diagrams, all arrays from these magmatic provinces (Cameron Line, Kenya, Ahaggar, Soudan, Afar, Massif Central and Eiffel) appear to radiate from the same point 'FOZO' identified in the Atlantic Oceanic Islands Basalts (Azores, Cap Verde, Canaria and St Helena). The contribution of this common mantle reservoir for all these magmatic provinces appears to be consistent with the hypothesis of a 'mega-plume' beneath Africa and Europe. It is noteworthy that the contribution of the enriched mantle components is less important than that of the OIB such as in Hawaii and Pitcairn (EM1) or Samoa and Societies (EM2). The variations defined by the isotopic diagrams of all these Cenozoic magmatics are consistent with contribution of an enriched mantle source and a HIMU mantle reservoir. Ahaggar magmatics summarize this large isotopic heterogeneities. In this area, the radiation near the isotopic signature of the 'FOZO' from an enriched end-member (EM1-like, or continental crust, or lithospheric mantle (Wilson and Downes, 1991) structured in that case during the pan-african orogeny) to a HIMU-like reservoir, could reflect the spatial and temporal variations magmatic evolution at the scale of the Ahaggar swell (tholeiitic to alkali affinity). Two possible scenarios could be proposed to explain these variations: the first one invokes a convective mantle cell at the boundary of two contrasting lithosphere (West African Craton and Panafrican mobile belt), and the second one a small sized plume near HIMU composition. On the opposite, magmatic sources of the Eastern African rift follow a different scheme. In this province, magmatism is generated from a depleted mantle source (DM-like) and shows stronger isotopic variations, suggesting a larger crustal contamination.

Morgan JP, *Geochem. Geophys. Geosyst.*, **1**, (1999).

Hart SR & Hauri EH, *Sciences*, **256**, 517-520, (1992).

Hauri EH, Whitehead JA & Hart SR, *J. Geophys. Res.*, **99**, 24,275-24,300, (1994).

Wilson M & Downes H, *J. Petrol.*, **32**, 811-849, (1991).

MS07 : WEpo08 : PO Permian Mafic Rocks in the Alps: A Post- Orogenic Mantle Melting Event Illustrated by the Mont Collon-Matterhorn Intrusion (Austroalpine Dent-Blanche Nappe)

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The Variscan belt in Europe is characterized by its scarcity in mafic rocks, which occur as discrete volumes of lamprophyric dykes and enclaves within large granitic massifs. Involvement of mantle is mostly inferred from thermal calculations and isotopic constraints from the granites. A dramatic change occurs in Early Permian, with the intru-

sion of many mafic complexes in the future Austroalpine and southern Alpine domains (e.g. Mont Collon-Matterhorn, Anzasca, Malenco, Ivrea, Sondalo). These occurrences, which must be clearly distinguished from gabbros of the Jurassic Tethyan rifting, evidence an major melting episode of the mantle ascribed to the post-orogenic thinning of the Variscan lithosphere. Only then did the uprising mantle reach shallow enough levels to melt extensively.

The Mont Collon-Matterhorn mafic complex is the best preserved example of this Permian tholeiitic magmatism in the Central Alps. It mostly consists of Ol+Opx+Cpx+Pl+Prp±Phl-bearing melanorites to gabbros. Mineral coronas between plagioclase and olivine point to late-magmatic to post-solidus reequilibration at decreasing P-T. Thermobarometric calculations on pyroxenes yield a range of 950-1100°C and 0.7-1.0 GPa, and late-magmatic intercumulus amphibole yields pressures of 0.85 GPa, pointing to a lower crustal intrusion level of a hydrous magma. However, amphiboles from reaction coronas indicate distinctly lower pressures of 0.6 GPa, reflecting reequilibration during a decompression process, as commonly observed in the other Permian Mafic Complexes (= PMC) of the Alpine belt.

Four concordant single- to 3-grain zircon fractions of a pegmatitic gabbro from the northern wall of the Mont Collon yield a TIMS U-Pb mean age of 284.2±0.7 Ma, interpreted as the magmatic age of the intrusion. It is very similar to that of other PMC, e.g. Anzasca (288±2/-4 Ma), Ivrea (285±7/-5), Malenco (274±5) or Sondalo (280±10).

Post-orogenic extension of the European Variscan belt is well documented at all crustal levels and led to mantle uprising and melting in the Permian. Whether melting was initiated by simple decompression or triggered by other processes such as lithospheric delamination and input of additional heat through upwelling of asthenospheric mantle is not yet known. On the other hand, the source of melts is definitely the lithospheric mantle, as evidenced by new initial eHf values of zircons from the Mont Collon-Matterhorn gabbro scattering between -1 and +1.

MS07 : WEpo09 : PO An Image of Tectonics into the Continental and Oceanic Mantle Structure

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Three 3-D P-velocity models of the mantle beneath Europe, central Asia and a region between Asia and Australia from Indonesia to Solomon Islands has been represented. The massive collection containing first-arrival times of P-waves from strong seismic events exploits as initial observed data set. The traveltimes tomography method developed by V. Geyko use for data recovering. Analysis of models deduces to the following general solid properties. The mantle of the explored subcontinent together with the flanked margins of the Pacific, Atlantic and Arctic falls into the two shells by the global boundary situated at 550-680 km depth. The upper shell (tectonosphere) is notably inhomogeneous laterally, while the lower one is more near to radially-symmetric (deeper than 750-780 km). The boundary of the upper and lower tectonosphere situated at depths 390-450 km, as the astenosphere are not global. The former is peculiar to the ancient and formed tectonic structures and later to those actively living now. Into velocity distribution not only main elements of plate tectonics clear are expressed but new, before unknown tectonic structures are revealed such as orogens that are coincided with gently sloping immersing slabs (the orogens of Middle and Central Asia, Caucasus, the Alps, the Carpathians, the Dinarides, the Menderes Massif, Sumatra, Philippines etc) or with rising to surface astenosphere and it spreading (Iceland, the Rhine Graben, the Shetland Trough, the Central Tabria, the South Azerbaijan Massif, the Negros Arc, the Sulu Depression, the Banda Sea etc) and another kinds of tectonic phenomenon are stripped including plumes. Age and genetic type of the tectonic structures reflect in the thickness and structure of the tectonosphere. The tectonic structures of the first order (plates) have 'roots' piercing full the tectonosphere, while those of higher order are clear-cut in the upper and unclear in the lower tectonosphere. Separated great tectonic structures, belts and assemblies tectonic structures imaging as unit at

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Thursday PM Session

MS07 : THpm22 : F6

The Role of Mantle Plumes in the Break-Up of Gondwana

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The number of continental flood basalt (CFB) provinces within Gondwana is less than the number of mantle plumes that are likely to have been emplaced beneath it in the 300 Ma prior to its initial break-up. The difference between the age of the peak of CFB volcanism and that of the oldest adjacent ocean crust decreases with the age of volcanism during the break-up and dispersal of Gondwana (i.e. from ~180 to 60 Ma). The older CFB of the Karoo and the Ferrar appear to have been derived largely from source regions within the mantle lithosphere, and it is only in the younger Parana-Etendeka and Deccan CFB, that there are igneous rocks with major, trace element and radiogenic isotope ratios indicative of melting within a mantle plume. These younger CFB are also clearly associated with hot spot traces on the adjacent ocean floor. The widespread 180 Ma magmatic event is attributed to partial melting within the lithosphere in response to thermal incubation over 300 Ma, and in the case of the Ferrar this was focussed by regional plate margin forces. The implication is that super-continents effectively self destruct in response to the build up of heat and resultant magmatism, since these significantly weaken the lithosphere and make it more susceptible to break-up in response to regional tectonics. The younger CFB of the Parana-Etendeka are also older than the oldest rocks on the adjacent ocean floor, and detailed modelling indicates that they were generated at least in part because the continental lithosphere had been thinned in response to regional tectonics. In the Deccan, magmatism was triggered by emplacement of the plume, but that too may have been beneath slightly thinned lithosphere, as has been documented for the North Atlantic Tertiary Province.

MS07 : THpm23 : F6

The Transition from Flood to Shield Volcanism in the Ethiopian Volcanic Province

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The Ethiopian flood volcanics erupted 30 Ma ago, within a 1 m.y. period, to form a bimodal mafic-felsic volcanic plateau up to 2 km thick and covering an area of 7.5×10^5 km². Pik et al. (1999) have demonstrated a regional zonation: basalts and rhyolites in a NW segment are tholeiites with relatively low contents of Ti and incompatible trace elements; lavas from the central and SE plateau are also tholeiitic but have higher levels of these elements. The flood volcanics are overlain by a number of large shield volcanoes whose ages range from 30 Ma to less than 20 Ma. In the literature most of these are described as having alkalic compositions. To better understand the origin of the Ethiopian plateau and particularly the nature of the transition from flood to shield volcanism, we have undertaken an investigation involving field mapping, petrology, geochronology (K-Ar and Ar-Ar) and geochemistry (major and trace elements, Sr, Nd and Pb isotopes). Preliminary results indicate that the change from flood to shield volcanism is not accompanied by a major change in magma composition. The Semien shield volcano in the NW consists almost entirely of tholeiitic basalt (except for a bimodal basalt-rhyolite-trachyte sequence at the top of the western flank). The transition from flood to shield

volcanism is marked by a small jump in levels of Ti and incompatible elements but even the uppermost lavas are low-Ti tholeiites. A basalt from near the summit has been dated at 30.4 ± 0.3 Ma, within error of the age of flood basalts from the lowermost flood basaltic unit. Two shield volcanoes on the central plateau, Choke and Gugufu, are also composed of tholeiitic basalts, with bimodal mafic-felsic sequences near their present summits. Levels of Ti and incompatible elements are higher than in the Semien volcano, but similar to those of underlying high-Ti flood basalts. Isotope data show similar relationships: there are systematic differences in isotope compositions between lavas from the NW and central parts of the province, but in each region flood and shield basalts are indistinguishable. These results indicate that the transition from flood to shield volcanism was rapid and involved magmas derived from the same source. Between now and the time of the conference we will obtain additional data to establish whether this source(s) was in the lithosphere or plume, and to explain the cause of the regional variation in geochemical composition.

MS07 : THpm24 : F6

More about Rare Gases in Kola Devonian Plume: The Most Degassed Giant Alkaline Complexes Khibiny and Lovozero

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The highest measured in terrestrial samples ³He concentrations (up to 4×10^{-9} cc/g) and quite low ⁴He/³He ratios (30,000 or 24 R/Ra) were reported for relatively small Devonian ultrabasic-alkaline-carbonatitic complexes (UACC) on the Kola Region, NE part of the Baltic Shield. These data indicate a contribution of lower mantle plume component. In this paper we present rare gas isotope abundances and parent element concentrations for the giant apatitic foidolite-syenite massifs, Khibiny and Lovozero.

Concentrations of trapped ³He (extracted by crushing) in Khibiny samples are by a factor of 20 below those in UACC. As a consequence of the lower ³He concentrations, ⁴He/³He ratios are elevated by the same factor and generally exceed the atmospheric value, 715,000 (<1 R/Ra). ⁴He/³He ratios are decreasing from massive khibinites in the periphery of the Khibiny massif to foyaites in the central part. Carbonatites constituting a stockwork in the eastern part show almost radiogenic ⁴He/³He ratios up to 10₈. The rocks of so called "central arc", rishchorrites, ijolites, urrites and apatite-netheline ores, are characterized by variable ⁴He/³He ratios. As compare with the Khibiny, more radiogenic He is typical of Lovozero samples, ⁴He/³He ratios are generally above $3 \times 10_6$. Within ⁴He/³He versus (U+0.24 Th)/³He and ⁴He/³Ar versus (U+0.24 Th)/K diagrams data points of both complexes shift to the right off the respective reference lines indicating a considerable loss of helium isotopes. Comparison of the calculated (assuming similar rate of loss of radiogenic ⁴He* and trapped ³He) initial ⁴He concentrations and those observed for Khibiny and Lovozero rocks implies that major gas loss occurred during postmagmatic ~370 Ma long evolution. However a significant portion of ³He-bearing mantle fluid could have been lost during magmatic stage, as it is indicated by fenitisation of the Kola UACC host rocks and also by host gneisses of the Lovozero massif: ⁴He/³He ratios in the gneisses are even lower than those in the alkaline rocks.

Preliminary interpretation of available data envisages similar initial abundances of mantle He in parent melts for UACC and both giant plutons, Khibiny and Lovozero. The latter, however, were crystallised at lower levels then, for example, Sebl'yavr and Kovdor UACC, and therefore had lost more He before and during the crystallisation stage. More active fluid regime of these relatively close to the surface massifs and high concentrations of U and Th (especially in Lovozero samples) stimulate further removal of trapped mantle helium and its replacement by radiogenic one.

the same time can distinguish motley heterogeneous inner pattern. Velocity inhomogeneities represent the sutures and boundaries between great structures. Into zones flanking to sutures and boundaries immediately observes usual anomalous velocity varying that reflects effect of the smoothness, diffusing of the contact region stipulated by coupling, interacting and collision of the associated structures. Thus, velocity heterogeneity reflects density ones that induce at different depths diverse scale gravitational unsteadiness that probably is a principal cause of tectonic and dynamic phenomenon. Recovered P-wave velocity values are the comparatively precise determined physical characteristic of the mantle reflects objective its true material composition and PT conditions. They can consider as original basic data for proved combine different geological and geophysical information interpreting and for meaningful tectonic and physics explaining, in particular for developing and enrichment of the plate tectonics theory.

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MS07 Sub-Continental Mantle Plumes

MS07 : THpm25 : F6 Light Noble Gas Systematics of Ultramafic Rocks of the Northern Red Sea: Tracing a Mantle Plume

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The Red Sea is a young rift system with active rifting starting 5 Ma ago, associated with volcanic activity mainly on the rift shoulder situated on the Arabian Peninsula. Rifting was related to the ascent of a mantle plume now confined to the Afar region. The plume head reached the surface 30 Ma ago, when large volumes of continental flood basalts erupted. At the time of its arrival, the plume head intruded into the continental crust and the underlying subcontinental lithospheric mantle (SCLM), introducing mantle volatiles via migrating fluids. Mantle volatiles can therefore serve as useful tracers of plume imprints. In particular, the noble gases helium and neon have distinct isotopic compositions for asthenospheric and plume related mantle sources and, hence, are suited to characterize the extension of plume derived volatiles.

The Afar plume is characterized by a high ³He/⁴He-ratio of 20 R_A (Marty et al., 1996) (R_A is the atmospheric ³He/⁴He-ratio, 1.3841 E-6). Analyses of Red Sea ridge basalt glasses (Moreira et al., 1996) show a transition in He isotopic composition from high ³He/⁴He-ratios at the Afar region to MORB-like He with a ³He/⁴He-ratio of about 9 R_A in the northern Red Sea. However, the Ne isotopic composition of northern Red Sea basalts hints at a possible influence of a mantle plume source, indicating a decoupling of He and Ne isotope systematics.

Here we report the isotopic composition of Ne and He in ultramafic rocks from Zabargad Island (northern Red Sea) and the Saudi-Arabian volcanic fields Uwayrid and Al Birk, the latter situated closer to the Afar region.

We applied stepwise crushing extractions to preselected samples with high concentrations of mantle argon. ³He/⁴He-ratios are in the range between 6.5 and 7.5 R_A, indistinguishable from analyses of worldwide SCLM rocks (Gautheron and Moreira, 2000), and do not evidence a plume influence. Ne isotope systematics of Zabargad rocks however, show a small contribution of a plume source, confirming a decoupling of He and Ne isotope systematics. Apparently Ne isotopes reflect plume imprints better than He isotopes do, indicating a better preservation of plume Ne in the SCLM.

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MS07 : THpm26 : F6 The Northernmost CAMP: ⁴⁰Ar/³⁹Ar Age, Petrology and Sr-Nd-Pb Geochemistry of the Kerforne Dyke: (Brittany, France)

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The earliest Jurassic Central Atlantic Magmatic Province (CAMP) represents the largest Phanerozoic continental flood basalts (CBF) province. CAMP is defined by tholeiitic basaltic flows and dykes associated with the initial Pangea break-up and Atlantic Ocean rifting at 200 Ma. These tholeiites occur in once-contiguous part of North America, Africa, south America and Europe reaching a total area of about 7 million square km and stretch over a distance of 6000 km. The Kerforne dyke, located in Brittany (NW France), represent the northernmost outcrop of this province, more than 1500 km from the main Atlantic

rift. Despite its location, this dyke a similar Ar/Ar age (193 ± 3 Ma, obtain on plagioclase separates) and chemical composition as the other CAMP tholeiites. Kerforne dolerites are characterized augite and minor plagioclase phenocrysts. According to petrographic observation and microprobe analysis, some of these plagioclase contain resorbed high-An (An₈₅) possibly xenocrystic cores which may be evidence of interaction with a mafic lower crust. The low TiO₂ (ca. 1 wt%) tholeiitic Kerforne basalts are characterized by a negative Nb anomaly, by a positive correlation between εSr (+15 to +23) and εNd (0.76 to -1.22), by radiogenic ²⁰⁷Pb/²⁰⁴Pb (15.59 to 15.64) and ²⁰⁸Pb/²⁰⁴Pb (38.18 to 38.34) at relatively unradiogenic ²⁰⁶Pb/²⁰⁴Pb (18.2 to 18.37) and by an enrichment in LREE relative to HREE (La/Yb_n = 2.37 to 2.57). These chemical features, along with the mineralogical observations, are indicative of a minor contamination with the lower crust, similar to that represented by I.s. granulitic xenoliths of the Massif Central. By contrast, contamination with the silicic upper crust (e.g. with the granitic basement) was negligible. The isotopic composition of the Kerforne basalts, which are less contaminated by the continental crust (e.g. enriched in radiogenic Sr and ²⁰⁷Pb), is similar to that of most other CAMP tholeiites and is different from most oceanic basalts. Therefore, it is suggested that this enriched signature was inherited by assimilation of metasomatized portions of the continental lithospheric mantle, similar to the source of Variscan lamproites of Brittany. Consistently, REE modeling suggest that Kerforne basalts were generated from a mantle peridotite in the garnet + spinel stability field, i.e. at about 60 Km depth, in the lithosphere. Tholeiitic basalts with similar age, isotopic and geochemical composition outcrop from central Brazil to northern France, and require a common origin. In view of their location, most of the CAMP basalts (e.g., Kerforne) can not be considered as a direct magmatic expression of the Central Atlantic rifting. A deep-seated mantle thermal anomaly is required, which may have been generated by a giant mantle plume-head or by a sub-lithospheric thermal incubation below the mega-continent Pangea.

MS07 : THpm29 : F6 Evidence for a Mantle Plume beneath Kasachstan

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We present results from seismic tomography and geodynamic modelling that support the idea of a mantle plume beneath Kasachstan, which has previously been postulated because of a heat flow anomaly of about 65 mW/m² on a background of about 45-50 mW/m², and 500-1000 km across, centered a few hundred km north of the Caspian Sea (e.g. Christoforova et al., 1995).

Seismic tomography shows a slow anomaly resembling a tilted plume rising from the CMB up and towards the East to a depth of about 1000 km. The plume location at that depth would be about beneath central Kasachstan. However in the mid-mantle the anomaly is rather weak and not well resolved, and there is a very broad slow anomaly in the upper mantle beneath the lithosphere, such that no tilt can be determined there. The predicted shape of a plume conduit that is tilted and distorted in large-scale mantle flow is qualitatively in accordance with this: If the plume location beneath the lithosphere is assumed at the center of the heat flow anomaly, the predicted location in the mid-mantle is a few hundred km further to the East to Northeast, and the predicted source location at the CMB is a few hundred km West to Northwest of the mid-mantle location (the latter prediction being more robust). The global mantle flow models are based on models of seismic tomography, assuming that wavespeed anomalies represent density anomalies. The flow models were also used to compute how heat entering from the core gets advected within the thermal boundary layer at the base of the mantle. Our results indicate that a positive thermal anomaly should exist in the lowermost mantle beneath Kasachstan and Russia, which is thus a likely location for a plume source. This is in agreement with tomographic models of D", which see a slow anomaly in that region (Castle et al., 2000). Our predicted thermal anomaly pattern is globally highly correlated with seismic D" velocities.

Each of these point of evidence by itself is not convincing, however we believe that the combination makes a strong case for a subcontinental mantle plume. We have also computed a compressive lithospheric stress anomaly in that region, based on forces acting on the lithosphere from mantle flow and from within the lithosphere. This may help to explain the absence of surface volcanism.

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MS07 : THpm30 : F6 Characteristics of a Thermal Boundary Layer at the Core-Mantle Boundary Inferred from Numerical Models of Convection

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Using the results of a recent numerical model of convection, we estimate the thickness of an eventual thermal boundary layer at the bottom of the mantle. The model of convection considers a strongly temperature-dependent viscosity fluid heated from below, and was used to study the stability of a lower thermal boundary layer (Deschamps and Sotin, 2000). This resulted in scaling laws relating the thermal, rheological and physical properties of the mantle. We investigate the influence of important parameters including temperature at the core-mantle boundary, viscosity of the lower mantle and activation energy of the viscosity law. Depending on the values of these parameters, the thickness of the thermal boundary layer yields between 25 and 70 km. These values are small compared to the usual estimations for the thickness of the D" layer, suggesting that the D" layer is more complex than a thermal boundary layer. This conclusion agrees with previous seismological studies (e.g. Nataf and Houard, 1993). In addition, we perform a similar approach to estimate the amount of heat that can be transferred through the thermal boundary layer (and therefore through the mantle). We find that the total power is in the range 1-6 TW. Such values are consistent with values required for the dynamo to operate and with the hypothesis that the top of the outer core may transfer heat by conduction (Labrosse et al., 1997).

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MS07 : THpm31 : F6 New Evidence for Baby-Plumes beneath Central Europe: Comparing the Massif Central and the Eifel Plume Tomographic Images

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In recent years seismic tomography has proven to be a veritable tool in searching for plume structures (see the review article by Nataf, 2000, for details), one of them being a small-scale plume beneath the Massif Central in Central France. The detection of this plume structure by means of tomographic imaging of the P-velocity perturbations caused by the uprising hot plume yielded in collaboration with other geophysical parameters, such as the Bouguer anomaly signal and the geothermal structure, and with studies on the distribution of basaltic volcanic zones across Europe and their geochemical signatures, the hypothesis of a common origin of the different oligocene to holocene volcanic zones of Central/Western Europe at a somewhere deeper level in the earths mantle and the existence of a number of "baby-plumes" (Granet et al., 1995).

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It as well triggered a series of subsequent seismic projects, the largest of them being the so called EIFEL PLUME project, to search for these baby-plume structures and their possible origin.

In our presentation we will give new evidence for the existence of baby-plumes by comparing the images of two continental plume structures beneath the Massif Central and the Eifel region in Germany.

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MS07 : THpm32 : F6 Constraints from the Geochemistry and Thermometry of Coarse-Grained Peridotite Xenoliths on Plume-Subcontinental Lithospheric Mantle Interaction beneath French Massif Central

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Extensive volcanic activity in the Massif Central (France) has entrained a large number of mantle-derived peridotite xenoliths. Several geophysical observations indicate that this volcanic activity is related to upwelling of a small-scale mantle plume as has been also postulated for other Cenozoic volcanic areas in Europe. Mantle xenoliths in Massif Central constitute a unique opportunity to investigate geochemical and thermal evolution of the Subcontinental Mantle Lithosphere (SCLM) during its interaction with a mantle plume, in both time (60 Ma to Quaternary) and space ($> 2 \times 10^4$ km²). The quantitative textural study reveals the presence of two groups of coarse-grained xenoliths in Massif Central, located respectively in volcanic centers north and south of latitude 45° 30'. The peridotite xenoliths of the northern domain show protogranular textures, whereas peridotites of the southern domain are devoid of pyroxene-spinel clusters. In agreement with textural variations, the geochemistry of xenoliths defines two contrasting spatial domains. The peridotites in the northern domain are rather refractory and depleted in MREE relative to HREE, but pervasively enriched in LREE and LILE. They show normalized patterns with negative anomalies of Nb, Ta, Zr and Hf relative to LILE and REE. Xenoliths from the southern domain are distinguished by more fertile compositions and relatively flat MREE-HREE patterns. Most lherzolites in this domain are depleted in LREE and LILE. The compositional differences between peridotites of the two domains cannot be accounted for by plume upwelling nor compositional layering of the SCLM. To some degree, their compositional differences are reminiscent of those observed between circumcratonic and cratonic SCLM domains. We ascribe their geochemical differences to the existence of two different lithospheric SCLM blocks accreted during the Variscan orogeny. Seismic tomographic studies indicate that asthenospheric upwelling beneath Massif Central is focused beneath the southern domain and follows a NW-SE trend parallel to Variscan crustal structures. The thermometric study of coarse-grained xenoliths reveals a remarkable regional coherence between the thermal record of xenoliths and seismic tomographic evidence for plume upwelling. Pyroxenes in peridotite xenoliths from volcanic centers located along the NW-SE trend record heating from lithospheric conditions to quasi-asthenospheric conditions. Peak temperatures in xenoliths decrease as a function of the distance to this NW-SE trend, as it would be expected from a two-dimensional conductive profile imposed by a tabular plume emplaced along this trend. Because this trend roughly coincides with the boundary of the two compositionally distinct SCLM domains, it is conceivable that it corresponds to a former mechanical boundary between these domains. Hence, the enhanced heating recorded in xenoliths along this trend leads us to suggest that the inherited 'architecture' of the SCLM may have played a critical role during Cenozoic plume-lithosphere interaction by somehow channeling plume upwelling through this boundary.

MS07 : THpm33 : F6 Spatial and Temporal Variations in Lithospheric Mantle above the East African Mantle Plume- Geochemical Evidence from the Mt. Meru/Mt. Kilimanjaro Region, N. Tanzania

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Temporal variations in the compositions of Quaternary magmas in northern Tanzania primarily reflect the diverse style of metasomatic enrichment that occurred within the lithospheric mantle, as a consequence of the southward propagation of the East African Rift (EAR) over a plume head. Low β factors (~ 1.2) and thick lithosphere preclude a significant amount melt generation in the convecting mantle beneath this part of the EAR.

The earliest plume-related volcanism in northern Tanzania occurred between 8 and 2 Ma. This is represented by regional flood lavas and volcanic centres, such as Monduli and early activity at Mt. Kilimanjaro. These magmas are mildly alkaline and volatile-poor. Fractionated heavy rare-earth element ratios (e.g. $[\text{Dy}/\text{Lu}]_n = 2$ to 2.5) and relative depletions at Ti, Rb and K (e.g. $[\text{K}/\text{Nb}]_n = 0.2$ to 0.4) on normalised multi-element plots are consistent with melting of a phlogopite/amphibole-bearing garnet peridotite source. This early phase of melting appears to have been generated by conductive heating of H₂O-rich metasomatic veins in the basal lithosphere (at depths up to ~ 150 km). Subsequent localised crustal extension at ~ 1.2 Ma immediately precedes the generation of small-volume silicate melts (ankaramites), which are characterized by relatively high Zr/Hf ratios. These ankaramites are typically associated with the eruption of carbonatite tuffs. Strongly alkaline magmas at Mt. Meru, and mildly alkaline magmas at Mt. Kilimanjaro, represent the most recent phase of volcanism (< 0.2 Ma) on the eastern flank of the EAR in northern Tanzania. The Meru lavas are characterised by similar compositions to giccochemical glasses that occur in peridotites from the nearby Olmani cone, and which are thought to represent partial melting in the presence of a CO₂-rich fluid (Jones et al, 1983).

The genesis of the Meru magmas requires wide-scale melting of CO₂-rich metasomatised lithosphere (~ 100 km) to produce the large volume (> 150 km³) of erupted magmas. This may have resulted from: 1) melting of lithospheric mantle that had recently undergone incipient metasomatism by CO₂-rich asthenosphere derived melts; 2) the percolation and advection of heat from asthenospheric melts into an 'ancient' layer of CO₂-metasomatised lithosphere; or 3) conductive heating of a CO₂-rich metasomatised layer by the anomalously hot mantle plume. Large-scale conductive heating of the lithosphere would, however, be too slow to melt a CO₂-rich layer at 100 km depth within a 150 km thick lithosphere. Melting of this layer may be more readily explained if the lithospheric mantle had been thinned by recent delamination. Such a process would have been facilitated by an increase in density due to pervasive volatile- and Fe-rich metasomatic melts.

Jones AP, Smith JV & Dawson JB, *J. Geology*, **91**, 167-178, (1983).

MS07 : THpm34 : F6 Rifting and Mantle Plumes in the Circum-Carpathian Area

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Mantle plumes associated with hot spots play an active role in rifting and initial phases of spreading. Several mantle plumes expressed by hot spot activities were involved in the spreading of the Neotethys branches during Mesozoic. The Jebel Mara hot spot during the Permian and Triassic time was located in the Eastern Mediterranean area where rifting occurred accompanied by Mid-Late Triassic extensive, alkaline basalt flows known from Levant to Morocco. The rifting was followed by sea-floor spreading recorded by Triassic Mamonnia ophiolites. The Erastothenes Seamount could also be the hot spot product. The Afar, Comores, Reunion, and St. Paul hot spots could be associated with the rifting and drifting along the Arabian and Indian margin, accompanied by alkaline to transitional magmatism. These hot spots could be an expression of

mantle upwelling that was one of driving forces of the Cimmerian plates drifting from Gondwana to Eurasia. This force could explain systematic migration of continental blocks from the southern to the northern side of Tethys and the associated asymmetry of this part of Tethys, bounded by passive margins to the south and active margin to north. The Tibesti hot spot could be connected to Pyrenean rifting in later and volcanism could mark the southern part of Ligurian Ocean. In the Western Carpathian area the Trogocina porphyritic andesite could be a volcanic expression of the Jurassic disintegration of the southern margin of the North European Plate which became later the site of the Outer Carpathian rifting. It could represent an early stage of the hot spot activity in this area. The next stage of volcanic activities occurred in the Western Carpathians during Hauterivian-Barremian time. The teschenites intrusions display the features of mantle plume volcanism and were perhaps generated by a hot spot activity. In the Eastern Carpathians the Jurassic andesite tuffites could be an expression of the early stage of the hot spot volcanism while diabase-melaphyre within the 'black flysch' of the Eastern Carpathians represent the later stage. It looks like there were two hot spots in the Carpathian region. The first one, in the Western Carpathians was connected with the Jurassic Trogocina andesites and Early Cretaceous teschenites. Today, the Western Turkey and Northern Aegean volcanics are located at the same latitude and longitude. The second hot spot, in the Eastern Carpathians was connected with the Early Cretaceous diabase-melaphyre. Today, the Levantine (e.g., Dead Sea) hot spot volcanics are located at the same latitude and longitude. These two mantle plumes played an important active role in rifting and formation of the Outer Carpathian basin.