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Trace elements and Sr–Nd–Pb isotopes of K-rich, shoshonitic, and calc-alkaline magmatism of the Western Mediterranean Region: Genesis of ultrapotassic to calc-alkaline magmatic associations in a post-collisional geodynamic setting

Sandro Conticelli [a,b,*], Luisa Guarnieri [a], Alice Farinelli [a], Massimo Mattei [c], Riccardo Avanzinelli [a,1], Gianluca Bianchini [d], Elena Boari [a], Simone Tommasini [a], Massimo Tiepolo [e], Dejan Prelević [f], Giampiero Venturelli [g]

[a] Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Via Giorgio La Pira, 4, I-50121, Firenze, Italy
[b] Istituto di Geoscienze e Georisorse, U.O. Firenze, C.N.R., Via Giorgio La Pira, 4, I-50121, Firenze, Italy
[c] Dipartimento di Scienze Geologiche, Università degli Studi di Roma Tre, Largo S. Gesualdo Murialdo, 1, 00146, Roma, Italy
[d] Dipartimento di Scienze della Terra, Università degli Studi di Ferrara, Campo Universitario, Via Giuseppe Saragat, 1, Ferrara, Italy
[e] C.N.R. — Istituto di Geoscienze e Georisorse — U.O. di Pavia, via Ferrata 1, Pavia, Italy
[f] Geowißenshaften Institut, Johannes Gütemberg Universität, Becherweg, 7, Mainz, Germany
[g] Dipartimento di Scienze della Terra, Università degli Studi di Parma, Campus Universitario, Parma, Italy

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ABSTRACT

High-MgO ultrapotassic rocks are found in four different areas of the Western Mediterranean basin associated in space and time with shoshonitic and calc-alkaline rocks. They represent different magmatic events at the active continental plate margin from Oligocene to Pleistocene. These rocks are found within the Western Alps (Northern Italy), in Corsica (France), in Murcia-Almeria (South-Eastern Spain), and in Southern Tuscany (Central Italy). Ultrapotassic terms are mostly lamprophyres, but olivine latitic lavas with a clear lamproitic affinity are also found. Lamproite-like rocks range from slightly silica under-saturated to silica over-saturated, and they are characterised by low Al_2O_3, CaO, and Na_2O contents. They are plagioclase-free rocks, but K-feldspar is abundant beside other K-bearing phases. Shoshonitic and calc-alkaline rocks are invariably space associated to lamproites, and they either precede or follow them. High-Mg ultrapotassic rocks are characterised by strong enrichment of incompatible elements, which prevent further enrichment due to shallow level crustal contamination. K_2O and incompatible element contents decrease passing from high-Mg ultrapotassic to high-Mg shoshonitic and calc-alkaline rocks suggesting that K and incompatible trace elements enrichments are a primary characteristic. Ultrapotassic to calc-alkaline rocks from Western Mediterranean regions, in spite of their different age of emplacement, are characterised by similar incompatible trace elements distribution. Depletion of High Field Strength elements with respect to Large Ion Lithophile elements is observed. Positive spikes at Th, U, and Pb, with negative spikes at Ba, Nb, Ta, Sr, P, and Ti, are common characteristics of ultrapotassic (lamproitic) to high-K calc-alkaline rocks. Ultrapotassic rocks are extremely enriched in radiogenic Sr and unradiogenic Nd with respect to the associated shoshonitic and calc-alkaline rocks. Different isotopic values are distinctive of the different magmatic provinces irrespective of magmatic affinities. $^{87}Sr/^{86}Sr_i$ ranges between 0.71645 and 0.71759 for Western Alps lamproites, between 0.71226 and 0.71230 for Corsica lamproite, between 0.71642 and 0.72259 for Murcia-Almeria lamproites, and between 0.71578 and 0.71672 for Tuscany lamproites. Radiogenic Sr decreases along with K_2O through shoshonitic to calc-alkaline rocks. Conversely $^{143}Nd/^{144}Nd_i$ values increase with decreasing K_2O, with the highest value of 0.51243 found for the one samples from Murcia-Almeria. Contrasting trends are observed among initial values of lead isotopes, but all falling well within the field of upper crustal rocks. Different trends of $^{207}Pb/^{204}Pb_i$ and $^{208}Pb/^{204}Pb_i$ vs. $^{206}Pb/^{204}Pb_i$ for samples from the different provinces are observed. Several evidences indicate that most of the magmas of the different provinces have been generated in a depleted upper mantle (i.e., lithospheric) modified by metasomatism, but an asthenospheric component is also recognised in Corsica. At least two different subduction-related metasomatic agents re-fertilised the depleted original upper mantle source. Carbonate-free siliciclastic sediments and carbonate-rich sediments have been recycled within the upper mantle through subduction and partial melting. Assuming that metasomatic component is concentrated in a vein network, in Tuscany and Corsica, time relationships

* Corresponding author. Dipartimento di Scienze della Terra, Università degli Studi di Firenze, Via Giorgio La Pira, 4, I-50121, Firenze, Italy.
E-mail address: sandro.conticelli@unifi.it (S. Conticelli).
[1] Now at: Department of Earth Sciences, University of Bristol, Bristol, UK.

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indicate that low degree of partial melting of the pure vein produced lamproitic-like magmas, whereas an increase in the partial melting involve the surrounding upper mantle, then diluting the alkaline component and produced the entire spectra of magma observed. In South-Eastern Spain calc-alkaline magmatism preceded lamproitic ones, and might be generated by partial melting of mantle wedge metasomatised by fluids from oceanic slab prior to collision. Lamproitic magmas followed after melt-dominated metasomatic agents invaded the lithospheric upper mantle domain. Migration of the magmatism with time is the result of eastward migration of subduction with subsequent opening of Balearic, Ligure-Provençal, and Tyrrhenian basins.

1. Introduction

K_2O enrichment is one of the most striking features of the mostly Mio–Pliocene to present time subduction-related volcanic rocks in the Western Mediterranean (Savelli, 2002, and references therein), with few Oligocene volcanic rocks in the Western Alps (Venturelli et al., 1984a). The increase in K in orogenic magmatic associations is a common characteristic of Mediterranean volcanic rocks. Indeed it is also found in the Aeolian Arc (Francalanci et al., 2007, Tommasini et al., 2007 and references therein), in the Balkan Peninsula (e.g., Altherr et al., 2004; Cvetković et al., 2004a; Prelević et al., 2008, and references therein), in Anatolia (e.g., Francalanci et al., 2000; Agostini et al., 2005; Innocenti et al., 2005) and at a minor extent in the South Aegean Volcanic Arc (e.g., Francalanci et al., 2005). Ultrapotassic rocks in the Mediterranean area are silica saturated, lamproites, and silica under-saturated, kamafugites/leucitites. Sometimes leucite-bearing lamproites are also found (Venturelli et al., 1991a).

It is generally accepted that alkaline K-rich magmas in the Mediterranean have been produced by partial melting of a depleted peridotite modified by metasomatism (e.g., Thompson, 1977; Dal Piaz et al., 1979; Venturelli et al., 1984a; Peccerillo et al., 1988; Foley and Venturelli, 1989; Conticelli and Peccerillo, 1992; Conticelli, 1998; Peccerillo, 1999; Prelević and Foley, 2007; Prelević et al., 2008). K-rich metasomatising agents permeating and reacting with depleted peridotitic mantle may cause local refertilisation, thus producing veins of clinopyroxene/amphibole/phlogopite minerals at the expense of olivine and orthopyroxene (e.g., Sekine and Wyllie, 1982; Foley, 1990, 1992; Conceição and Green, 2004). Partial melting of the diverse vein mineralogy produces high-Mg K-rich magmas with different degrees of silica saturation/under saturation. Magmatic rocks of mantle origin generated during continental collision are common in the Western Mediterranean Basin (Fig. 1). Among ultrapotassic rocks Barton (1979) and Foley et al. (1987) recognised at least three different groups of rocks characterised by different contents of CaO, Na_2O, and Al_2O_3, which are reflected in a different mineralogy. In the Western Mediterranean all the different types of ultrapotassic rocks crop out. Kamafugitic and leucititic ultrapotassic rocks, however, are confined in the Roman Magmatic Province and in very recent times, from the Pleistocene to Holocene (Conticelli et al., 2004, and references therein), and their possible genesis and relationships with calc-alkaline rocks are extensively discussed by Avanzinelli et al. (2008).

Ultrapotassic rocks from Western Mediterranean are generally interpreted as subduction-related: Alpine subduction, “south-south-eastward”. Dipping beneath Africa–Adriatic plates (e.g., Doglioni et al., 1999; Peccerillo and Martinotti, 2006) and Apennine subduction, north-north-westward dipping beneath the Eurasian plate (Peccerillo and Turco, 2004). Alternatively, a plume-related genesis is suggested to account for the isotopic characteristics of the overall magmatic rocks found in the Central Mediterranean region (Gasperini et al., 2002; Bell et al., 2004). In detail in Central-Southern Italy the spatial isotopic variations have been variously interpreted (e.g., Hawkesworth and Vollmer, 1979; Conticelli et al., 2002; Bell et al., 2004; Martelli et al., 2004; Avanzinelli et al., 2008) causing scientific debate about some major issues: 1) the genesis of the high-Mg variably K-enriched silica-saturated magmas; 2) the processes involved in diluting the alkaline component passing from high-Mg ultrapotassic to high-K calc-alkaline and calc-alkaline s.s. associated magmas; 3) the geodynamics of the Western Mediterranean that may account for the mechanism for mantle metasomatism and magma generation.

To shed some light on these issues we focus attention on four magmatic provinces of the Western Mediterranean area. In this region ultrapotassic rocks with lamproitic affinity are associated, spatially and temporally, to shoshonitic, high-K calc-alkaline and calc-alkaline rocks. Samples from Western Alps (Northwestern Italy), Corsica (France), Murcia-Almeria (South-Eastern Spain), and Tuscany (Central Italy) (Fig. 1) have been collected. New high precision trace elements and Sr, Nd, and Pb isotopic data have been performed to compare a homogeneous data set to avoid possible laboratory bias. The geochemical and isotopic data are supplemented with petrology and discussed in the frame of the structural geological, seismic tomography and palaeomagnetic data pertinent to constraint the geodynamics of the Region.

2. Geodynamic framework of the Western Mediterranean

The geologic setting of the Mediterranean region is the result of a complex geodynamic history due to the different velocities of movement of Africa and Eurasia plates. This brought to the convergence of the two plates with formation in the Western Mediterranean of arcuate mountain belts and extensional back-arc basins (Horvath and Berckheimer, 1982; Dewey et al., 1989). Since 35 Ma, convergence has been achieved by continuous subduction processes (Doglioni et al., 1999; Rosembaum et al., 2002; Faccenna et al., 2004), whose slabs are well imaged by seismic tomography and deep seismicity (Wortel and Spakman, 2000).

Geodynamic models indicate that about 30–35 Ma ago, the subduction plane was located along the Iberian margin, between the Apennines and Gibraltar. Since that time, the tectonic evolution of the area has been characterised by the differential backward motion of the subduction trench. This backward motion induced the formation of the Liguro-Provençal (30–16 Ma) and Tyrrhenian (12–1 Ma) back-arc basins on the top of the Ionian slab, and of the Alboran basin (Lower Miocene) on the rear of the Gibraltar arc. The back-arcs opening has been coeval with the progressive bending of the Gibraltar and Calabrian arcs and with the formation of the northern Apenninic arc, on the front of the northern Tyrrhenian Sea basin. The bending processes of such arcs has been proved in detail by a large amount of paleomagnetic data, which show systematic, opposite, vertical axis rotations along the two arms of the arcs (e.g., Lonergan and White, 1997; Platt et al., 2003; Mattei et al., 2004, 2006, 2007; Cifelli et al., 2007, 2008).

The Gibraltar Arc represents the westernmost segment of the Alpine–Mediterranean Belt. The arc is formed by the Rif (North Africa) and the Betic Cordillera (Southern Spain) fold-and-thrust belt, with his associated foredeep and foreland basins along its outer margin (Guadalquivir Basin and Gharb basin in Spain and Morocco respectively). Extensional tectonics started during early Miocene times forming sedimentary basins in the internal part of the Betics and Rif, and in the Alboran Sea (Watts et al., 1993; Comas et al., 1999). During