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Origin of "ultra"-rocks

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1 Introduction and state of the art

Despite decades of investigation, the origin and evolution, as well as the genetic relationship among exotic igneous rocks such as carbonatites, kimberlites, kamafugites, melilitites and ultramafic lamprophyres are still matter of debate [1]. Several are the hot topics about "ultra"-rocks. With such a term I refer to compositions poor in felsic minerals (i.e., foids, feldspars and/or quartz), such as ultramafic rocks. These usually are characterized by ultrabasic chemical compositions (e.g., SiO_2 <45 wt%), but a direct link between ultrabasic and ultramafic compositions cannot be automatically drawn. Also the origin and classification of ultralkaline magmas, i.e., rocks with particularly high Na_2O+K_2O content independently from the degree of evolution (i.e., SiO_2 and MgO) are lines of investigation worth of interest. Among these, the classification of ultrapotassic products has always represented a major problem [2], considering that they group lithologies ranging from strongly SiO_2-undersaturated (e.g., with modal and/or CIPW normative leucite) to SiO_2-oversaturated (i.e., orthopyroxene-bearing), with ultrabasic to intermediate compositions. The definition of rigorous and standard guidelines has not yet been reached, especially for lamprophyres, lamproites, kimberlites and kalsilite-bearing rocks. What emerges is the presence of different classification schemes and genetic models proposed in literature, resulting in a confuse framework of investigation. This lack of clearness in the classification of the "ultra"-rocks, with variable alkali content and K_2O/Na_2O ratios, led to more enigmatic interpretations of their genesis and petrological history. The deciphering of the possible petrogenetic connection among carbonatites, kamafugites, lamprophyres, foidites, mela-nephelinites and melilitites still deserves a detailed investigation.

Several studies have been conducted on ultramafic volcanic rocks. Ultramafic lamprophyres are uncommon but are widespread worldwide as hypabyssal rocks and generally linked with continental rift settings, such as in Antarctica [5, 12, 13] and Labrador [14, 15]. The sources for these magmas have been identified in a peridotitic matrix with veins of phlogopite and carbonate [5]. Kamafugites have been recorded in Italy [2, 16, 17, 18, 19, 20, 21, 22], SE Brazil (Alto Paranaiba) [23, 24, 25], the western branch of the East Africa Rift System (Toro Ankole and Virunga) [26, 27, 28, 29]. Also in this case, a common petrogenetic model to fit the compositions of all the products from the different localities has not yet been proposed. The kamafugites from San Venanzo and Cupaello are characterized by different chemical and isotopic features with respect to their Ugandan and Brazilian counterparts [2]. The complete absence of olivine and the very abundant modal clinopyroxene of Cupaello kamafugites make these rocks different from the olivine-rich and clinopyroxene-poor kamafugites of San Venanzo, requiring different petrogenetic processes, not yet understood. The ultrabasic products from San Venanzo are nearly indistinguishable from leucitites, plagio-leucitites and lamproites found in Italy in terms of incompatible element budget. The connection between venanzites and coppaelites with compositions rich in lime (classified in literature either as true carbonatites [30] or as pseudo-carbonatites [2]) increases the complexity of the system. To increase the confusion, rocks defined as lamproites do not match the required characteristics proposed in literature (e.g., [31]), with the proposed chemical classification schemes not always matching the mineralogical constraints accepted by IUGS. Once defined the rules according which the compositions (both mineralogical and geochemical, including specific petrographic characteristics) of specific igneous rocks can be associated to a given rock group, it remains to propose the petrogenetic aspects, also in connection with geodynamics. Complex models that involve ancient subduction-related modifications, coupled with variable degrees of interaction of ultrabasic melts generated by a carbonated peridotite with sedimentary carbonates, increase the difficulty to propose a general petrogenetic model [2, 32].

The geodynamic settings and the relation between basaltic magmatism and tectonic processes have been object of studies for decades and today it is more or less properly understood. Unfortunately, this approach cannot be extended to the much rarer non-basaltic primitive magmas found in very different tectonic settings [33, 34, 35, 36, 37].

2 Aim of the work

The general aim of the project is to propose a petrological model to explain the origin of different ultrabasic and/or ultralkaline (including ultrapotassic variants) rocks (kamafugites, ultramafic lamprophyres, melilitites, leucitites, mela-nephelinites and similar exotic compositions). These magmas, often volatile-rich, are commonly associated to high amounts of carbonate material of not certain origin, alternatively interpreted as carbonatites, pseudo-carbonatites, hybrid carbonate-silicate magmas or endo-exo-skarns. A deeper comprehension of the mantle source features and the processes responsible for the generation of these quite rare – but often economically important – lithologies is highly required. In particular, the definition of specific terms and the choice of mineralogical, geochemical or geo-tectonic tools to use need profound rethinking. The specific object of this project is a petrological, geochemical and isotopic comparison between products from different sampling sites (Italy, Uganda, South Africa, Antartica, Canada and Brazil) that will be used to highlights similarities, if present, that could be useful to reach the general petrogenetic model.

3 Planned research activities

The research will be focused on exotic rocks coming from several worldwide localities. Samples from Uganda, Antarctica and Brazil are already available because collected in previous field trips by foreign research groups with whom I will work (see below). All these samples, together with the ones already available from the Italian ultrabasic localities (San Venanzo, Cupaello and Polino), are more than adequate to provide a valid petrological model. An additional fieldwork activity in San Venanzo and Cupaello will be probably needed to collect more samples to complete the database. Other possible Italian areas of investigations comprise Vulsini Mts. (Montefiascone melilitites and kalsilite-bearing melilitolites) and the scattered outcrops of ultrabasic tuffs dispersed within the central axis of Apennine Mts.

The study will adopt a multidisciplinary approach, based on major oxide and trace element study, mineral chemical investigation (including EMP and LAM-ICP-MS), isotopic investigation of several systematics (Rb-Sr, Sm-Nd, U-Th-Pb, Lu-Hf, Re-Os, He, Ar, Ne, Xe), all based on detailed petrographic investigation.

A strong point of the present project is the collaboration with prof. Stephen Foley of the McQuarie University of Sydney (Australia). The present project on the Italian volcanic rocks is already framed in a research cooperation with colleagues of CNR-IGG of Pisa (dr. Samuele Agostini) and INGV of Palermo (dr. Antonio Caracausi) on Sr-Nd-Pb isotopic systematics and He-Ar-Xe noble gas isotopes, respectively. Under investigation is the possibility to start also a Mg isotopic study in collaboration with Di-Cheng Zhou of Beijing (China University of Geosciences).

The project includes the study of natural samples but also many petrological innovative experiments, that will be carried out during the second and the third year, under high-pressure conditions, to outline possible similarities or differences between several type compositions (e.g., the Italian and Ugandan kamafugitic magma). About 30 experimental petrology runs are scheduled with specific starting compositions at constrained P-T- fO_2 conditions. The McQuarie University of Sydney will provide new rapid-quench piston-cylinder apparatuses, with extra cooling channels, to optimise quenching of volatile-rich melts in experiments, allowing a better characterization of melt compositions, relevant to CO_2-rich conditions (pressure from 0.5 to 3 GPa). HP-HT facilities are already available or are scheduled to arrive soon at the Dipartimento di Scienze della Terra of Sapienza University.

4 Bibliography

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