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Bruno Scaillet

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Guest editor: Bruno Scaillet (Institut des Sciences de la Terre d'Orléans, CNRS, France)

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Perspectives on alkaline magmas / *Perspectives sur les magmas alcalins*

Perspectives on alkaline magmas

Bruno Scaillet [a]

[a] Institut des Sciences de la Terre d'Orléans, UMR 7327, Université d'Orléans-CNRS-BRGM, 1a rue de la Férollerie, 45071, Orléans, France
E-mail: bruno.scaillet@cnrs.fr

Although volumetrically minor on Earth [e.g. Marks and Markl, 2017], magmas rich in alkalies are actively studied for several reasons. One is that they represent a significant component in the building of many volcanic islands, notably those related to active hotspot settings [e.g. Jeffery and Gertisser, 2018], hence a threat for those islands which are densely populated. The study of such islands offers also a unique geochemical window into the functioning of deep seated structures (in the lower mantle) that ultimately feed many of these oceanic volcanoes [e.g. Moreira et al., 2012]. Alkali magmas are similarly abundant in the intermediate stage of rift-related settings, and perhaps the best example of such an occurrence is nowadays represented by the East African rift zone [e.g. Macdonald, 2002]. There, besides the volcanic hazards associated with active alkali magmatic centres [e.g. Biggs et al., 2011], interest in their study comes from the geothermal energy they fuel [Varet, 2020]: such a C-free and local source of energy is actively exploited in countries hosting the rift zone, such as Kenya or Ethiopia, to the benefit of their populations.

Another socio-economic reason is that alkali magma series end with fractionated products notoriously rich in many rare metals (Nb, Ta, ...) which are vital for the functioning of modern societies (https://eos.org/science-updates/geological-surveys-unite-to-improve-critical-mineral-security).

But why it is so? Peralkaline rhyolites, termed comendites or pantellerites, and possibly many of their undersaturated counterparts (phonolites sensu latto), are largely believed to be the by-products of extensive (>80%) basalt fractionation [Macdonald et al., 2021a], carrying with them all elements not easily incorporated in the structure of the main rock-forming minerals. The excess of alkalies over alumina (i.e., peralkaline) that typifies oversaturated and most undersaturated alkaline felsic magmas, is a key contributing factor that boosts the potential of the silicate melt to accommodate many elements (ions having high field strength or large radius), which are otherwise excluded from its structure (such as it happens in metaluminous liquids). This chemical effect induces an equally important physical one: the excess of alkalies is indeed known to decrease the viscosity of silicate melts [Dingwell et al., 1998], which facilitates melt segregation processes, hence the potential for the system to isolate sizeable metal-rich bodies. Along the same line of reasoning, the propensity and capacity of alkali magmas to concentrate climate affecting species, such as halogens or sulphur [Scaillet and Macdonald, 2006], is also a major reason to study them so as to quantify the volatile yields into the atmosphere of their eruptions, and their short to long term environmental impact [e.g. Oppenheimer, 2003].

When the parental basalt is rich in alkalies, it typically gives rise to phonolite magmas as common felsic derivatives. In general, the richness of the parental basalt in alkalies reflects the largely incompatible behaviour of alkalies during the incipient stages of partial melting of a "normal" mantle. But it is worth noting that it can be also due to the metasomatism of the same mantle (leading to its enrichment in alkalies) by a geodynamic process, such as subduction. Possible examples of the latter process include the threatful Vesuvius–Campi Flegrei or Tambora volcanoes [Cioni et al., 1995, Orsi et al., 1996, Self et al., 2004], which, though related to a subduction context, have produced abundant evolved alkali magmas (phonolite–trachyte), in sharp contrast to common convergent zones whose prevailing magmatic output is characterized by the andesite–dacite–rhyolite subaluminous association.

In some instances at least, the fractionation towards undersaturated derivatives can go a step further, producing carbonatites, possibly via immiscibility with a silicate melt [Hamilton et al., 1979]: hence, this magmatic series is characterized by a binary end point, so to speak, and not by the phonolite eutectic alone as a cursory look of the petrogeny residua system would suggest: for that reason (extensive fractionation), carbonatites may concentrate a bunch of industrially important elements, in particular the Rare Earth Elements (REE), that make these rocks so interesting. But carbonatites may equally represent the very first moment of mantle partial melting [e.g. Gaillard et al., 2008], being for that reason extremely enriched in some critical elements as well: having the same term to quote either the start or the end of an evolutionary process is a source of ambiguity, to say the least, and clearly of confusion for teaching. It underscores the limits of current terminology to classify rocks, and in any case their limited petrogenetic value, at least to anyone interested in putting numbers on the process (which temperature, which pressure, which water content, which $fO_2 \ldots$?). Save the grand categories, that is, a basalt will be almost always hotter than a rhyolite, simplifying rock terminology should be a general objective of future studies. A more fundamental reason to keep working on alkali magmas is their recent discovery as abundant rocks outcropping on the surface of Mars [Stolper et al., 2013], a planet free of plate tectonic motion as we know it on Earth, which therefore calls perhaps for a different mode of alkali magma production on the distant red body relative to what happens on our blue one.

Defining the conditions of alkali magmas production and evolution, that is, their pressure–temperature-redox path, their volatile and metal endowments, or their lifetime, is therefore essential to take full advantage of the beneficial aspects of this peculiar magmatism for what concerns its usage in our society, but also to understand the evolution of planets and rocky bodies populating the Solar system. In this special issue, some strands of the different aspects listed above are addressed or reviewed.

Macdonald et al. [2021a] report a detailed state of the art of the occurrence and petrogenesis of the quartz-saturated variety of the alkaline clan (comendite, pantellerite), reviewing *inter alia* the geodynamic context, mode of production and evolution till eruption of such magmas, using for that purpose all information available. Sautter and Payre [2021], provide an informative review of our current knowledge about the magmatic alkali rocks which have been revealed by orbiting spacecrafts or those scrutinized so far by the rovers/landers active on the surface of Mars, and the implications of these findings for magma production on Mars, as well as for the petrogenesis of Martian meteorites which were until recently the only accessible rocks of that planet. Maestrelli et al. [2021] take on a terrestrial tectonic perspective and review the relationships between the rift evolution and calderas in an area, the East African Rift, where the peralkaline rhyolites were first used by Norman L. Bowen, the father of modern igneous petrology, to propose a mechanism able to drive a liquid from a metaluminous towards a peralkaline condition [via the so-called plagioclase effect, Bowen, 1937]. More specifically, Maestrelli et al. [2021] look at calderas in the central portion of the Main Ethiopian Rift. These structures are the geomorphologic evidence left over by powerful, and devastating if they were to happen today, ignimbrite-forming eruptions. They are rooted into shallow reservoirs hosting peralkaline rhyolites, and their shape and orientation bear evidence, these authors conclude, of the intimate links existing between volcanism and tectonic in this area, but also of the possible role played by pre-existing tectonic structures on the architecture of plumbing systems feeding volcanoes in rift settings.

Rotolo et al. [2021] present the current state of knowledge of the volcanological evolution of the island of Pantelleria, where the term pantellerite was coined, in large part because more than 80% of rocks outcropping there is made of well pre-

Figure 1. Photograph of the 2021 Cumbre Vieja eruption at La Palma, Canary islands. The picture shows the land around the newly born cone covered by the tephra produced by the explosive fragmentation of the H_2O–CO_2–S-rich erupting alkali basalt (dark, ash-rich, clouds), and the same but more degassed basalt feeding a glowing lava fountain supplying a descending lava flow (Photograph by B. Scaillet).

served strongly peralkaline rhyolites. Their review of available geochronological data and field constraints on volumes of magma erupted led them to suggest that the volcanic activity at Pantelleria may well be on a waning trend. Jordan et al. [2021] review in turn the petrological and geochemical evidence of magma evolution in the reservoirs active beneath Pantelleria during the last 190 ky, where the pantellerites and associated trachytes were stored, stressing out the extensive fractionation process that such magmas require to be produced, as illustrated by the extreme enrichment (Zr, Nb, Cl…) or depletion (Sr, Ni,…) that some elements achieve. They also suggest that comendite and pantellerite liquids may signal different conditions of magma evolution, comendites reflecting deeper and more oxidized conditions than pantellerites. Stabile et al. [2021] focus on the determination of pre-eruptive conditions of those magmas, but also on what happens during their decompression in the conduit, both aspects being considered in light of available experimental constraints, highlighting the difference with the more viscous metaluminous rhyolites, notably with respect to the conditions leading to magma fragmentation during eruption.

Macdonald et al. [2021b] illustrate how a detailed mineralogical and crystallographical study can give information on processes of magma evolution, in this particular case mixing, using the example of the Gold Flatt Tuff, an extensive peralkaline ignimbrite sheet outcropping in Nevada, USA. In doing so, they report also the first occurrence of chevkinite-group minerals in a pantellerite: chevkinite is a Ti- and REE-rich mineral that reflects the extreme content in some elements (LREE) reached by these magmas and the authors suggest it may replace aenigmatite, another Ti-bearing silicate diagnostic of the peralkaline condition in evolved magmas. Khezerlou et al. [2021] study shows what can be learnt about the mantle source of some alkali magmas, by looking at mantle xenoliths brought up to the surface by alkali basalts from the Uromieh Dokhatar magmatic belt in NW Iran, which the authors show, may inherit their alkali character from a previous subduction event. Mollé et al. [2021] report new experiments bearing on the stability of bastnaesite, the main REE host mineral in carbonatites, concluding that this phase is most likely hydrothermal in origin, not magmatic. Similarly, Nabyl et al. [2021] provide experimental constraints on the partitioning of REE between carbonatites and conjugate silicate liquids, exploring in particular the role of F, Cl, or P. The experimental results lead the authors to conclude that these elements play no significant role on REE behaviour in carbonatites. France et al. [2021] use rocks erupted 11 ky ago by the only active carbonatite volcano on Earth, Oldoinyo Lengai in Tanzania [Dawson, 1964]. They document, via the study of melt inclusions hosted by nepheline, the coexistence of silicate and carbonate liquids, concluding that immiscibility is a long lasting process in the Oldoinyo Lengai reservoir, showing in addition that it operates over a significant temperature interval.

The two last papers of the volume bear on the volatiles cargo of alkali magmas. Jiménez Maria et al. [2021] have experimentally defined the solubility laws of water and CO_2 in alkali basalts from Tenerife in the Canary archipelago, which were emitted recently on that island, being similar in composition to those erupted nearby either at El Hierro island in 2011 or to that ejected by La Palma's current eruption (at this time of writing, Figure 1). The new experimental constraints allow the authors to get refined pressure estimates of magma storage regions of Canarian basaltic volcanism, which is an important piece of information in the context of volcanic hazard assessment. Finally, Romano et al. [2021] revisit the solubility of water in peralkaline rhyolite and trachyte melts, providing improved experimental constraints on this topic, in an effort to better define the pressure depth of the magma reservoirs feeding peralkaline felsic eruptions on the still active Pantelleria island and elsewhere.

The papers that constitute this special issue obviously do not cover all aspects of alkali magmas, but illustrate nicely the variety of concerns behind them and the diversity in approaches used to document, characterize, and ultimately understand this fascinating clan.

Conflicts of interest

Author have no conflict of interest to declare.

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