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Foreword

New aspects of magma storage and transfer

Magmatic processes have played, and still play, a key role in the evolution of Earth. Their surface manifestations via explosive eruptions that propel gases and ashes high into the atmosphere, or high-temperature geothermal fields that fuel power plants, continuously remind us that our planet is still active, striving daily to dissipate its internal energy via upward transport of hot material. Despite decades of intensive research, the largely hidden nature of source processes driving magmas has hampered our quantitative understanding of this phenomenon. Answering fundamental questions such as the lifetime of a magmatic system, the occurrence and style of the next eruptive episode of volcanoes still requires a wealth of assumptions or simplifications that almost always limit current model predictions to qualitative assessments at best.

This is why there exists a very active community worldwide whose purpose is to make progress in the field. Among the main issues at stake are the conditions attending the construction of magmatic systems (e.g., Scaillet et al., 2016). We know these conditions in sufficient detail to fill-up textbooks, but our level of knowledge falls short when sound modelling of magmatic processes is demanded. We know that magmas involve hot, partly or fully molten silicates, at temperatures generally ranging from 650°C to 1200°C, and we also know that magmas may hold considerable amounts of dissolved volatiles, particularly water and CO_2, whose abundances and exsolution largely dictate eruptive behaviour. Yet, the fact of accurately determining temperature and volatile contents, which exert a prime control on transport properties of magmas (viscosity, density), still remains a challenge in most instances. We know for sure that the molten lava comes from deep in the Earth, but how deep the magma sourced is, how long it stays at rest, or how much time it takes to travel towards the surface are open questions for many magmatic systems, even for those benefiting from detailed laboratory and field data, including geophysical surveys.

Factors controlling magmas, such as those mentioned above, vary within or across centres, and are strongly interrelated (i.e. the pressure control on volatile solubilities), making the elaboration of a unique model or answer difficult, if not illusory. The diversity of magma types and tectonic contexts, together with the likely influence of the latter on magma dynamics, call for an inevitably time-consuming approach on a case-by-case basis. One good illustration of our lack of detailed understanding of system functioning is the current debate on what is a magmatic system (e.g., Lundstrom and Glazner, 2016): field excursions across many granitic terranes reveal that magmas in the continental crust tend to amalgamate at rather restricted locations forming rather homogeneous plutons, which, for some, represent fossil reservoirs. However, the very existence of large magma reservoirs in the shallow crust has been called into question, in part because geophysical methods deployed in active volcanic fields have so far failed to reveal the existence of such large reservoirs of molten material. The ordinary view of a single level of magma accumulation is now challenged by the concept of trans-crustal magma system, in which magma accumulation develops almost everywhere across the crust, the chemical diversity of magmas being mostly acquired in the deep hot crust (Cashman et al., 2017). Robust petrological evidence for such an architecture is scant, however, and if any, it is merely available in broad outline and only for a restricted number of areas, which prevents the worldwide generalisation of that concept. The nature of the relationships between frozen plutons and active systems is difficult to establish because exposed intrusives represent the end-result of time-integrated processes, while volcanoes yield only discontinuous snapshots along this chain (assuming that plutons and volcanoes belong to the same chain). Altogether, the questions of where and why magma ponding in the crust occurs (shallow, deep, or everywhere), and how much of it is liquid at any given time (e.g., Bachmann and Huber, 2016), stand out as priority issues to be solved if progress is sought in the area.

The papers collected in this thematic issue of *Comptes rendus Geoscience* under the heading of Labex VOLTAIRE (see http://www.univ-orleans.fr/fr/osuc/news/granites-summer-school) illustrate some of the various ways the community is currently handling to answer the above questions. Rondet et al. (2019) have performed a series of phase equilibrium experiments on a representative rock coming from the Chaîne des Puys, which is host to the most

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recent volcanic manifestation in the French Massif Central. Their work exemplifies the use of experiments to set robust limits on critical parameters such as P, T, or the water content prior to eruption. They also shed light on fractionation mechanisms controlling the chemical evolution of magmas once at rest in the crust, revealing in this case the critical role of so-called minor phases (biotite) on liquid evolution. Pichavant et al. (2019) report detailed experiments on the role of calcium on the phase relationships of the haplogranite system. This system is known to be a good analogue of the chemical composition of residual liquids produced during the fractionation of metaluminous magmas. Recent work has suggested that the pressure effect on the haplogranite system, as documented by the pioneering work of Tuttle and Bowen (1958), can be used to infer the pressure evolution of Qz-saturated felsic melts, but debate has arisen over the role of components such as Ca on the phase relationships of the Qz–Ab–Af system. Pichavant et al. (2019) report new phase equilibria and related compositions that explore such an effect and suggest that caution is required when applying the available models, in particular those empirical, to infer the crystallisation pressure of Qz-saturated felsic compositions.

Pressure appears to be one of the most difficult parameters to constrain in magmatic systems, in particular when magmas evolve in the low-pressure range, say the first 10 kb, where the vast majority of (transient?) reservoirs feeding felsic eruptions are believed to lie. Unfortunately, most petrological geobarometers are associated with large errors, on the order of ±2 kb, which makes their application to shallow-crust processes rather impractical. Much effort has been thus dedicated to improving the reliability of petrological tools in recent years (e.g., Putirka, 2008). Erdmann et al. (2019) have made experiments on felsic magmas, focusing on the stability of titanite, a common accessory mineral of granites. They suggest that titanite occurrence and composition (its aluminium content) both depend on pressure, offering a new approach for constraining pressure conditions of frozen felsic intrusives: this is a valuable addition to the existing panel of barometric tools.

The conditions of magma production and evolution can be also tackled via numerical models, assisted by field observations and thermophysical data, which altogether permit a large-scale picture approach, such as the multimillion year thermal evolution of a partially melted crustal section. Vanderhaeghe et al. (2019) present the results of 1D numerical simulations aimed at modelling the thermal evolution of continental crust during the Archean eon. Their results suggest that the lower crust may have remained partially molten for several hundred million years in the early Earth, an admittedly thought provoking view that is likely to fuel further debate on the evolution of the continental crust.

Magma evolution is in large part governed by its ability to move, which depends on its density and viscosity. Yet, the viscous behaviour of polyphase suspensions such as magmas remains unclear, in particular how the percentage of crystals of a magmatic slurry affects viscosity. Arbaret et al. (2019) provide new experimental data on this topic, focusing their efforts on crystal-poor, or near-liquidus, magmas. Their results show that suspensions with about 15% crystal (volume) behave in a Newtonian fashion when sheared, owing to the absence of particle interactions. They also document that the fabric, or preferential orientation of anisotropic crystals, does record information about the conditions of magma flow, in particular the sense of shear. Both results are important, since they inform numerical models and help interpreting field observations.

This series of papers illustrates perfectly that nowadays the petrological community is firmly engaged in a quantitative evaluation of magmatic processes, in an approach that uses state-of-the-art experimental, analytical, or numerical tools, building upon but reaching well beyond the traditional practice of rock description and categorisation. The majority of first-order processes controlling the origin and evolution of magmas has already been identified. What is on the agenda now is to put figures on them so as to develop truly predictive models.

References

Arbaret, L., Bystricky, M., Launeau, P., et al., 2019. Crystal clustering in magmas: insights from HP–HT experiments. C. R. Geoscience 351 (8), 547–585.

Bachmann, O., Huber, C., 2016. Silicic magma reservoirs in the Earth's crust. Am. Mineral. 101 (11), 2377–2404.

Cashman, K.V., Sparks, R.S.J., Blundy, J.D., 2017. Vertically extensive and unstable magmatic systems: a unified view of igneous processes. Science 355 (6331) eaag3055.

Erdmann, S., Wang, R., Huang, F., Scaillet, B., Zhao, K., Liu, H., Chen, C., Faure, M., 2019. Titanite: a potential solidus barometer for granitic magma systems. C. R. Geoscience 351 (8), 551–561.

Lundstrom, C.C., Glazner, A.F., 2016. Silicic magmatism and the volcanic–plutonic connection. Elements 12 (2), 91–96.

Pichavant, M., Weber, C., Villaros, A., 2019. Effect of anorthite on granite phase relations: experimental data and models. C. R. Geoscience 351 (8), 540–550.

Putirka, K.D., 2008. Thermometers and barometers for volcanic systems. Rev. Mineral. Geochem. 69 (1), 61–120.

Rondet, M., Martel, C., Bourdier, J.-L., 2019. The intermediate step in fractionation trends of mildly alkaline volcanic suites: an experimental insight from the Pavin trachyandesite (Massif Central, France). C. R. Geoscience 351 (8), 525–539.

Scaillet, B., Holtz, F., Pichavant, M., 2016. Experimental constraints on the formation of silicic magmas. Elements 12 (2), 109–114.

Tuttle, O.F., Bowen, N.L., 1958. Origin of granite in the light of experimental studies in the system $NaAlSi_3O_8$–$KAlSi_3O_8$–SiO_2–H_2O. GSA Mem. Geol. Soc. Am. 74.

Vanderhaeghe, O., Guergouz, C., Fabre, C., Duchêne, S., Baratoux, D., 2019. Secular cooling and crystallization of partially molten Archaean continental crust over 1 Ga. C. R. Geoscience 351 (8), 562–573.

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