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Magma ascent and emplacement in a continental rift setting: lessons from alkaline complexes in active and ancient rift zones

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A key feature of continental rift evolution is the development of large chemically-evolved alkaline magmatic systems in the shallow crust. At active alkaline systems, for example in the East African Rift, the volcanic complexes pose significant hazards to local populations but can also sustain major geothermal resources. In ancient rifts, for example the Gardar province in Southern Greenland, these alkaline magma bodies can host some of the world's largest rare element deposits in resources such as rare earths, niobium and tantalum. Despite their significance, there are major uncertainties about how such magmas are emplaced, the mechanisms that trigger eruptions and the magmatic and hydrothermal processes that generate geothermal and mineral resources. Here we compare observations from active caldera volcanoes in the Ethiopian Rift with compositionally equivalent ancient (1300–1100 Ma) plutonic systems in the Gardar Rift province (Greenland).

In the Ethiopian Rift Valley we use InSAR and GPS data to evaluate the temporal and spatial evolution of ground deformation at Aluto and Corbetti calderas. We show that unrest at Aluto is characterized by short (3–6 month) accelerating uplift pulses likely caused by magmatic fluid intrusion at $\sim$5 km. At Corbetti, uplift is steady ($\sim$6.6 cm/yr) and sustained over many years with analytical source models suggesting deformation is linked to sill intrusion at depths of $\sim$7 km. To evaluate the validity of these contrasting deformation mechanisms (i.e. magmatic fluid intrusion and sill emplacement) we carried out extensive field, structural and geochemical analysis in the roof zones of two alkaline plutons (Ilímaussaq and Motzfeldt) in Greenland. Our results show that the volatile contents (F, Cl, OH and S) of these magmas were exceptionally high and that there is evidence for ponding of magmatic fluids in the roof zone of the magma reservoir. We also identified extensive sill networks at the contact between the magma reservoir and the overlying country rock. These new constraints on magma ascent and volatile ponding in alkaline plutonic systems complement the deformation mechanisms and conceptual models developed for active systems in the Ethiopian Rift. Volcanic-plutonic pairs are rarely considered together but these data demonstrate the power of using constraints from 'fossil' magma chambers to infer sub-volcanic processes at active complexes and vice-versa.