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Large-scale fluid movement through crustal rocks by transition porosity generation: Feldspar replacement reactions within the Larvik Plutonic Complex, SE-Norway

Karin Los (1), Rick Verberne (1), Oliver Plümper (1,2), Bjørn Jamtveit (2), and Håkon Austrheim (2)

(1) Department of Earth Science, Utrecht University, the Netherlands (karinlos91@gmail.com), (2) Physics of Geological Processes (PGP), University of Oslo, Oslo, Norway

Fluid flow through rocks transports heat and mass across the grain to tectonic plate scale. Fluids promote mineral reactions, redistribute elements to form ore deposits, cool the planet and form habitats for life. A fundamental understanding of fluid flow through rocks is central to interpreting geodynamic and geochemical interactions between the geosphere, hydrosphere and biosphere. Some geological systems are open to fluids, but the majority are nearly impermeable. Surprisingly though, even in rocks that are impermeable, evidence for widespread fluid-rock interactions are observed leading to the question: How can fluids migrate through vast amounts of initially impermeable rocks? Here we present work on the Larvik Plutonic Complex (SE-Norway) that provides an ideal natural laboratory to study fluid movement and feldspar re-equilibration reactions.

The Larvik Plutonic Complex shows fluid-rock interactions on tens of kilometres. In the field, this is observed as a colour change: the blue larvikite rock is (partly) replaced by red tønsbergite. On the grain scale, mineral replacement is visible as porous crystals surrounding larvikite feldspar relicts. Chemical analysis shows that the alteration is zoned, from non-porous larvikite feldspar at the core to porous albite and orthoclase at the rim. A possible explanation would be infiltration of several fluids; another possibility is a changing fluid activity for Na+ and K+, resulting in a front which shifts during the reaction. The mineral replacement looks pervasive, starting with fluid flowing around the grain boundaries over a long distance. This is followed by slower consumption of the old mineral; the degree of alteration varies throughout the area of interest. Locally, alteration is related to fracture zones with pseudotachylites, which are overprinted by fluids in the vicinity of feldspars.

Fluid flow and element mobilisation is controlled by an interaction between grain boundary diffusion and reaction front migration through an interface-coupled dissolution-reprecipitation process. Recent studies have shown the importance of this mechanism in fluid-rock interactions; it involves atomic scale bond-breaking and dissolution of the primary mineral followed by pseudomorphic precipitation of the new, porous phase. Porosity development is controlled by molar volume changes and relative solubilities of the reagent and product. The reaction proceeds by this porosity development, enabling fluid to remain in contact with the old phase at the reaction interface. In natural and experimental samples porosity can be evaluated based on three-dimensional reconstructed volumes across reaction interfaces.

Isocon diagrams are used to quantify element mobilisation. Surprisingly, major and minor element analysis show no large elements flux related to fluid flow. Although the appearance of the rock is strongly altered and a chemical change is observed over the reaction interface, the bulk rock composition has remained roughly constant.

Future work can study this discrepancy in the light of the nearby found ore deposits. Fluid origin can be determined using isotopic signatures of reagent and reactant, and lithium isotopes can be analysed for reaction speed and duration.