5.4.14

Skaergaard liquid line of descent revisited

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There is a fundamental conflict between the expectation that the iron contents of Skaergaard liquids increase during Fe-Ti oxide fractionation [1] and the observation that at the same time f_{O2} drops by two log units below FMQ [2]. We address this conflict using forward modeling based on new experimental results and constraints from Skaergaard gabbros. The modeling predicts that fractionation of LZa troctolitic gabbro drives derivative liquids towards high iron content. Strong iron enrichment continues, together with a small decline in silica, during LZb crystallization due to the appearance of augite as a fractionating phase. The fractionation of Fe-Ti oxides in LZc suppresses the rate of iron enrichment and reverses the silica trend to one of enrichment. Continued evolution into UZa produces liquids with a maximum FeO^* of 21-22 wt. % and SiO_2 of 52-53 wt. % (FeO^* is total iron as FeO), while crystallization of UZb is associate with only a small decline in FeO^*. The maximum in FeO^* is dependent on several factors of which the oxygen fugacity (f_{O2}) and plagioclase modes have the strongest effects. Relatively high plagioclase modes in the solid fractionate will enhance the enrichment in iron prior to and during Fe-Ti oxide fractionation. However, this effect is unlikely to account for more than a few percent increase in FeO^*, considering the good correspondence between observed and experimental gabbro modes. Under closed system evolution incorporation of ferric iron into augite during formation of LZb restricts the increase in f_{O2} to ~0.1 ΔFMQ. Likewise, crystallization of LZc through UZa involving Fe-Ti oxide minerals leads to a decline of f_{O2} of less than 0.5 ΔFMQ. This behavior can account for the iron-rich character of MZ-UZ gabbros, as well as, their low modal content of Fe-Ti oxides (~15%). Thus, evolved Skaergaard liquids are indeed high in iron, but also high in silica. Our model does not account for the two-log-unit drop in f_{O2} relative to FMQ through the layered series, requiring an unacceptably high proportion of Fe-Ti oxides (>20 %) in the fractionating assemblage. This is inconsistent with both the phase relations and Skaergaard modal data, and as shown by [3] leads to a dramatic drop in FeO* immediately after the appearance of Fe-Ti oxides in LZc.

References

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5.4.15

Extreme Fe enrichment and liquid immiscibility in Skaergaard: Evidence from apatite-hosted melt inclusions

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The Skaergaard Intrusion, East Greenland, has for the past 70 years played a central role in the understanding of differentiation of tholeiitic magma. However, there is still no agreement on the general line of liquid descent in Skaergaard. Whether the trend was towards silica enrichment or towards iron enrichment, or Fe- and Si-rich melts were at some point both generated by liquid immiscibility remains contentious.

We have identified for the first time melt inclusions in cumulus apatite of UZb and UZc in drill core 90-22. The inclusions are 10 to 70 micrometer and often fill negative crystal shapes demonstrating the primary entrapment during crystal growth. The inclusions are glassy, though some post-entrapment crystallization is common. Apatite is an ideal host for melt inclusions. Its composition rules out diffusional equilibration of key elements such as Si, Mg and Fe, and the lack of cleavage planes limits the risk of leakage.

Broad-beam electron microprobe analyses identified extremely iron-rich ferrobasaltic inclusions in UZb apatite. With 26-32 wt % FeO_{tot} and low SiO_2 (41-46 wt %) the trapped melts are, to our knowledge, the most iron-rich ferrobasalt reported in nature and compare only to iron-rich ferrobasalts identified experimentally in UZ rocks of Skaergaard [1]. Olivine in equilibrium with melt inclusions at the base of UZb is Fo_{44} and close to cumulus olivine of the host cumulate (Fo_{40}).

In UZc, the inclusions are of two distinct types: one being rich in Si, Na, K and Al; and the other being rich in Fe, Ca, Mg and Ti. Both types are in equilibrium with Fo_{5-2} olivine demonstrating an immiscible relationship. This confirms the suggestion that melanogranophyre and ferrodiorite of UZc formed from immiscible liquids [2].

Although our results are preliminary and still lack homogenisation experiments, we believe that apatite-hosted melt inclusions will offer alternative constraints on evolved liquids of layered mafic intrusions.

References

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