5.4.16

Incompatible element abundances in cumulate minerals in layered intrusions

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Elements with partition coefficient values in the range 0.01 - 0.2 (typified by the REE) have been used to determine the composition of magma from which cumulus minerals in layered intrusions form. We suggest that such calculations are incorrect, because they ignore the effect of re-equilibration with trapped liquid. This effect is well-known and well-accepted in changing the Mg/Mg+Fe value of mafic minerals, and is called the trapped liquid shift effect [1].

We have determined the REE content of orthopyroxene in pyroxenites from a 100 m section of the Lower Critical Zone of the Bushveld Complex to test for the trapped liquid shift effect. Up to this level no cumulus plagioclase has formed. Ce abundances in opx vary randomly by a factor of 10 from 0.4 to 4 ppm. The samples also display a range of chondrite-normalised negative Eu anomalies from 0.75 to 0.25. Applying the principle that the liquid composition is given by cumulus mineral content divided by the partition coefficient produces magma compositions with 27 to 270 ppm Ce. Such values are unrealistically high. Since no plagioclase has formed there should be no Eu* anomaly. Further, it should not be possible for the liquid to vary randomly as this vertical interval accumulated.

The abundance of Zr in whole rock can be taken as a measure of the proportion of trapped liquid in each sample. The REE in opx correlates positively with the content of Zr in whole rock. The magnitude of the Eu* anomaly also increases with increasing Zr in whole rock.

These results become explicable if it assumed that the composition of the cumulus opx is modified by reaction with interstitial liquid with causes major increases in the abundance of the REE in opx [2]. Quantifying the effect of reaction with trapped liquid involves the following assumptions. Opx is the only cumulus mineral. The trapped liquid is assumed to solidify to an assemblage of 20% opx, 20% cpx and 60% plag. Complete re-equilibration of the REE occurs between the three phases based on their D values.

The presence of a mere 10% trapped liquid can cause a tenfold increase in the REE content in the equilibrated opx compared its true cumulus composition. Hence, if a magma composition is computed from the analysis of the opx, on the assumption that it preserves the cumulus composition, the REE content will be overestimated by a factor of 10.

References

[1] Barnes, S.J. (1986) *Contrib. Mineral. Petrol.* **93**, 524-531.
[2] Cawthorn, R.G. (1996) *Contrib. Mineral. Petrol.* **123**, 109-115.

5.4.17

REE in bulk cumulates and the trapped liquid shift in the Bjerkreim-Sokndal layered intrusion (Norway)

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Rare earth elements in bulk cumulates and in separated minerals (plagioclase, apatite, Ca-poor and Ca-rich pyroxenes, ilmenite and magnetite) from the Bjerkreim-Sokndal layered intrusion (Rogaland Anorthosite Province, SW Norway) are investigated to better define the proportion of trapped liquid and its influence on bulk cumulate and cumulus minerals composition.

In leuconoritic cumulates (made up of plagioclase, Ca-poor pyroxene, ilmenite, ±magnetite, ±olivine), where apatite is a postcumulus phase, even a small fraction of trapped liquid significantly affects the REE pattern of the bulk cumulate. Contrastingly, in the gabbronoritic cumulates characterized by the presence of cumulus Ca-rich pyroxene and apatite, cumulus apatite buffers their REE content. La/Sm and Eu/Eu* vs. P_2O_5 variations in leuconorites display mixing trends between a pure adcumulate and the composition of the trapped liquid, assumed to be similar to the parental magma. Assessment of the trapped liquid fraction ranges randomly from 2 to 25% with no relation to the stratigraphic location.

The REE patterns of liquids in equilibrium with some primitive leuconoritic cumulates are calculated with mass balance equations [1] using a consistent set of partition coefficients for REE between cumulus minerals and a jotunitic liquid. Calculated liquids from the most primitive cumulates are similar to a primitive jotunite representing the parental magma of the intrusion, taking into account the trapped liquid fraction calculated from the P_2O_5 content.

Consistent results demonstrate the reliability of liquid compositions calculated from bulk cumulates and the hypothesis that the trapped liquid has crystallized as a closed-system without subsequent mobility of REE in a migrating interstitial liquid.

Finally, a comparison between analysed and calculated plagioclase composition for various trapped liquid fractions shows that plagioclase has not been extensively re-equilibrated with the trapped liquid, due to the early interstitial saturation of apatite.

Reference

[1] Bédard (1994) *Chem. Geol.* **118**, 143-153.