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Plagioclase compositions in the upper zone of the bushveld complex

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Abstract

The approximately 2 km thick Upper Zone of the Rustenburg Layered Suite represents a series of differentiated rocks with the appearance of magnetite, olivine and apatite in that order, as cumulus phases in the stratigraphy. Plagioclase is the dominant cumulus mineral throughout the sequence; hence its composition provides a continuous record of differentiation. 126 plagioclase mineral separates have been obtained and analyzed from bore core drilled through the Upper Zone. Anorthite content decreases from An_{60} close to the base of the Upper Zone to An_{30} at the top. Six reversals were identified in a previous study occurring over a vertical interval of 16 to 69 m and in which the An increases upward by 3 to 6%. A detailed examination of one prominent reversal in the present study shows that the reversal is gradual. Sr in plagioclase concentrations increase erratically upward from about 400 ppm to 800 ppm. Ba contents in plagioclase vary irregularly between 200 and 500 ppm throughout the lower 1.5 km of stratigraphy and only increase to about 700 ppm towards the top of the sequence. The reversals which are observed in the An content are not observed in the Ba and Sr contents of plagioclase. Data for Sr and Ba in plagioclase exist for the Skaergaard intrusion and have not been quantitatively modeled before. Hence, Rayleigh fractionation models are developed to quantitatively model both intrusions. For the Skaergaard intrusion, Sr in plagioclase increases slowly from 400 at the base to about 600 ppm at 80% crystallized. It then increases rapidly to 1300 ppm at the end of crystallization. Ba varies erratically between 79 ppm and 200 ppm until 90% of crystallization from where its concentration increases to over 600 ppm at the end of crystallization.

The most simplistic model for the evolution of such trace elements in a layered intrusion is to assume a homogenous magma chamber crystallizing a mineral assemblage in constant proportions, with constant partition coefficients and with a constant proportion of trapped liquid so that bulk D is constant throughout crystallization. However, these assumptions are totally inappropriate for natural situations because mineral assemblages, their proportions, trapped liquid fractions and partition coefficients change as magmas fractionate. It therefore becomes necessary to subdivide the crystallization into a very large number of small Rayleigh fractionation stages, and change any or all of these four variables at each stage.

For the Skaergaard intrusion, the following variables are used. Values for F are estimated from the percentage of crystallization of the entire intrusion which is then subdivided into 100 small stages of fractionation. Observed plagioclase mode and trapped liquid fractions are set to change from 55 to 33% and 45 to 4% upwards respectively so that cumulus plagioclase mode can be calculated. Utilizing the conventional Rayleigh modeling by calculating a starting liquid content from $D=C_M/C_L$ and applying the Rayleigh Law to the section does not fit typical parental magma compositions and observed data for plagioclase. Consequently, a value for the Skaergaard parental magma within the range of typical Ba contents of starting liquid is then used to model the section and allowance is made for the trapped liquid shift (TLS) effect. The Ba content of calculated re-equilibrated plagioclase differs by a factor of 3 from the calculated original cumulus plagioclase content. Incorporation of the TLS effect produces the observed range of values for Ba in plagioclase. In all the models, a constant D_{Ba} of 0.4 is used throughout fractionation because the model is relatively insensitive to changing D_{Ba} in plagioclase. Sr which is compatible into plagioclase has a smaller TLS effect, thus the model is more sensitive to variations in D_{Sr} in plagioclase. The best fit with the observed data is obtained if D_{Sr} in plagioclase is varied smoothly from 1.7 at the start of fractionation to 1.9 at the end.

In the case of the Upper Zone of the Bushveld Complex, values for F, D_{Ba} in plagioclase, plagioclase mode and TL fraction are used to set up a calculation similar to the Skaergaard intrusion. A constant D_{Ba} in plagioclase of 0.4, D_{Sr} in plagioclase from 1.5 to 2.1, observed plagioclase mode from 65 to 45% and a constant proportion of trapped liquid of 10% are used. Different starting liquid compositions are then tried until values are obtained for which Ba and Sr contents of calculated re-equilibrated plagioclase are in agreement with analytical data. Based on modeling of the Upper Zone of the Bushveld Complex, Ba contents of calculated re-equilibrated plagioclase also differ significantly from respective original cumulus contents due to the TLS effect. Therefore, applying the model to the Upper Zone of the Bushveld Complex validates the importance of allowing for the TLS effect. The computed liquid contents at the base of the UZ are 273 and 325 ppm for Sr and Ba respectively. In view of the reversals in mineral composition and small scale variations in the Sr and Ba contents of plagioclase, various magmatic processes such as magma addition and internal overturn which have been proposed to occur in the Upper

Zone are inferred to be possible. There are a number of uncertainties with the modeling, hence none of these processes can be conclusively ruled out.