Layered, PGE-Bearing Magma Chambers in a Single Pulse

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Finite element computational fluid dynamic modelling of freezing magma chambers has suggested that inclusion of the effect of suspended crystal load (which increases the effective density) serves to split the magma chamber up into a number of stratifications, each stratification a layer of magma of significant depth, but each layer varying in composition. The experience of other disciplines (e.g., industry, limnology, etc) not only establishes that such phenomena occur but has yielded means to make quantitative estimates of the vertical dimensions of individual stratifications. Carrying over the science of these other disciplines into the magmatic environment yields times of evolution of the development of these layers. They evolve as follows.

Magma initially cools at the roof of the chamber, bringing the roof to incipient melting. The magma develops a crystal load during this cooling which is dumped to the bottom of the chamber as a turbidity current. This creates a layer of suspended crystal load at the bottom which continues to convect, although sluggishly due to the increase in viscosity from cooling and the inclusions of crystals in the melt. Because there has been little assimilation of roof material up to this point, this first turbidity current carries little contamination with it to the lower reaches of the chamber. The turbidity current forces the remaining, hotter magma to the top of the chamber which renews the convective heat flux to the roof. The chamber is now split into an upper convecting region and a lower convecting region separated by sharp boundary layers, the lower layer containing refractories and the upper layer of a more evolved composition. The renewal of heat to roof rock that has previously been brought to the proximity of its melting point now serves to secure significant contamination of magma which is cooling at the roof. A new load of suspended crystals develops in the upper reaches of the chamber. This new suspended load also eventually cascades down to rest atop the first stratification whose higher density (due to continued cooling) prevents penetration by the second slump of material. Remaining melt is again forced to the roof but as the magma chamber is cooling and low temperature components have been extracted from the roof rock into the magma chamber, leaving only restites at the roof, the final upper stratifications do not acquire the same degree of contamination of the material now occupying the middle of the chamber.

Depending on the depth of the fresh magma and cooling histories, there are variations to this scenario (e.g., number of stratifications). In any instance, however, the broad trend that sets in is as follows. The lowermost layers are closest to the original composition of the magma. The middle layers are significantly contaminated with country rock and of a more evolved composition. The uppermost stratifications are the most evolved but possess a contamination level between that of the lower and intermediate layers. Double diffusive effects and convective scavenging driven by dispersive pressure (i.e., the Bagnold effect) also attend to provide the fine detail of large layered intrusives. One aspect of this scenario is that it provides a rationale for the observation that only those layered intrusions of significant initial depth possess PGE ore bodies that are of economic interest.

The above scenario does provide for observed geochemistry of these units such as the double peaking of Pt in, say, the UG2 chromitite layer of the Bushveld Complex.

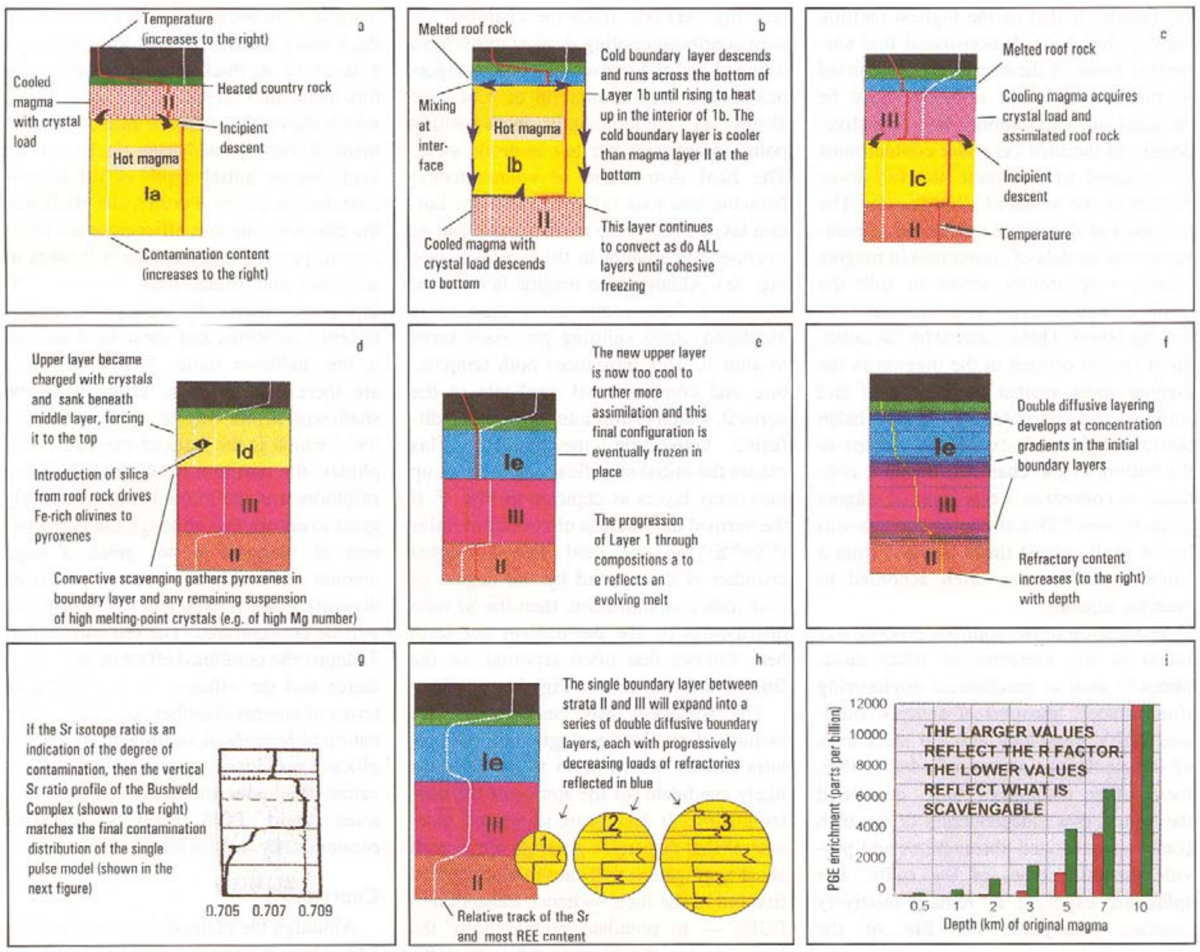

Figure 1. a) depicts an idealized column of melt in a magma chamber. Country rock is dark. The magma is yellow. Magma cooling at the roof acquires a suspended load of crystals which eventually falls to the bottom of the chamber as a turbidity current. The magma heats the roof but at this point has not yet begun to assimilate significant amounts of roof, hence contamination. The composition of the bottom layer is primitive, that of the upper layer more evolved. b) depicts the layer of suspended load now at the bottom, with remaining hot magma pushed to the top to renew the heat to the roof. The bottom layer continues to convect due to heat loss at the sides and due to a cold boundary layer that descends from the roof to flow along the top of the suspended load. c) depicts the formation of another suspended load at the roof. The roof has now been brought to a temperature wherein there is significant assimilation, hence contamination of the new suspended load. d) depicts the second layer of suspended load settling on top of the first, driving the last of the initial pulse of magma to the roof. As the last of the magma from the initial input has become cooled and the roof stripped of its low melting point components, the degree of assimilation has died off. e) indicates the final vertical distribution of contamination. f) depicts the development of double diffusive layering throughout the chamber from the original stratifications and the anticipated development of vertical compositional variation, the most primitive material at the bottom and the most evolved at the top. g) shows the vertical distribution of the Sr ratio in the Bushveld Complex. If the Sr ratio reflects the degree of contamination, then this distribution is in accord with the single model pulse as developed through Figs a to e. Refer to the next figure, h), which shows again the expected contamination distribution in the vertical from the single pulse model. h) also depicts the accumulation of primocrysts in the boundary layers due to dispersive pressure and the growth of additional boundary layers about the first as a manifestation of double diffusive convection. If the primocrysts are laden with PGE's, then double peaks in concentration are expected and this is observed. Fig. i depicts the effect of magma chamber size on both R factor and convective scavenging. The larger the vertical extent of the chamber, the larger the Rayleigh number and the more efficacious the convective scavenging.