Origin of the Merensky Pegmatitic Pyroxenite, Bushveld Complex

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The feldspathic pegmatitic pyroxenite associated with the platinum mineralization of the Merensky Reef, Bushveld Complex, has been extensively studied, because it has often been considered to be fundamentally interrelated to the mineralization itself. In this study it is suggested that this association is not a prerequisite for mineralization, although both are related to the same event. The pegmatite formed by recrystallization from a pre-existing pyroxenite or harzburgite at the crystal-magma interface. It was not formed by a secondary replacement process deep in the crystal pile. It contains a small proportion of cumulus plagioclase, some of which may have been derived from the footwall succession, and so the initial Sr isotopic characteristics of the pegmatite are controlled by mixing of two sources (earlier formed plagioclase with a low ratio and interstitial magma with a high ratio). The pegmatite is not enriched in incompatible elements, but a zone about 50-70 cm above the basal chromitite is enriched. The host rock may be either pegmatite or pyroxenite depending on the thickness of the pegmatite. This enrichment results from trapping of an upward migrating residual magma from the footwall. The mineralization event was coincident with the formation of the upper chromitite above the pegmatite, but this immiscible sulphide liquid percolated down by 1 metre. Hence, there is no genetic correlation between the mineralization and the very specific host-rock in which it now occurs.

Geometry

The Merensky cyclic unit typically consists of a lower chromitite, a feldspathic pyroxenite, a thin norite and an anorthosite. The pyroxenite usually has a lower layer that is pegmatitic, in which case there also will be an upper chromitite layer related to this coarse-grained rock. On the southern half of Impala Platinum Mine in the western limb, this feldspathic pegmatitic pyroxenite (henceforth termed the pegmatite) is developed, but to the north it is absent (Leeb-du Toit, 1986). The two facies will be referred to as pegmatitic and pyroxenitic reef respectively. PGE grades do not appear to differ in these two facies.

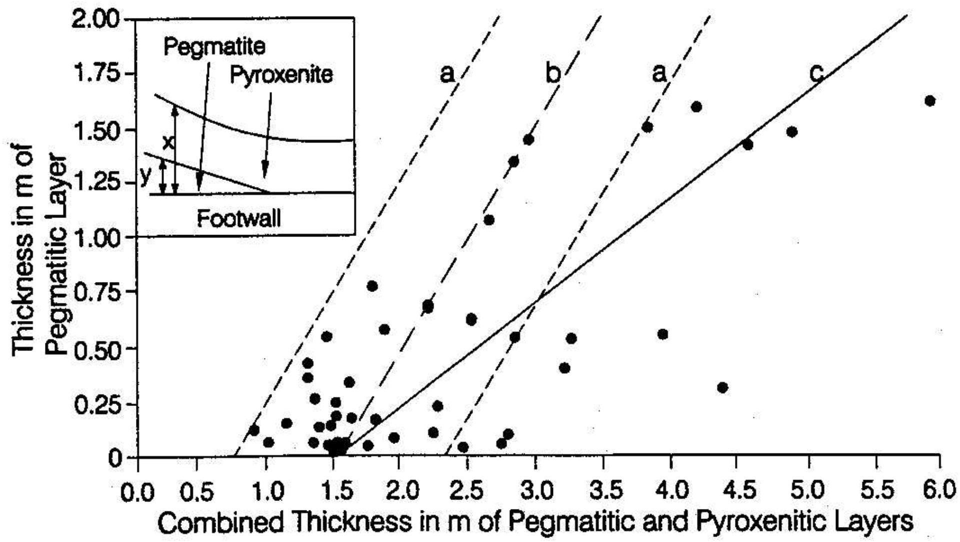


__Figure 1.__ Plot of thickness of feldspathic pegmatitic pyroxenite versus combined thickness of the pegmatite plus overlying pyroxenite, based on 128 bore core intersections from Impala Platinum Mine. If the pegmatite had formed by replacement of the overlying pyroxenite total thickness should remain constant, whereas it significantly increases, showing that the two layers are additive in thickness, not replacive. The inset shows the schematic relationships for the measured thicknesses, and also the geometry observed on Impala Platinum Mine where there is a pegmatite layer developed in the south of the property, but not in the north.

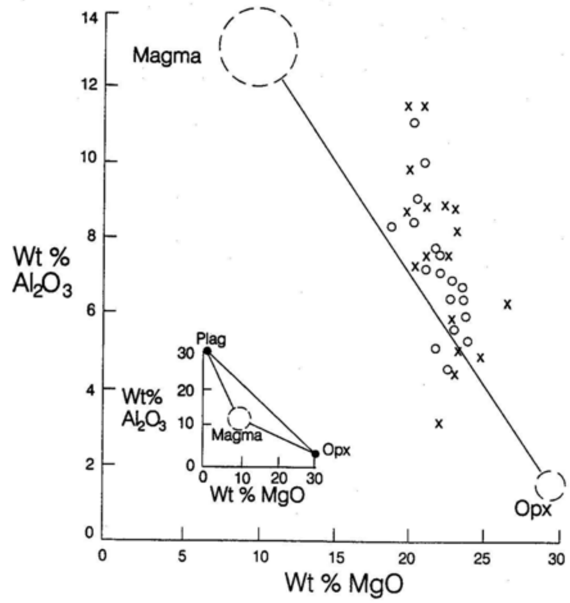
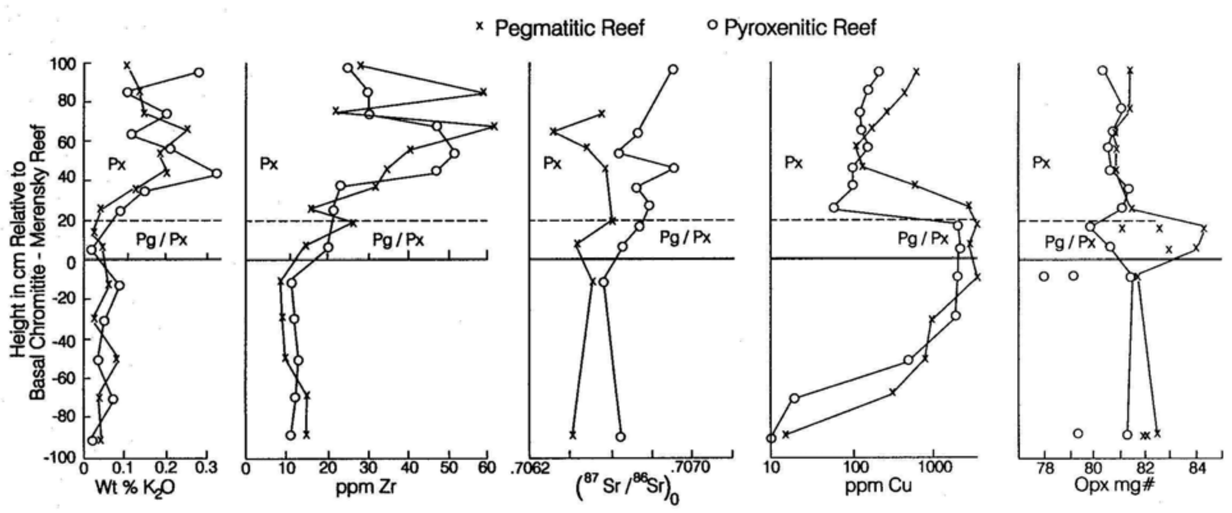


Figure 2. *Plot of MgO versus Al_2O_3 for the pegmatite (crosses - this study, circles from Lee, 1983; Wilson et al., 1999, Barnes and Maier, 2002). The inset shows the expected relationships depending upon cumulus mineralogy. The data clearly indicate that there is some cumulus plagioclase in these rocks.*

Models for the origin of this pegmatite can be divided into syngenetic and epigenetic. The epigenetic models would envisage replacement of a pre-existing ultramafic rock, typically by fluid or residual magma infiltration, when this layer was buried within the crystal pile. The syngenetic models envisage reconstitution at the crystal-magma interface before the rest of the Merensky cyclic unit was deposited. A simple test is available to distinguish these models, based on measured thicknesses of the Merensky pegmatite and overlying pyroxenite (Fig. 1). If a layer of pyroxenite had existed within the crystal pile and was replaced by upward percolating material, pegmatite formation would have progressively thinned the remaining pyroxenite. The total thickness of pegmatite plus pyroxenite ought to have remained relatively constant. Alternatively, if the pegmatite formed and was subsequently overlain by pyroxenite of a uniform thickness, the combined thickness would increase as the pegmatite thickness increased. The measurements from 45 borecore intersections through the pegmatitic and 83 through pyroxenitic reef are shown in Fig. 1. Pyroxenite from pyroxenitic reef has an average thickness of 1.5 m with a standard deviation of 0.8 m. The combined thickness, where pegmatite also is present, shows a broad increase with increasing thickness of pegmatite. Curve b is the trend expected for addition of an average thickness of pyroxenite to the pegmatite. Curves a show the same trend allowing for the standard deviation. Curve c is the best-fit line through the data. If there had been replacement of pyroxenite by pegmatite a vertical trend would be expected. The slope on curve c exceeds that for curves a and b, indicating that there is a slight increase in thickness of pyroxenite for thicker sections of pegmatite. Such an observation is the exact reverse of that predicted by the epigenetic replacement model.



Figuer 3. *Plots of K_2O, Zr, initial $^{87}Sr/^{86}Sr$ values, Cu and mg# in orthopyroxene through the Merensky reef and foot- and hanging wall rocks. Sections in which pegmatite is present are shown by cross symbols, sections having no pegmatite are shown by circles. Note that the lowest K_2O and Zr occur in the pegmatite, and that the highest values occur at about 50 - 70 cm above the base of the ultramafic rock, regardless of whether it is pegmatite or pyroxenite.*

Cumulus Plagioclase

Most descriptions of the Merensky feldspathic pegmatitic pyroxenite conclude that there is cumulus pyroxene and intercumulus plagioclase. This statement is not consistent with whole-rock analyses. The relationship between whole-rock MgO and Al_2O_3 is shown in Fig. 2. A rock containing only cumulus pyroxene and interstitial liquid ought to plot between the magma composition and pyroxene. Most samples of the pegmatite have higher Al_2O_3 contents than this trend. The inset in Fig. 2 shows that such compositions must contain cumulus plagioclase. The source of this plagioclase cannot be uniquely constrained. Eales et al. (1991) reported inclusions of amoeboid plagioclase inside orthopyroxene grains in certain pyroxenite layers and argued for retention in the magma of plagioclase from the previous cycle. Alternatively, the orthopyroxene in the Merensky pegmatite has a composition of mg# 81-84, comparable to that predicted for the beginning of cotectic crystallization with plagioclase (Cawthorn and Biggar, 1993). Therefore, the plagioclase in the pegmatite could have a component derived from the footwall crystallization event or be an equilibrium cumulus mineral.

Trace-Element Geochemistry

There have been very few rigorous, statistically significant, studies of the whole-rock geochemistry through the Merensky Reef. Here, six cores through pegmatite and eight through pyroxenite reef were continuously sampled from the lower chromitite upward for one metre, with samples 10 cm thick. The footwall was sampled continuously every 20 cm. The mg# for orthopyroxene and whole-rock K_2O, Zr and Cu, and initial $^{87}Sr/^{86}Sr$ in plagioclase separates are plotted in Fig. 3. The mineral compositions in the pegmatitic rocks have higher mg# than in the surrounding rock types, suggesting that there was addition of a more primitive magma, not recrystallization under the influence of residual magma. The incompatible trace elements, K_2O and Zr, show that the pegmatite is not enriched in these elements. Immediately above the lower chromitite the lowest values found in the entire section above this level are recorded. Concentrations steadily increase to a height of 40-70 cm. This increase occurs regardless of whether the rock type at this elevation is pegmatite or pyroxenite. It therefore appears that the zone of highest incompatible element abundance, inferred to reflect higher degrees of trapped liquid than elsewhere, is not related to the pegmatitic textured rocks. The studies of Lee (1983), Wilson et al. (1999) and Barnes and Maier (2002), show exactly the same trends with peaks at 50 to 70 cm height.

The initial $^{87}Sr/^{86}Sr$ values in plagioclase give some indication of the source of this trapped liquid. Above the lower chromitite this ratio increases upward, a feature universal to the Merensky Reef (Kruger, 1994). However, the sample from each section that has the highest trapped liquid content also shows the lowest initial Sr ratio, closer to the value from the footwall, suggesting derivation of residual liquid or cumulus plagioclase grains therefrom.

Mineralization

Mineralization may be coincident with the pegmatitic layer, but not necessarily so. Almost half of the mineralization (as defined by Cu content) occurs below this unit as shown in Fig. 3. However, the location of the mineralization from mines in the western Bushveld varies according to thickness of pegmatitic layer (as reviewed by Cawthorn et al., 2002). In thick pegmatite facies, mineralization occurs within it, in thin or no pegmatite facies mineralization is developed in the footwall. The best-mineralized mining cut (80 - 100 cm) is often placed symmetrically about the top of the pegmatite, where there is a thin chromitite layer. With reference to the interpretation of the pegmatite made above, it is suggested that the lower chromitite and pegmatite were the base of a pre-Merensky cyclic unit (Viring and Cowell, 1999) that was recrystallized during the event that produced the upper chromitite and the bulk of the mineralization. The sulphide liquid that accumulated during this event, being dense and fluid, percolated down through the underlying unconsolidated crystal mush. Now a significant portion of the mineralization occurs in rocks that should be defined as footwall rocks relative to the timing of mineralization (Cawthorn, 1999). Thus, models that attempt to correlate mineralization with their specific host rock may be incorrect.

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