
Multielement and Isotopic Geochemistry of the J-M Reef, Stillwater Intrusion, Montana

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Introduction

The Stillwater Intrusion of southern Montana is the highest grade platinum-group element (PGE) deposit being mined in the world today, and a thorough understanding of its characteristics and genesis are of great interest. The mineralized horizon which is currently being exploited is referred to as the J-M Reef and is hosted in a classic layered mafic intrusion, similar in overall features to the larger Bushveld Intrusion of South Africa. Within these layered intrusions with dimensions of perhaps 50 to 300 km in length, and with thicknesses of several thousand meters, are found the J-M and Merensky Reefs which are only one to two meters thick. These reefs are planar mineralized features which are stratabound with respect to the distinct igneous layering characteristic layered mafic intrusions.

A serious debate over the origin, strictly magmatic or deuteric/hydrothermal, of this reef-type mineralization continues today, and any genetic model must explain the observed petrographic features, geochemistry, and geometry

of the deposits. In fact, to geologist who have not read Boudreau and McCallum (1992), the geometry of the reefs is the principal confounding feature when considering whether the deposits are deuteric/hydrothermal in origin. This paper describes an elegant deuteric/hydrothermal genetic model compatible with the petrography, geochemistry, and, especially, the geometry of the reefs. Simply put, this model envisages volatiles being expelled from intercumulus melt at the base of the crystal pile in a crystallizing magma chamber. These volatiles rise through the cumulus pile until they encounter overlying magma which is undersaturated in water and halogens but which is at or near saturation with respect to sulfur, a feature common to mafic magmas. At this planar interface, water and halogens will re-dissolve in the overlying magma, while sulfur cannot, and base and precious metals being transported by the volatiles will precipitate as metal sulfides at the interface. This horizon ultimately comprises the reef-type deposits that we see today.

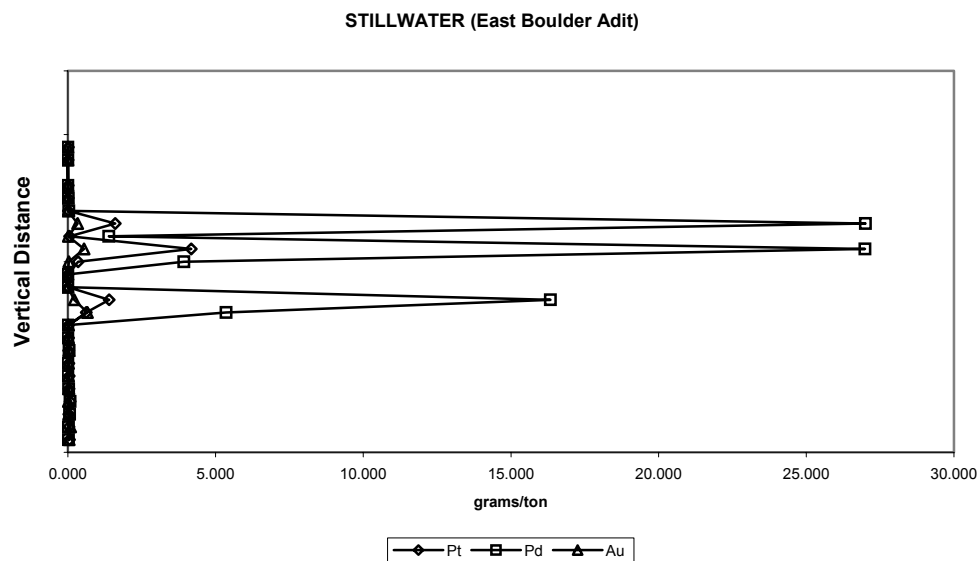


Figure 1. Distribution of Pt, Pd, and Au in the J-M Reef, showing absence of metal zoning present in the mineralized horizons of several other layered mafic intrusions.

The magmatic view of the genesis of reef-type mineralization is that precipitating sulfides will scavenge PGEs from the magma because of their high partition coefficients (D factor) in favor of sulfide over magma. If the sulfides interact with a large amount of magma (R factor) a significant amount of PGEs can accumulate in the settling sulfides. This process would result in precious metals being found together in the resulting sulfide layer (reef), and this is the configuration seen at the J-M Reef (Figure 1). However, this is not the case in some other mineralized layered mafic intrusions such as Lake Owen, Wyoming, Rincon del Tigre, Bolivia, Great Dyke, Zimbabwe, and Munni Munni, Australia, for example, where distinct metal zonation occurs across the reef zone (Prendergast, 2000 and references within). In fact, in some occurrences the precious metals are somewhat decoupled from the sulfide zone as well (Boudreau and Meurer, 1999).

pegmatoid which, by analogy with felsic pegmatites, is likely to have developed in the presence of a volatile or aqueous phase which promoted the growth of large crystals. Second, the spatial relationship of PGE-bearing sulfides with alteration of surrounding silicates to hydrous phases like chlorite and serpentine point to the involvement of an aqueous phase in their genesis. Third, rocks at and below the J-M Reef contain elevated contents of Cl, F, Br, NH_4 , and NO_3 (Figure 2), signatures of the volatiles that permeated these rocks. Fourth, along with the volatiles mentioned above, the content of precious metals in rocks beneath the J-M Reef is distinctly higher than above the reef (figure 3), another relict signature of the metal-bearing fluids that permeated these rocks. Fifth, $\delta^{18}\text{O}$ analyses of the J-M Reef and surrounding rocks show a striking depletion in ^{18}O at the reef, especially in the serpentinized lower half of the mineralized zone. This shift from values of +6 to values of +2 to 3 (figure 4), reflect the marked interaction of non-magmatic water with this horizon, probably during the silicate alteration event.



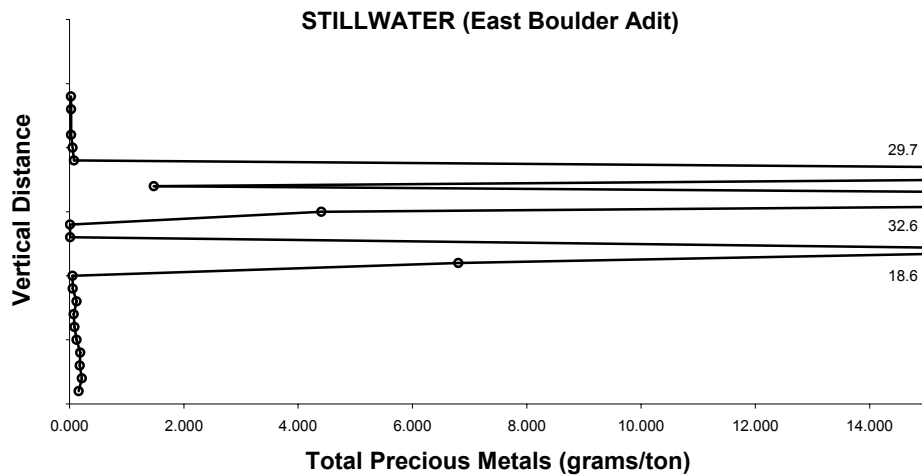


Figure 3. Distribution of total precious metals (Au+Pt+Pd+Rh+Ru+Os+Ir) in rocks surrounding J-M Reef. Enrichment in footwall is compatible with transport by volatiles from below rather than settling of sulfides from above.

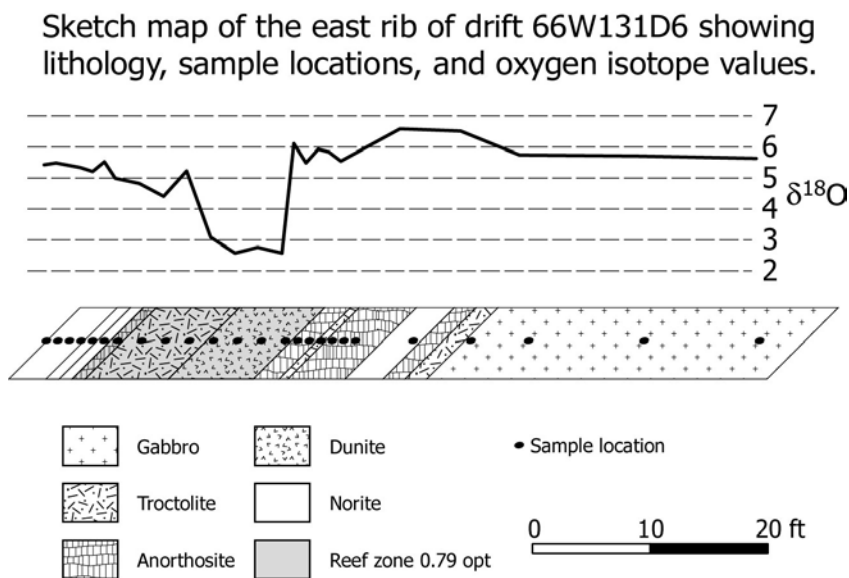


Figure 4. Graph of oxygen isotopes in rocks surrounding J-M Reef (footwall to right). Depletion in values are distinct at reef and indicate involvement of non-magmatic water, probably during alteration of silicates

Conclusions

The features of the J-M Reef described above are compatible with a deuteric/hydrothermal origin for the mineralization, but are not consistent with a simple magmatic origin relying on the settling of sulfides, regardless of D or R factors. If the observable and measurable features of the PGE-mineralized J-M Reef cannot be explained by the simple settling of magmatic sulfides scavenging PGEs from the surrounding magma, or by some

hydrid combination of magmatic and hydrothermal processes, the deuteric/hydrothermal process should be accepted as the best current explanation of the genesis of J-M Reef mineralization.

References

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