Rare Earth Element Geochemistry Orientation Survey of Plagioclase Cumulates Below, Within, and Immediately Above the J-M Reef, Stillwater Mine, Nye, Montana

Diane Wolfgram
Geological Engineering Department, School of Mines & Engineering, Montana Tech, Butte, Montana 59701
e-mail: dwolfgram@mtech.edu

In 1996, samples for a geochemical orientation survey were taken from plagioclase cumulate (anorthosite) layers in DDH 8881, one of now in excess of 12,000 core holes drilled on a 50 X 50 foot grid pattern throughout the Stillwater Mine at Nye, Montana. Mineral separates from these samples were prepared and analyzed for REE and trace elements by ICAP-MS in the clean lab facilities of Monash University. The first sample, Sample 44, represents a thin anorthosite layer sandwiched between two "feldspathic websterties" in the sequence of rocks below the J-M Reef. This anorthosite layer is representative of a much thicker sequence of anorthosite and leucocratic norite layers that has "pinched out" along strike because of a low-angle angular unconformity. Sample 68 is from an anorthosite layer in an uncomformable, chaotic sequence of norties, leuconorites, and bronzitites, with erractically distributed "buckshot" textured dunites that lies at variable distance below the J-M Reef (in the mine area, the base of the J-M Reef is a major unconformity). Sample 84 is from the J-M Reef Package itself. Although mineralization in DDH 8881 is localized near the contact of the Reef Package with the hanging- wall sequence, in other drill holes in this sector of the mine mineralization occurs directly above this particular anorthosite layer, sometimes below it, but not within it. Sample 144 is from the hanging-wall sequence, which overlies the J-M Reef Package with pronounced angular unconformity in this sector of the Stillwater Complex. Condrite-Normalized REE patterns for these four samples are shown in Figure 1.

Parent-magma REE patterns were calculated from these samples using the distribution coefficients from McKay, 1981, which are illustrated in Figure 2. As shown in Figure 3, the calculated parent magmas for samples 68 and 84 have the gently sloping REE patterns that have historically been identified as being characteristic of post-Ultramafic Series, A-type magmas. Calculated parent magmas for samples 68 and 144 have the steeper REE patterns characteristic of the U-type magmas from which the Ultramafic Series formed (Lambert and Simons, 1987; Lambert and Simons, 1988; Loferski et al., 1994).

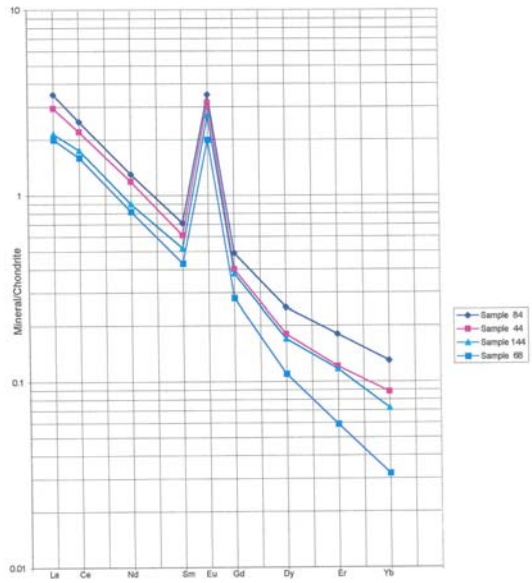

Figure 1. *Chondrite-normalized REE patterns for plagioclase separates from anorthosites, Gabbronorite I Zone (44 and 68), the J-M Reef package (84), and its unconformable hanging wall sequence (144).*

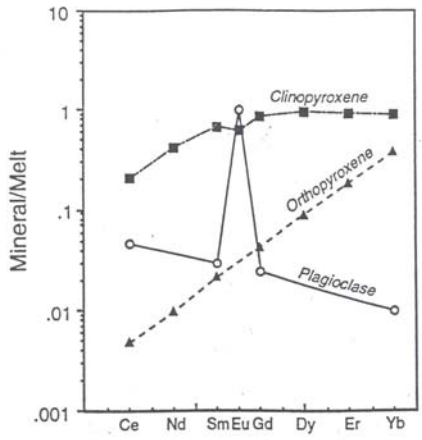

Figure 2. *Mineral-melt REE D patterns for plagioclase (McKay, 1981) used to calculate parent liquid REE patterns in this study. Figure from Loferski, et al. (1994).*

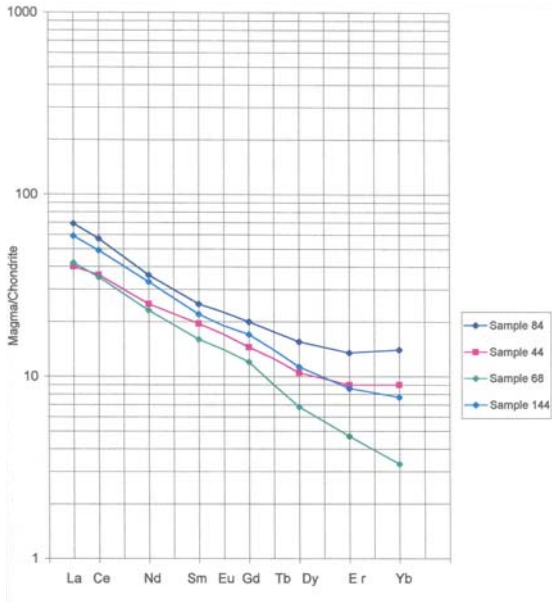

Figure 3. *Chondrite-normalized REE patterns for calculated parent magmas for Stillwater anorthosite samples.*

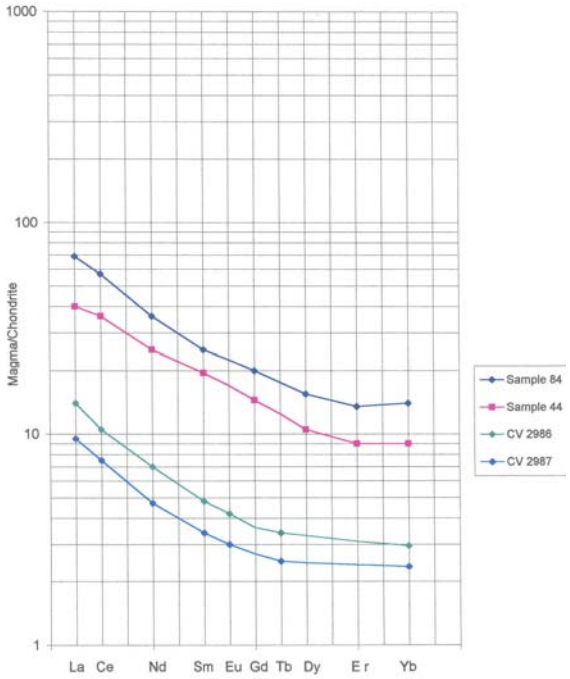

Figure 4. *Comparison of chondrite-normalized REE patters for calculated parent magmas for Stillwater anorthosite samples 44 and 84 and for selected boninites from Cape Vogel, Papua, New Guina (Data from Hickey and Frey, 1982).*

As shown in Figure 4, the slightly concave upwards REE patterns for A-type magmas, represented by samples 44 and 84, are very similar to those of boninites from Cape Vogel, Papua, New Guinea (Hickey and Frey, 1982). The higher REE concentrations calculated for the Stillwater samples are attributable to crystal fractionation. Hickey and Frey (1982) concluded that boninitic magmas could be formed by mixing small amounts of an LREE-enriched source component with a LREE-depleted source component and it appears possible that both the A-type and U-type Stillwater magmas could be derived from mixing slightly different proportions of these two-types of source components. On the other hand, the steeper REE patterns for samples 68 and 144 may have resulted from factionation of clinopyroxene during the formation of Gabbronorite I Zone.

It is interesting that, within reason, the REE pattern for Sample 144's parent magma can be modeled by mixing the parent magmas of samples 68 and 84. This is, however, not conclusive evidence of magma mixing, as Sample 144's REE pattern may simply represent an A-type magma from which less clinopyroxene had fractionated than from that of Sample 68 or a slightly different mixture of source components. In the latter two cases, however, its lower calculated REE concentration would indicate that it was not as evolved as the magma from which the anorthosite within the J-M Reef itself crystallized (Sample 84).

The calculated REE pattern for Sample 44's parent magma indicates that the sequence of anorthosites and leuconorites that typically overly "feldspathic websterites" in the sequence of rocks below the J-M Reef did not crystallize from a magma from which a significant amount of clinopyroxene had previously fractionated. This dispels any notion that the anorthosite/leuconorite sequence was derived from the same magma batch as the underlying "feldspathic websterite" unit and represents the crystallization product of a magma depleted, previously, in its clinopyroxene component.

Since "modern" boninites are restricted to destructive plate margin tectonic settings, the boninitic REE pattern for calculated Stillwater magma suggests that the complex may have formed in a similar tectonic environment during the Archean.

The author concludes that development of a more detailed and systematic REE stratigraphy of the rock layers below, within, and above the J-M Reef would be very useful for further characterizing

the magmas involved in their formation and documenting magma evolution with respect to the formation of the Stillwater Complex and the J-M Reef. Because of the highly unconformable nature of the Reef Package and its hanging-wall sequence in the Stillwater Mine section of the Complex, samples for such a study must be selected with great care to achieve meaningful results.

References

Hickey, R.L., and Frey, F.A., 1982, Geochemical characteristics of boninite series volcanics: Implications for their source, Geochem. Cosmochem, Acta, v.46, p. 2099- 2115.

Lambert, D.D., and Simmons, E.C., 1987, Magma Evolution in the Stillwater Complex, Montana: I. Rare-earth element evidence for the formation of the Ultramafic series, Amer. J. Sci., V.287, p. 1-32.

Lambert, D.D., and Simmons, E.C., 1988, Magma Evolution in the Stillwater Complex, Montana: II. Rare-earth element evidence for the formation of the J-M Reef, Econ. Geol., v.83, p. 1109-1126.

Loferski, P.J., Arculus, R.J., and Czmanske, 1994, Rare earth element evidence for the petrogenesis of the Banded series of the Stillwater Complex, Montana and its anorthosites, Jour. Petrology, v.35, part 6, p. 1623-1649.