Mineralogical Investigation of the Aggeneys-Gamsberg BHT District, South Africa: Implications for Classification of a Classical Broken Hill-type District

Craig R. McClung and Fanus Viljoen

Paleoproterzoic Mineralization (PPM) Research Group, Department of Geology, University of Johannesburg, P.O. Box 524, Auckland Park, 2006, South Africa; crmcclung@uj.ac.za

Introduction:

The definition and genesis of Broken Hill-type (BHT) deposits continues to be a highly controversial topic (Large, 2003; Leach et al., 2005; Spry et al., 2009). This controversy is primarily due to their high-grade of metamorphism, structural complexity, unique mineralogical assemblage, sulfide remobilization, post-peak metasomatism, etc., which has resulted in the creation of numerous genetic models and classification schemes. For example, some authors (Large, 2003) characterized BHT deposits as a distinct group, others (Leach et al., 2005) classify them as metamorphosed SEDEX deposits and still others (Spry et al., 2009) defined them as a continuum. The South African BHT deposits of the Aggeneys-Gamsberg district have been divided into two or more camps (Large, 2003; Spry et al., 2009) or incorporated into a single camp (Leach et al., 2005). Therefore, the purpose of this investigation is to evaluate the various mineralogical and mineral chemical variations between the Broken Hill and Gamsberg deposits.

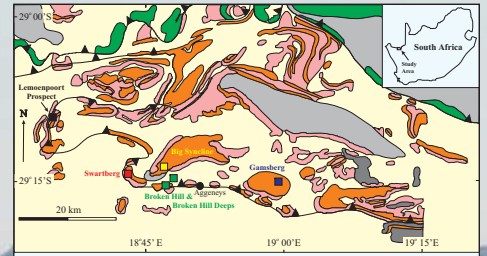


Figure 1: Locality map of the Aggeneys-Gamsberg District, after Reid et al. (1997).

Regional Geology:

The stratabound and stratiform, polymetallic sulfide-barite deposits of the Aggeneys-Gamsberg district (Fig. 1), Northern Cape Province of South Africa, are hosted by the Mesoproterozoic Bushmanland Group, central Namaqua Metamorphic Complex (NMC). The Bushmanland Group comprises a thin (<1 km), multiply deformed and metamorphosed, volcano-sedimentary succession deposited in a shallow, continental margin environment that experienced intense polyphase deformation combined with high-T/low-P metamorphism during the Namaquan Orogeny between 1000-1250 Ma. Despite the limited size of the Aggeneys-Gamsberg district, *ca.* 70 km^2, it hosted five deposits (Fig 1; Swartberg, Broken Hill, Broken Hill Deeps, Big Syncline and Gamsberg) with an initial estimated mineral resource of 505 Mt @ 4.18% Zn, 1.40% Pb, 0.18% Cu and 18 g/t Ag. The Broken Hill and Gamsberg deposits represent the largest and economically most-significant deposits. Regionally, the Aggeneys-Gamsberg district displays a metal zonation from Pb-Zn-Cu-Ag at Swartberg in the west to Zn-Pb-Ba at Gamsberg in the east. In particular, the world-class Gamsberg deposit (265 Mt @ 6.14% Zn and 0.31% Pb) is distinctly different from the Broken Hill/ Broken Hill Deeps (56.7 Mt @ 5.56% Pb, 3.19% Zn, 0.55% Cu and 73.5 g/t Ag) and associated deposits of the Aggeneys area. While the former is Zn dominate, with economically significant amounts of strata-bound/stratiform barite, the Broken Hill and associated deposit of the Aggeneys area are much smaller, Pb- and Cu-rich with only minimal barite.

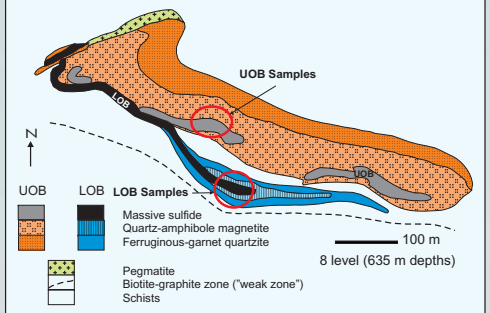


Figure 2A: Cross-section through the Broken Hill Mine illustrating the spatial distribution of the main lithologies and geometry of Upper Orebody (UOB) and Lower Orebody (LOB).

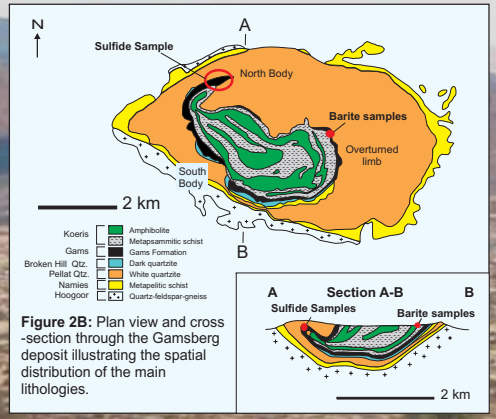


Figure 2B: Plan view and cross-section through the Gamsberg deposit illustrating the spatial distribution of the main lithologies.

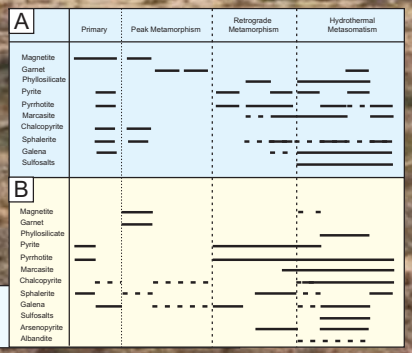


Figure 3: Paragenetic sequence for the Broken Hill, A (light blue), and Gamsberg, B (light yellow) deposits.

Mineralogy:

Detailed petrographic (Fig. 4) analyses of the Broken Hill (Fig. 2A) and Gamsberg (Fig. 2B) deposits reveal that both display complex history characterized by repeated phases of recrystallization, metamorphic annealing, ductile deformation and retrogressive metasomatic overprinting. Despite these complexities and analogs to the paragenetic sequence presented by Ryan et al. (1986), four phases of sulfide deposition have been identified at the Broken Hill and Gamsberg deposits (Fig. 3): 1) pre-peak metamorphic (i.e. primary); 2) peak-metamorphic; 3) post-peak/retrograde metamorphic; and 4) late hydrothermal/metasomatic retrograde metamorphic. Irrespective of the deposit, primary, pre-metamorphic sulfides principally consist of galena, pyrrhotite, honey-yellow to orangish-brown sphalerite and very fine-grained, euhedral pyrite cubes with accessory amounts of chalcopyrite observed at the Broken Hill deposit. In the Broken Hill deposit, primary sulfides are characterized by small, spherical-shaped inclusions in garnet, while in the Gamsberg deposit they consist of very fine-grained (10's micron) crystals disseminated throughout the host rock. Peak-metamorphism sulfides from both deposits, although volumetrically minor, consist of fine- to medium-grained, foliated to banded, cataclastic (Broken Hill) schlieren- to durchbewegung-textured (Gamsberg) reddish-brown sphalerite and pyrrhotite with minor amounts of chalcopyrite. The final two phases of sulfide deposition, post-peak/retrograde and late hydrothermal/metasomatic retrograde metamorphism, consists of several generations of annealed pyrite and sphalerite with secondary open-space-filling galena, pyrrhotite, chalcopyrite, marcasite and various sulfosalts. Sulfosalts from the Broken Hill deposit consist of jamesonite [Pb_4 (Fe,Mn)(Sb,Bi) $_6S_{14}$] and freibergite (34% Ag), while subordinate amounts of cobaltite and bravoite have also been observed. By comparison, significant quantities of open-space- and fracture-filling arsenopyrite are observed in the Gamsberg deposit, while subordinate amounts of tetrahedrite and albandite [MnS] are locally observed.

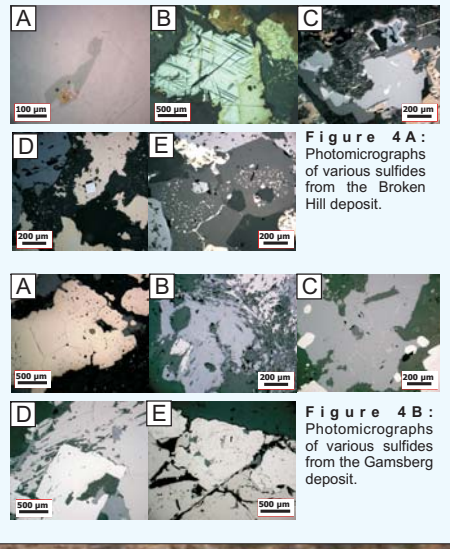


Figure 4A: Photomicrographs of various sulfides from the Broken Hill deposit.

Figure 4B: Photomicrographs of various sulfides from the Gamsberg deposit.

Mineral Chemistry:

Analogous to the petrographic analyses, trace element chemical analyses of the sulfide minerals in the Broken Hill and Gamsberg deposits confirms the existence of multiple generations of sulfide deposition (Fig. 5). For instance, sulfides of the primary, pre-metamorphic event display elevated concentrations of iron and manganese in sphalerite and chalcopyrite, while the sulfides of the peak-metamorphic event display elevated concentrations of cobalt in sphalerite, cobaltite and bravoite. By comparison, the sulfides of the post-peak/retrograde metamorphic event are characterized by elevated concentration of manganese in sphalerite with minute (micron-sized) inclusions of albandite. Finally, sulfides of the late hydrothermal/metasomatic retrograde metamorphic event display elevated concentrations of silver, antimony, bismuth and arsenic in galena, sulfosalts and arsenopyrite.

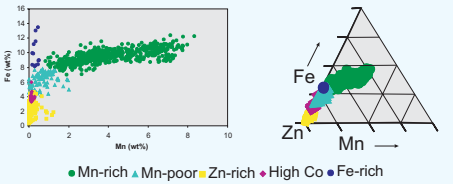


Figure 5A: Spot analyses of Gamsberg sphalerite plotted on a bi-variant Fe-Mn and tertiary Fe-Mn-Zn diagram illustrating the clustering of various populations.

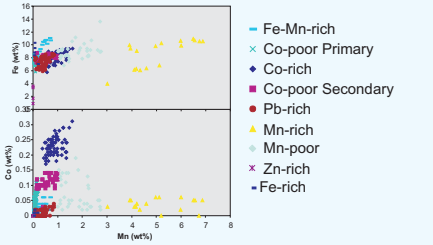


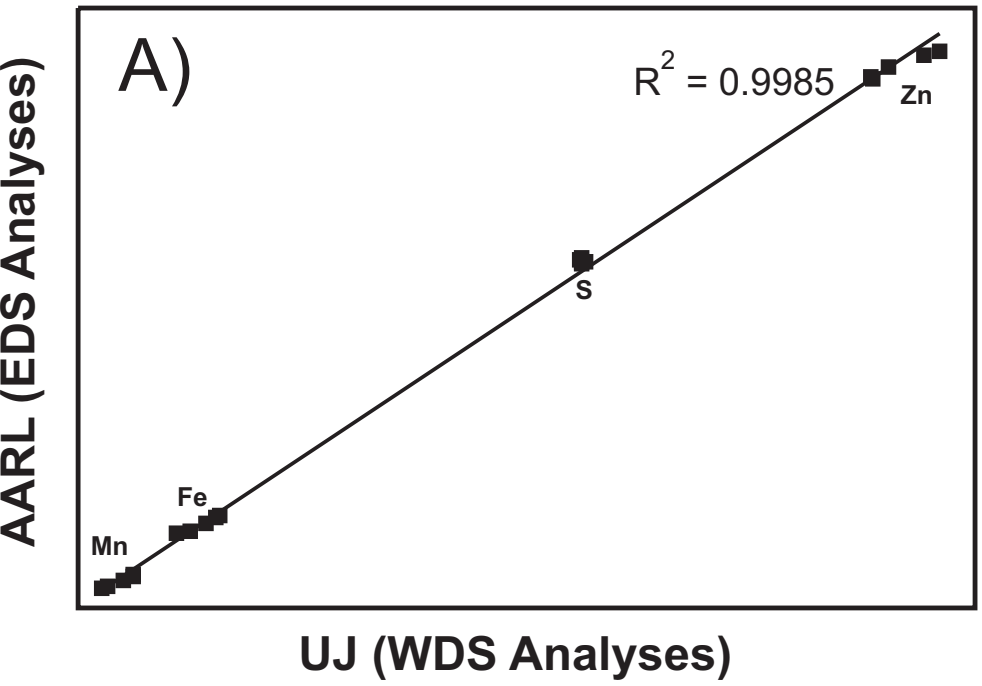
Figure 5B: Spot analyses of Broken Hill sphalerite plotted on a bi-variant Fe-Mn and Co-Mn diagram illustrating the clustering of various populations.

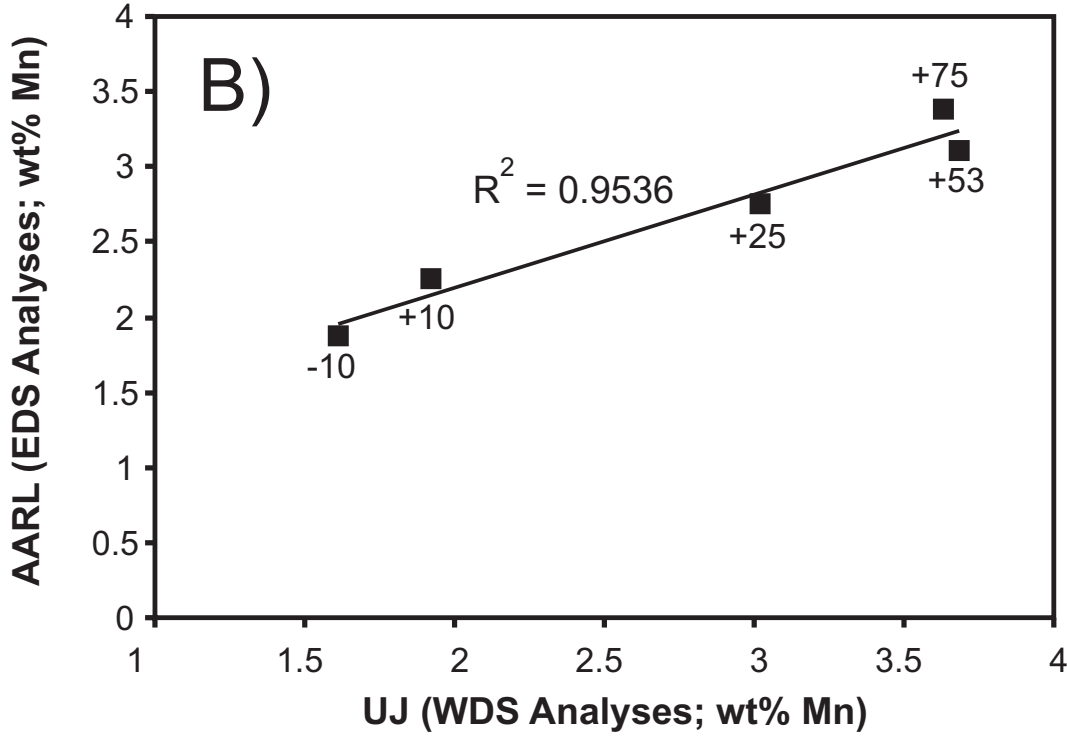
Conclusion:

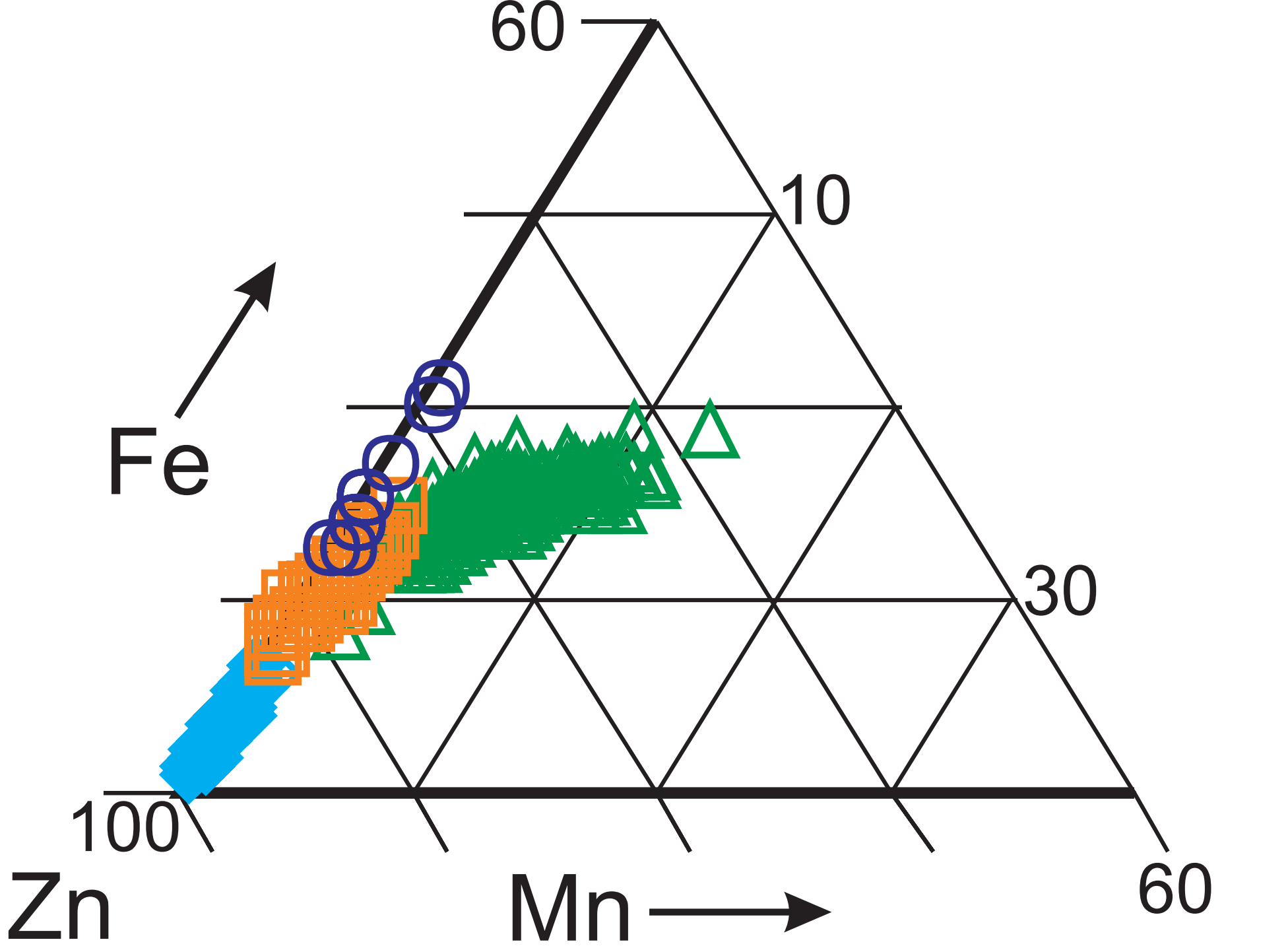
Despite the aerial separation of the Broken Hill and Gamsberg deposits, mineralogical and mineral chemical investigations reveal a complex history characterized by multiple metasomatic events. To date, no less than four distinctly different events have been identified. The pre-metamorphic sulfides consist of various base metal and iron sulfides with elevated concentrations of iron and manganese, while the sulfides of the peak metamorphic event comprise various base metal sulfides with elevated concentrations of cobalt. Sulfides of the post-peak/ retrograde metamorphic event are characterized by various base metal and iron sulfides with elevated concentrations of manganese. Finally, a diverse suite of base metal sulfides and sulfosalts characterizes the late hydrothermal/metasomatic retrograde metamorphic event.

References:

Large, 2003, Geoscience Australia Record 2003/13, p. 93-96; Leach et al., 2005, SEG 100th Anniv. Vol, p. 561-607; Ryan et a.l, 1986, Mineral deposits of Southern Africa: GSSA, Johannesburg, v. 2, p. 1447-147; Spry, 2009, GAC-MAC Conference, V21A-02.


A)
R^2 = 0.9985
Zn
S
Fe
Mn
AARL (EDS Analyses)
UJ (WDS Analyses)


B)
R^2 = 0.9536
+75
+53
+25
+10
-10
AARL (EDS Analyses; wt% Mn)
UJ (WDS Analyses; wt% Mn)
0
0.5
1
1.5
2
2.5
3
3.5
4
1
1.5
2
2.5
3
3.5
4


60
10
30
60
Fe
Zn
Mn
100
Zn-rich
Fe-rich
Mn-poor
Mn-rich