

Genesis of the stratiform BH-t Swartberg Cu-Pb-Zn-Ag deposit, Northern Cape, South Africa

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Abstract. Swartberg is a metamorphosed Broken Hill-type Cu-Pb-Zn-Ag deposit in the north-west of South Africa. The mineralogy and stratigraphy closely resemble that of the nearby Broken Hill, Deeps and Gamsberg deposits. Swartberg is the least-studied of these and this and ongoing studies aim to complete the picture of the district by providing a clearer understanding of the deposit. It comprises two discrete, stacked stratiform orebodies, both of which are deformed by a recumbent, isoclinal F2 fold and refolded by an open F3 fold. The orebodies were deposited in a northeast-southwest trending basin, hinged to the northwest by a hydrothermal feeder fault. Both the upper orebody (UOB) and lower orebody (LOB) formed as syngenetic exhalatives, with the LOB representing an early, precursor exhalation stage to the more extensive stage that formed the UOB. The UOB displays a clear gradation from vent-source proximal chemogenic sediments in the F2 fold hinge, deposited under hotter, more reducing conditions, to distal material formed under cooler, oxidizing conditions. After deposition, the basin underwent several episodes of deformation and metamorphism to medium grades (pressure < 4.5kbar), during which the sulphides underwent limited mobilization into the F2 hinge zone.

Keywords: Swartberg, Broken Hill-type deposit, Eh-pH zonations.

1 Introduction

Swartberg is one of three known economic deposits in the Aggeneys-Gamsberg district, along with Gamsberg, in pre-feasibility stage, and Broken Hill-Deeps, with a 7 year life-of-mine (Fig.1). In light of diminishing resources at Deeps, the previously-mined Swartberg was brought back into production early in 2013.

The Swartberg deposit currently contains measured and indicated resources of 15500kt, grading at 0.67% Cu, 2.90% Pb, 0.68% Zn and 33.52g/ton Ag. However, the deposit remains open down-dip, and an intensive drilling program is underway to increase and upgrade the resource.

While much is known about the nearby deposits, only one study has focused on Swartberg (Stedman 1980). A detailed genetic model is lacking, and little is known about the relationship between the two orebodies. Thus this study aims to clarify these aspects.

2 Geological setting

All of the district's Pb-Zn-Ag±Cu deposits are stratabound and, in most cases, stratiform, and closely associated with thin banded iron formations. All exhibit similar stratigraphy, stratigraphic position, mineralogy, chemistry and metal associations. All share a common

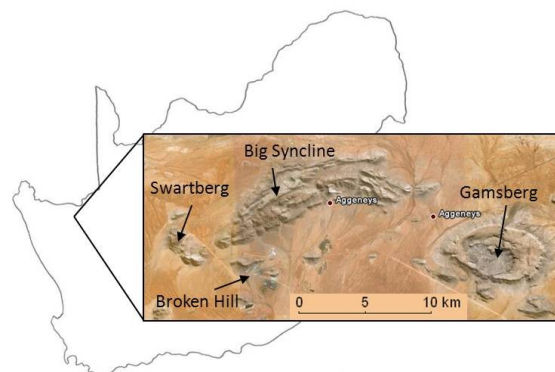


Figure 1. The base metal deposits of the Aggeneys-Gamsberg ore district (Image adapted from Google Earth).

exhalative-sedimentary genesis, followed by polyphase deformation and medium- to high grade metamorphism, and all may be classified as Broken Hill-type (BH-t) (Stedman 1980; Rozendaal 1982; Hoffmann 1993).

The deposits occur within the thin, supracrustal Aggeneys Subgroup, deposited at ca. 1120 Ma (Cornell et al. 2009), and forming part of the metasedimentary Bushmanland Group. These rocks constitute part of the western portion of the Namaqua-Natal Province, a polydeformed belt of greenschist- to granulite facies volcanic and sedimentary rocks.

3 Methodology

Polished thin sections were studied for mineralogy and textures. Quantitative mineral chemistry was carried out using a Zeiss EVO® MA15 SEM, with an Oxford Instruments® X-Max 20mm² detector for major elements and an Oxford Instruments® Wave Dispersive X-ray Spectrometer for traces. Whole-rock chemistry was analysed by ICP-MS at Acme Analytical Laboratories Ltd. in Canada, and used in conjunction with existing Chemex Laboratories assay data, provided by Black Mountain Mine (Pty.) Ltd. (BMM). Stratigraphic and structural interpretations were made using borehole data from BMM.

4 The Swartberg deposit

The Swartberg deposit comprises a package of metalliferous to baritic chemogenic metasediments, hosted by a succession of quartzite and predominantly aluminous schist. As a result of polyphase deformation, the sequence is enveloped by basement gneiss, and displays duplication of some stratigraphic units (Fig.2). As a result, the deposit has been subdivided into two separate orebodies. The upper orebody (UOB) comprises sulphide- and magnetite-rich iron formation in the F2 hinge zone, which grades into and overlies less well

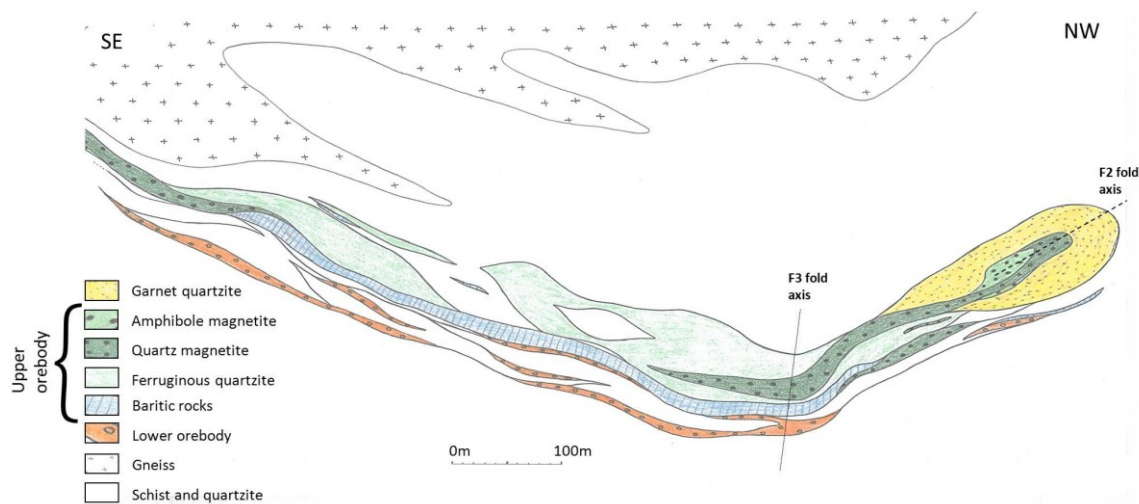


Figure 2. A representative cross-section through the Swartberg deposit, showing the structure of both orebodies.

mineralized hematite-barite and mixed siliclastic- and baritic rocks towards the flanks. The magnetite-rich part is dominated by quartz-magnetite, with increasing amphibole and pyroxenoid towards the F2 hinge zone. A prominent unit of garnet quartzite (cotecule), rich in mobilised chalcopyrite, wraps around the outside of the UOB iron formation in the hinge area. The structure of the garnet quartzite around the LOB is as yet unknown.

The LOB is a fine-grained mineralized pelitic pyritic schist, with minor magnetite- and barite lithologies. It closely resembles unmineralized quartz schist, and laterally it grades into barren quartz schist or quartzite. A variable package of quartz schist, quartzite and garnet quartzite separates the LOB from the UOB, as well as lenses of the LOB. The configuration of the LOB beyond the F2 hinge zone is as yet unknown.

In a NE-SW direction, there is limited variation in the major units. In contrast, there are rapid changes in the UOB in a NW-SE direction, from the F2 hinge to the limbs. These gradations correspond to a zonation in both the chemical composition and redox state of the rocks, from more reduced magnetite- and sulphide-rich rocks in the hinge, to barren, oxidized barite-hematite rocks on the limbs.

5 Mineralogy and textures

Minerals in the UOB are generally medium- to coarse-grained and clearly recrystallised and deformed. Quartz and barite vary between polygonal granoblastic and interlobate, indicating recrystallization and annealing under raised temperatures. Up to three distinct foliations are defined, generally by mica or amphibole lathes, but also by elongated grains of hyalophane, quartz, sheaves of fibrolitic sillimanite, or clusters of garnet. Most major metamorphic minerals occur as inclusions in one another, and inclusion trails of elongated, orientated quartz and magnetite blebs occur in garnet poikiloblasts. The dominant foliation parallels the compositional banding (and concordant lithological contacts), which is regularly observed in the quartz schist, pyroxenoid- and amphibole-bearing magnetite iron formation, and the barite-magnetite/hematite rocks. The presence of cordierite indicates that metamorphism did not exceed medium grade, or pressures of ca. 4.5kbar.

Two generations of pyroxenoid have been identified:

an early phase of rounded grains, and a later phase of overgrowths or rims, which display lower Fe, Ca and Mg, and higher Mn and Zn. This may indicate pyroxenoid growth during 2 separate metamorphic events, possibly the 1220-1170 Ma Kibaran and 1060-1030 Ma Namaquan events (Robb et al. 1999).

Secondary hematite is present as highly martitic magnetite, while primary hematite is less widespread, and occurs as lathes and clusters of specularite.

The sulphide minerals generally appear recrystallised, occurring as rounded to irregular blebs; as inclusions in one another and gangue minerals; as fracture-fills; interstitial to other minerals; and as fine-grained disseminations. Chalcopyrite in the garnet quartzite is mobilized, occurring as large blebs at the triple junctions between quartz crystals. Pyrite, however, may occur as euhedral cubes. Complex textures between the sulphides occur, such as pyrite-chalcopyrite intergrowths, and coronas of pyrite or pyrrhotite on chalcopyrite.

Prograde biotite, muscovite, sillimanite, barite, gahnite and sulphides may show varying degrees of retrogressive alteration. Chlorite is common, and late-stage retrogressive pyrosmalite occurs intergrown with galena. Various alteration minerals occur as rims on sulphides and magnetite. Sillimanite is commonly altered to muscovite, especially in aluminous schist adjacent to pegmatites, and gahnite may be highly retrogressed, and surrounded by an inner rim of white mica and an outer corona of secondary sphalerite.

6 Mineral chemistry

Those minerals that display solid-solution series, such as garnet, pyroxenoid and amphibole, are Fe-Mn-rich, occurring as almandine-pyrope, pyroxmangite and manganoan grunerite respectively. Although sphalerite is the dominant Zn-phase, Zn also occurs in gahnite, and is a minor constituent in pyroxenoid, amphibole, magnetite, hematite, chalcopyrite, pyrite and pyrrhotite. Biotite comprises variable proportions phlogopite (Mg), annite (Fe) and siderophyllite (Al), with up to 7.28% BaO imparting a significant ferrokinoshitalite component. The presence of Ba-rich muscovite, biotite and hyalophane indicates a Ba-halo in the footwall of the UOB, particularly surrounding the iron formation. Sphalerite is generally Fe-Mn-rich (<1.5% Mn), but later

secondary low Fe-Mn-phases occur as overgrowths. Chalcopyrite disease is common.

Silver is an important byproduct of the Swartberg deposit, and mostly occurs in solid solution with galena and chalcopyrite. Galena has an average Ag-content of 173ppm, but hosts up to 2317ppm. Bismuth and cobalt are both penalty elements and occur in galena, sphalerite and chalcopyrite. Cobalt may also occur as allosclerite. Whole rock geochemistry correlation coefficients support these mineralogical relationships.

7 Whole-rock geochemistry

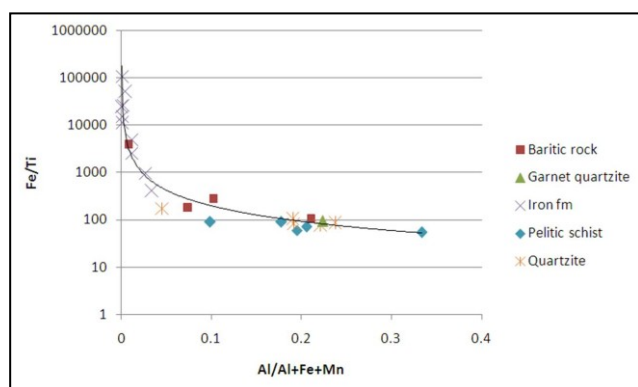


Figure 3. Fe/Ti vs Al/(Al+Fe+Mn) plot for the major Swartberg units. A top-left position indicates greater chemogenic component, with detrital material increasing to the right.

The iron formation has a predominantly chemogenic origin; the baritic units (which comprise varying proportions of barite, hematite, magnetite and quartz, with minor mica, garnet and sillimanite) follow a mixing trend between chemogenic and detrital material; and the pelitic schist and quartzite is predominantly detrital (Fig.3). No trend is visible for the garnet quartzite, due to limited data.

Geochemically the strongest correlations are between Zn and Cd ($r=0.92$), Pb and Sb ($r=0.86$), Ni and Co ($r=0.82$), V and Cr (0.79), K and Al (0.79), and Ag and Pb (0.69). These data support mineral chemistry findings that most Cd is hosted in the sphalerite crystal lattice, and that most Ag and Sb occur in galena. The strong Co-Ni correlation is explained by the partitioning of both of these elements into pyrite and pyrrhotite, as shown by their elevated concentrations in SEM analyses.

A comparison of whole-rock from Gamsberg, Deeps and Swartberg shows that Ag-Pb-Sb and Zn-Cd correlations are good throughout the Aggeneys-Gamsberg ore district. Swartberg, however, has significantly higher Ag- and Sb- to Pb ratios than Broken Hill-Deeps and Gamsberg.

8 Discussion and conclusions

8.1 Basin architecture

The sediments of the Swartberg deposit were deposited in a NE-SW trending basin, hinged to the NW by a feeder fault, as postulated by several authors (Rozendaal 1982; Lipson 1990; Hoffmann 1993; Stalder 2004). The lack of major NE-SW variation within lithological units,

compared to the rapid NW-SE gradation from iron formation to barite rock over several hundred metres, implies a NE-SW elongated basin.

Also, it appears that the formational fluids at Swartberg differed from those of Broken Hill and Gamsberg: according to thermodynamic modelling, hydrothermal fluids with low pH (3.5-4), high temperatures (350°C), and high chloride concentrations are conducive to transporting high concentrations of Ag and Sb (Pavlova et al. 2006). Following Allemann (2008, *unpub.*), this may indicate that the hydrothermal fluids that formed the Swartberg deposit, with its relatively high Ag+Sb/Pb ratio, were more acidic and chloride-rich than those forming Gamsberg or Broken Hill-Deeps, which have lower Ag- and Sb- to Pb ratios. This indicates that the fluids forming Gamsberg and Broken Hill may have had the same source, while the source of the Swartberg fluids differed, implying formation in a separate basin. The formational basin was thus narrow (hundreds of metres), elongate (several kilometres or more), and separate from those of the other deposits.

8.2 Zonations within the UOB

The gradation in the UOB from sulphide-rich, amphibole-bearing magnetite in the F2 hinge, to Pb- and Zn-rich iron formation and poorly mineralized barite-hematite rocks in the limbs, corresponds to lateral Eh-pH and temperature zonation in the basin: the hinge zone sulphide-oxide facies was deposited by dominantly reducing, high-temperature fluids proximal to the vent (Stedman 1980; Rozendaal 1982), whereas the barite-hematite facies along the limbs corresponds to deposition under cooler, more oxidizing distal conditions (Fig. 4). Comparison with the other, well-studied deposits of the district supports these ideas:

- The mineralogy of the F2 hinge zone resembles that of Broken Hill, which is considered to have formed proximal to a vent (Rozendaal 1982). Both deposits display sulphide-bearing magnetite iron formation, indicative of deposition by reduced hydrothermal fluids, and both contain Cu (although Swartberg is richer), indicating precipitation from hot fluids.
- Primary hematite and barite indicate deposition under oxidizing conditions, and at Gamsberg these have been linked to a distal chemogenic origin (Rozendaal 1982). Thus the barite- and hematite bearing portions of Swartberg (the F2 fold flanks) correspond to distal chemogenic deposition by cooler, oxidizing fluids.
- According to McClung (2006), oxygen isotope values show that the Cu-rich, Ba-poor parts of Swartberg (F2 hinge) formed at temperatures above 250°C.

8.3 Position of the feeder fault

The F2 hinge corresponds to the region of the feeder vent, as evidenced by the zonation from proximal lithologies in the hinge zone to distal lithofacies in the limbs. It is speculated that the tensional tectonic stress regime that controlled the orientation of the growth fault and basin architecture was also responsible for the later, albeit compressional tectonic, deformation; the feeder

fault would have acted as a zone of weakness during deformation (Stedman 1980). The footwall garnet quartzite could represent the metamorphosed feeder zone (Stedman 1980; Rozendaal 1982). A similar zone of copper-pyrite-rich footwall alteration underlies several stratiform Pb-Zn orebodies, particularly close to the hydrothermal fluid feeder zone (Stedman 1980).

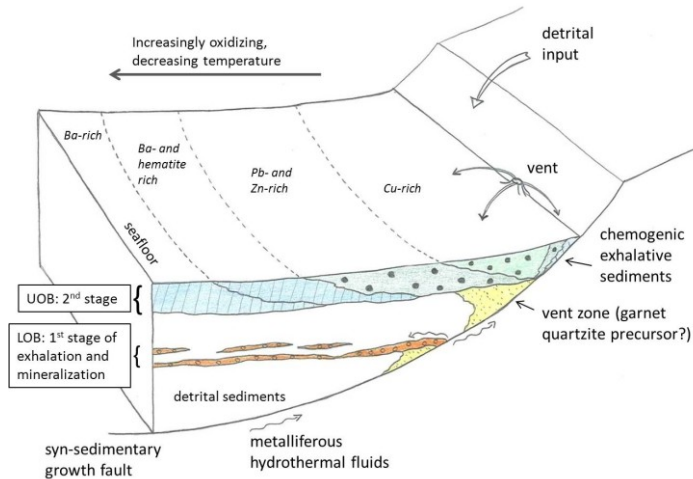


Figure 4. Schematic reconstruction of the Swartberg depositional basin, illustrating the positions of the UOB, LOB and feeder fault, and the lithological zonation of the UOB.

8.4 Mode of orebody deposition

The UOB is interpreted to be of synsedimentary exhalative origin, and formed by the direct precipitation of chemogenic lithologies mixed with limited detrital sediments on the seafloor. This is supported by:

- Several authors have interpreted finely-banded sulphides in the district as sedimentary layering (Stedman 1980; Rozendaal 1982; Lipson 1990).
- Magnetite-bearing units regularly display clear compositional banding parallel to concordant lithological contacts. Thus magnetite appears to be primary, deposited syndesimentarily with other chemogenic sediments.
- The transition from detrital metasediments (quartzite, aluminous- and quartz schist) to the chemogenic UOB lithologies is gradual, with concordant contacts.
- The ore minerals are restricted to specific lithologies, indicating syndesimentary precipitation together with the host units.

The LOB may have been deposited by an early exhalation event, prior to the more extensive exhalation of the UOB material. The two exhalation stages were separated by a period of predominantly detrital sedimentation, during which small amounts of early hydrothermal fluids were debouched onto the seafloor. These precipitated minor chemogenic material together with predominantly pelitic detrital sediments, creating the Ba-halo present in the footwall of the UOB.

8.5 Summary

The Swartberg deposit formed in a restricted basin, elongated in a NE-SW direction and hinged by a feeder

fault to the NE. The LOB was formed first, by an initial pulse of hydrothermal fluids exhaled onto the seafloor from the feeder fault. This was followed by a period of predominantly pelitic detrital sedimentation, along with small amounts of early hydrothermal fluids that formed the footwall Ba-halo. Finally, a more extensive exhalation event occurred, precipitating the predominantly chemogenic lithofacies of the UOB. This package displays lateral zonations, as a result of Eh-pH and temperature variations with distance from the vent.

Like the other three deposits of the ore district, Swartberg displays lateral and vertical facies changes; evidence of multiple hydrothermal pulses; and mineralization hosted by both chemogenic and pelitic sediments. However, the restricted nature of the Swartberg basin, and the differing physico-chemical properties of the hydrothermal fluids, suggest that it formed in a sub-basin separate from the other deposits in the area, as suggested by previous authors.

Swartberg remains open down-dip, and the laterally continuous nature of the lithofacies in this direction indicates the potential for a significant increase in the resources of this deposit: could Swartberg become the “next Gamsberg”?

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