Geology of the Salt River volcanogenic massive sulphide (VMS) deposit, South Africa

C.R. McClung, N. Norman & M. Welthagen
Thabex Exploration Ltd., P.O. Box 3899, Northcliff, Johannesburg 2115, South Africa

ABSTRACT: The Salt River Zn-Cu-Pb ± Ag-Au deposit is hosted by the Mesoproterozoic volcano-sedimentary rocks of the Geelvloer Sequence of the Northern Cape Province, South Africa. The stratigraphy of the Geelvloer Sequence consists of a basal package of volcanic rocks that are gradationally overlain by a thick package of volcanic, volcaniclastic, volcanogenic and calc-silicate-rich rocks collectively deformed during the ~1000-1200 Ma Namaquan Orogeny. Economic base-metal sulphide minerals are restricted to three zones, they consist of a capping semi-massive to massive, very fine- to fine-grained, durchbewegung-textured pyritic horizon (Upper Sulphide Zone) with localized stringer mineralization in Mg-rich altered rocks that become less conspicuous downwards (Middle to Lower Sulphide Zones). Geologic and mineralogic evaluations suggest that volcanism, sedimentation and base-metal sulphide mineralization occurred contemporaneously in a back-arc basin environment. Textural evaluations of the various sulphide horizons indicate that the Upper Sulphide Zone represents sulphide exhalation onto the seafloor, while the Middle Sulphide and Lower Sulphide Zones represent footwall stringer mineralization in Mg-rich altered footwall rocks. In conclusion, geologic, textural and mineralogic investigations of the Salt River deposit indicate that it represents a volcanogenic massive sulphide (VMS) or Kuroko-type base-metal mineralization.

KEYWORDS: VMS, Namaqualand, Mesoproterozoic, Copper-Zinc-Lead, South Africa

1 INTRODUCTION

In 1974, investigations of an aeromagnetic anomaly on the farm Adjoining Geelvloer 197 by Phelps Dodge Corp. lead to the discovery of an unassociated suboutcropping gossan. Subsequent geologic, geophysical and geochemical surveys resulted in the definition of a subeconomic orebody with an inferred resource of 7.2 Mt grading 2.31% Zn, 0.86% Cu, 0.51% Pb, 24 g/t Ag and 0.64 g/t Au. In spite of this, due to the low-grade and tonnage of the resource, the property was repeatedly dropped, picked-up and explored by various exploration companies until 1997 when the mineral rights were purchased from the farmer by Thabex Exploration Ltd.

In conjunction with the increase in metal prices, extensive diamond drilling and geologic work has resulted in upgrading of the orebody to an indicated resource of 42.5 Mt at 1.47% Zn, 0.65% Cu, 0.28% Pb, 12.3 g/t Ag and 0.18

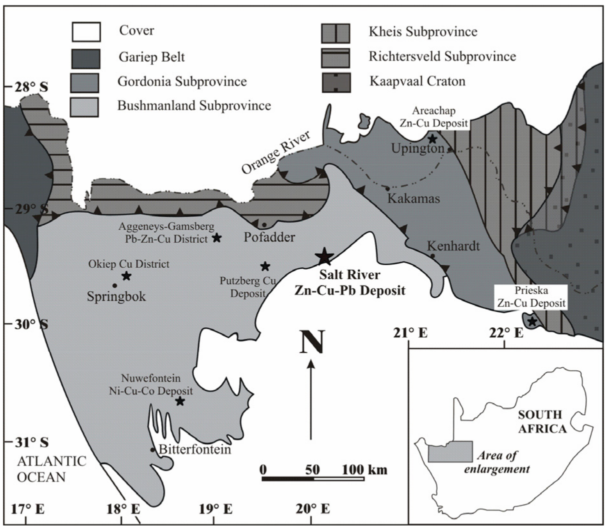

Figure 1: Map showing the South African extent of the Namaqua Province, location of the Salt River deposit and other important base-metal deposits/districts, as well as the tectonic subprovinces of the Namaqua Province.

g/t Au with a high-grade zone measuring 4.6 Mt at 3.35% Zn, 0.56% Cu, 0.54% Pb, 11.6 g/t Ag and 0.09 g/t Au. However, it should be noted that the deposit remains open down plunge to at least 3000m or roughly 1300m below surface.

2 REGIONAL GEOLOGY

The Salt River deposit occurs at the south-eastern outcrop limit of the Bushmanland Subprovince of the Namaqua Province (Fig. 1). The Namaqua Province represents a crescent-shaped belt of Palaeo- to Mesoproterozoic volcano-sedimentary rocks deformed and metamorphosed during the Namaquan Orogeny (1000-1200 Ma) and that crops out throughout southwestern Africa.

2.1 *Stratigraphy*

The supracrustal rocks of the Salt River deposit belong to the informally termed Geelvloer Sequence of the Bushmanland Group (McClung 2007). Schematically summarized in Figure 2, the stratigraphy of the Geelvloer Sequence consists of a basal pink-brown augen gneiss with numerous similarities to the intrusive granites of the Namaquan Orogeny. Locally, grey-green, banded and foliated para- to orthoamphibolites of the Basal Amphibolite sharply overlie the basal augen gneiss; however, where the Basal Amphibolite is absent, medium-grained, pink, quartzo-feldspathic granitic gneisses of the Pink Leptite sharply overlie the basal augen gneiss. The Pink Leptite is differentiated from the other "pink leptites/gneisses" by the common occurrence of small (mm to cm sized) "quartz eyes." The poorly exposed heterolithic Lower Biotite Gneiss separates the Pink Leptite (below) from the Upper Calc-silicate Gneiss (above). Composed of grey biotite gneiss, para- to orthoamphibolites, calc-silicate rocks, quartz-sericite and biotite-chlorite schists, as well as lenses of leptitic rocks, chert and sulphide horizons, the Lower Biotite Gneiss is the economically most significant unit and can be further subdivided as illustrated in Figure 2. Likewise, the conformably overlying Upper Calc-silicate Gneiss can be subdivided into calc-silicate rocks, grey leptite (calc-silicate-rich metagreywacke) and metaconglomerates. Although only exposed in drill core, the Upper Calc-silicate Gneiss is conformably overlain by a thick sequence (~450m thick) of biotite gneisses and micaceous schist of the Middle and Upper Biotite Gneiss, as well as the Micaceous Schist (Fig. 2).

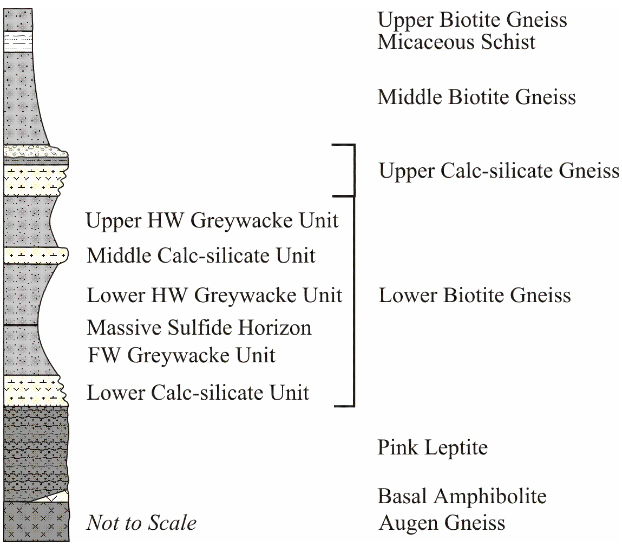

Figure 2: Schematic stratigraphic column for the Geelvloer Sequence at the Salt River deposit.

2.2 *Structure and Metamorphism*

Based on the structural and metamorphic investigation conducted by Maclaren (1988), the Geelvloer Sequence appears to have undergone similar styles of deformation and degrees of metamorphism as the remainder of Bushmanland Subprovince (Joubert 1986; Colliston & Schoch 2002; McClung 2007). In short, the rocks of the Bushmanland Subprovince underwent three phases of deformation and metamorphosed during the Namaquan Orogeny (~1000-1200 Ma). The first phase of deformation [D_2] consists of tight, isoclinal folding [F_1-F_2] associated with prograde to anatectic amphibolite-facies metamorphism [M_1-M_2] synchronous with the emplacement of numerous granitic intrusives that were rapidly followed by southward directed thrusting. The second phase of deformation [D_3] can be further subdivided into an early [D_{3a}] event characterized by large-scale open, asymmetrical folds [F_3] and amphibolite- to granulite-facies metamorphism [M_3], while the latter [D_{3b}] event consists of north-northeast trending monoclinal folds with eastward dipping limbs [F_4], late retrograde metamorphism [M_4] and oblique shearing.

3 MINERALIZATION

3.1 *Mineralogy*

Petrographic, XRD and SEM investigations reveal that pyrite is the most abundant sulphide, followed by sphalerite, chalcopyrite and galena with accessory concentrations of digenite/covellite and an unidentified highly reflective mineral (sulphosalt?). In thin-section, pyrite is observed to be fringed, cross-cut by and intergrown with sphalerite, chalcopyrite and galena. Furthermore, some crystals of sphalerite display intense chalcopyrite disease, while digenite/covellite forms an alteration halo on crystals of chalcopyrite. Due to the apparent absence of precious metal-bearing minerals, interelement correlations have been used and suggest that Ag is associated with Pb, possibly as argentiferious galena, and Au is associated with Cu, possibly as auriferous chalcopyrite.

3.2 *Styles of mineralization*

Base-metal sulphide mineralization of the Salt River deposit is largely restricted to the Massive Sulphide Horizon and Footwall Greywacke Unit of the Lower Biotite Gneiss; however, minor amounts of base-metal sulphide mineralization are locally observed in the Lower Hangingwall Greywacke Unit and rarely in the Middle Calc-silicate Unit (see Fig. 2). Four distinct styles of mineralization have been identified, they are: 1) semi-massive to massive, 2) mineralized biotite-chlorite schist, 3) stringer mineralization in Mg-rich altered rocks and 4) mineralized calc-silicate rocks. The semi-massive to massive style of mineralization is characterized by a very fine- to fine-grained, semi-massive to massive, durchbewegung-textured pyritic horizon. In contrast, mineralized biotite-chlorite schist is characterized by disseminations to stringers of semi-massive pyrite and chalcopyrite with lesser amounts of sphalerite and galena in foliated and contorted biotite-chlorite schist interbedded with Mg-rich altered rocks. Analogous to the latter, stringer mineralization in Mg-rich altered rocks consists of disseminations to stringers of semi-massive pyrite and chalcopyrite with lesser amounts of sphalerite and galena in a foliated quartz, cordierite, phlogopite and amphibolite-rich rock unit; this type of alteration is aerially restricted to the higher-grade portion of the deposit. Although restricted to a few intersections, mineralized calc-silicate rocks consist of silicified and/or brecciated calc-silicate rocks of the Middle Calc-silicate Unit cross-cut by veins of pyrite, chalcopyrite and sphalerite.

3.3 *Sulphide horizons*

As alluded to above, sulphide mineralization is largely restricted to three sulphide horizons, termed Upper, Middle and Lower Sulphide Zones (Fig. 3). The Upper Sulphide Zone (USZ) is characterized by a capping of semi-massive to massive sulphide with stringer mineralization in Mg-rich altered rocks becoming less conspicuous downwards. In contrast, the Lower Sulphide Zone (LSZ) comprises semi-massive to stringers of sulphide in biotite-chlorite schist and Mg-rich altered rocks with unmineralized Mg-rich altered rocks directly overlying the mineralized schist. In the higher-grade portion of the deposit, a third zone is developed between the USZ and LSZ. Termed the Middle Sulphide Zone (MSZ), it consists of sulphide stringers in Mg-rich altered rocks.

4 DISCUSSION

Detailed local and regional-scale geologic and stratigraphic evaluations of the Salt River deposit suggest that the Geelvloer Sequence was deposited in a tectonically active east-

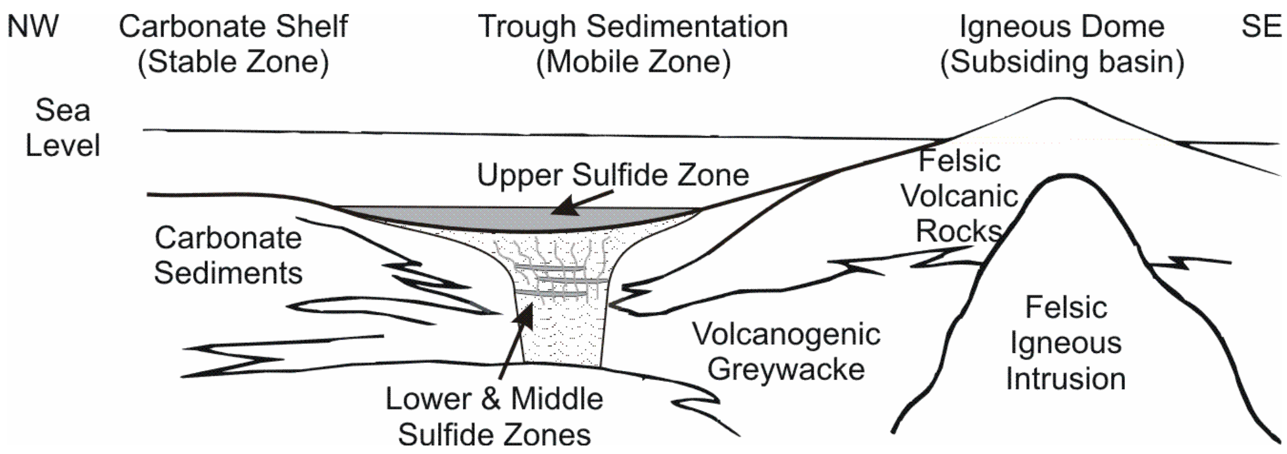

Figure 3: Schematic cross-section through the Salt River VMS deposit during deposition of the sulfide minerals, modified from Hutchinson *et al.* (1971).

northeast trending trough or half-graben. The presence of intraformational conglomerates in the Lower Biotite Gneiss and Upper Calc-silicate Gneiss are interpreted as evidence for deposition in an actively subsiding depositional environment. Analogously, the presence of thick laterally extensive calc-silicate rocks to the west-northwest and mixed shallow subaqueous volcanic rocks and calc-silicate rocks to the east-southeast (Fig. 3) further support deposition in structurally-controlled secondary or tertiary basins. The ubiquitous presence of bimodal volcanic, volcaniclastic and volcanogenic rocks throughout the Geelvloer Sequence, close spatial association with the granodiorite-tonalite intrusives of the T'Oubep Suite to the northeast and similar U-Pb zircon ages (*i.e.* ~1200 Ma) for the Geelvloer Sequence (McClung 2007) and T'Oubep Suite (Joubert 1986) indicate that volcanism and sedimentation occurred contemporaneously in a back-arc basin.

In addition to the above stated, the close spatial association between sulphides, volcanic rocks and Mg-rich footwall alteration, as well as the widespread occurrence of chalcopyrite disease in sphalerite, suggest that the Salt River deposit was formed in association with submarine volcanic activity, *i.e.* as a volcanogenic massive sulphide (VMS) or Kuroko-type deposit. Furthermore, the fine grain size of individual sulphide minerals, semi-massive to massive and laterally extensive nature of the Massive Sulphide Horizon (*i.e.* USZ) indicates that it may have formed through exhalation onto the seafloor. In contrast, the Cu-rich stringer mineralization and abundance of Mg-rich altered rocks in the MSZ and LSZ, suggest that they represent footwall stringer mineralization as described by Sangster (1972).

5 SUMMARY

In conclusion, geologic and mineralogic studies of the Salt River deposit indicate that contemporaneous volcanism, sedimentation and base-metal sulphide mineralization occurred in a back-arc basin roughly dated at 1200 Ma. Likewise, textural evaluations of the various sulphide horizons indicate that the USZ represents sulphide exhalation onto the seafloor, while the MSZ and LSZ represent footwall stringer mineralization in the footwall alteration zone. Geologic, textural and mineralogic investigations of the Salt River deposit indicate that it represents another example of volcanogenic massive sulphide (VMS) or Kuroko-type base-metal mineralization in South Africa.

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