Controls on Stratabound Copper Mineralization
at
Klein Aub Mine and Similar Deposits
within the Kalahari Copperbelt of
South West Africa/Namibia and Botswana

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DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the degree of Doctor of Philosophy in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any other degree or examination in any other University.

Johannesburg [illegible]

ABSTRACT

The Middle Proterozoic (1300-950 Ma) Sinclair Sequence and its stratigraphic equivalents crop out intermittently in a belt which extends from central SWA/Namibia to Botswana. Due to its numerous stratabound Cu occurrences, it is here called Kalahari Copperbelt. The sequence probably formed in the inland branch of an intercratonic failed rift system, situated between the Congo and the Kalahari Cratons. Development started with an initial, mechanical rift phase probably in response to an underlying mantle plume and resulted in bimodal tholeiitic volcanism and strong extensional tectonism of the Nückopf and Grauwater Formations. During Doornpoort Formation times, continental red beds filled the narrow fault-bounded grabens with alluvial fan, braided stream, local evaporitic playa lake, and aeolian dune sediments. A widening of the basin, an overstepping of the graben shoulders and a marine transgression, caused the deposition of laterally extensive, mixed siliciclastic/carbonate sedimentation (Klein Aub Formation) in a tidal flat environment. This resulted from a later thermal subsidence phase. Both tectonically and sedimentologically the Sinclair Sequence heralds the subsequent development of the early Damara rifting. The area underwent three phases of deformation; (D_1) syndepositional block faulting, possibly with a dextral strike-slip component, (D_2) the main deformational event of the Damara Orogeny, producing large-scale folding and a regional cleavage; (D_3) transpression, resulting in the development of a dextral, oblique-slip fault zone. Regional lower greenschist metamorphism affected the sequence and was accompanied by basalt alteration and a substantial depletion in Cu, Zn, Co, Mg, Na and K. Stratabound sediment-hosted Cu/Ag mineralization occurs in dark pyritic sediments at the redox interface between the red bed and marine unit. Precious elements (Au and PGE) are enriched in the initial acid volcanics at the base of the rift sequence and in the stratabound ores. Mineralization of the sediments was a two-phase event and produced disseminated, permeability- controlled ores during early diagenesis and fracture-hosted ores, superimposed on the e er phase, during or after deformation. Metals were supplied by the selective leaching of Cu from underlying basalts and Au and PGE possibly from red beds and transported as chloride complexes in acid, oxidizing fluids.

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CONTENTS

A—Twig. B—Trench.

From: De re metallica (Agricola, 1556)

"In Bergesadern, Mauersgründen,
ist Gold gemünzt und ungemünzt zu finden,
und fragt ihr mich wer es zu Tage schafft,
begabten Manns Natur und Geisteskraft."

("In mountain veins, old walls and underground,
is gold uncoined or minted to be found,
and if you ask who'll bring that store to light,
'tis the endowed with mind and natures might.")

Mephistopheles in Goethe's Faust II, Act I

1. PREAMBLE

This foreword is meant as a brief review of the published facts and fiction on sediment-hosted stratabound copper deposits. Deposits of this type have been extensively mined for several hundred years, but ore genesis models are not unequivocal and many opposing explanations have been proposed. Several of these controversial aspects are presented here to emphasize the complexity of these deposits without claiming complete coverage of all interpretations.

Sediment-hosted stratabound copper deposits supply some 25 percent of the world's Cu as well as significant amounts of Ag, Pb, Zn, Au, Pt, Pd, Os, U, Mo, Re and Bi. Amongst the largest and best documented of these deposits are the Kupferschiefer, Germany and Poland; White Pine, Michigan, Udokan and Dzhezkazgan, USSR; the Central African Copperbelts, Zambia and Zaire; Redstone River, Canada; Flowerpot Shale, Oklahoma, USA; and the Stuart Shelf, South Australia (Gustafson and Williams, 1981; Haynes, 1986 a,b). The deposits are characteristically associated with intracratonic regions and are often related to major episodes of continental breakups (Lorenz and Nicholls, 1976; Gustafson and Williams, 1981; Jowett and Jarvis, 1984; Jowett 1986; Sawkins, 1986). This type of deposit appears to have formed preferentially during two time periods - in the Early and Middle Proterozoic and at the boundary between the Paleozoic and Mesozoic (Meyer, 1981; Hutchinson, 1983; Badham, 1981).

An important sub-group is related to marine transgressions over red terrestrial volcano-sedimentary successions. Deposits of this sub-group include the Kupferschiefer, White Pine and the Central African Copperbelts. Commonly this sub-group is referred to as shale-hosted deposits, although mineralization occurs in a variety of different rock types such as conglomerate, sandstone, siltstone, shale or carbonate. This sub-group has been studied with regard to the sedimentology, mineralogy, tectonic setting, relationship to volcanism and isotopic signature. Advances in the understanding and explanation of this type of ore deposit have taken place during the last decades with a wide variety of opposing explanations being proposed for the source of metals, the transport and precipitation mechanisms; and the timing of metal emplacement. Ore genesis models range from syngenetic (Garlick, 1961; Dunham, 1964; Wedepohl, 1971; Binda 1975), to early diagenetic (e.g. Rentzsch, 1974; Brown, 1984; Brown and Chartrand, 1986; Haynes, 1986 a,b), to late diagenetic (Jowett, 1986) and at least partly epigenetic (Brown,1974, 1978; Friedrich et al., 1984).

Wedepohl (1971) interpreted the isotopic signature of copper sulphides as evidence for a syngenetic origin of the mineralization of the Kupferschiefer. Sulphur isotopic studies from many of these deposits show that the values are either characteristic for evaporites which are associated with many deposits or of biogenic sulphate reduction (Sangster, 1976; Gustafson and Williams, 1981). The epigenetic explanation was challenged by other authors (e.g. Badham, 1981) who pointed out that biogenic sulphate reduction can occur in lithified strata. Since the epigenetic replacement of synsedimentary or early diagenetic pyrite will produce a partly inherited biogenic signature, the application of this model appears questionable. Evidence for more than one phase of metal emplacement can be found in many of these deposits and polyphase ore genesis models have also been suggested by some authors (e.g. Badham, 1981; Schmidt, 1985; Borg and Maiden, 1987; Jowett, 1986; Schmidt et al., 1986; Speczik et al., 1986).

Other controversial discussions focus on the possible metal source (Gustafson and Williams, 1981). Based on lead isotopic signatures typical of local basement rocks, some authors favour a mineralized hinterland as the metal source (e.g. Binda, 1975; Wedepohl et al., 1978; Clemmey, 1978; Ruxton, 1986). Other sources proposed are underlying red beds and/or mafic volcanics from which the base metals were leached (e.g. Brown, 1978; Badham, 1981; Jowett, 19[illegible]; Lur'ye, 1986; Sawkins, 1986). Annels (1979) and Brown (1986) discussed the possibilities of exhalative and pene-exhalative mineralizing fluids with a magmatic metal source. A widely neglected possibility is the heritage of mineralized fluids, trapped in the basement underlying the volcano-sedimentary basins (Kelly et al., 1986). According to these authors, basement sequences, which are generally regarded as impermeable, often contain megascopic 'fluid inclusions' trapped by self-sealing mechanisms during deep burial. They regard the basement rocks and the associated ancient formation waters as an integral part of the basinal hydrologic regime. Surface water such as rivers (Wedepohl et al., 1978; Clemmey, 1978), seawater (Brongersma-Sanders, 1965) or ground water (Haynes, 1986 a,b) are proposed fluid driving mechanism for syngenetic or early diagenetic models. Basin loading, sediment compaction and basin dewatering is commonly regarded as the main fluid driving mechanism for metal bearing fluids in post-depositional models (Gustafson and Williams, 1981). Since the deposits are commonly associated with tectonically active intracratonic settings (Gustafson and Williams, 1981), seismic pumping (Sibson et al., 1975; Sibson, 1981) might have been an important driving force for basinal fluids. Convecting fluids, driven by a temperature gradient between basin centres and margins, are envisaged by Jowett (1986). Chemical aspects of the metal bearing fluids have been studied and reviewed extensively by Rose (1976), Haynes and Bloom (1987).

The significance of the various geological aspects for the complex ore genesis requires a broad geological approach in order to evade preconception of genetic interpretations.

2. INTRODUCTION

2.1 Location

Rocks of the Middle Proterozoic Sinclair Sequence (1300 - 950 Ma) in SWA/Namibia and correlatives in Botswana are exposed in a discontinuous, arcuate belt stretching from southern SWA/Namibia into the northern part of Botswana (Fig.2.1). Since each area hosts similar stratabound, sediment-hosted Cu mineralization the belt is referred to as the 'Kalahari Copperbelt' of SWA/Namibia and Botswana.

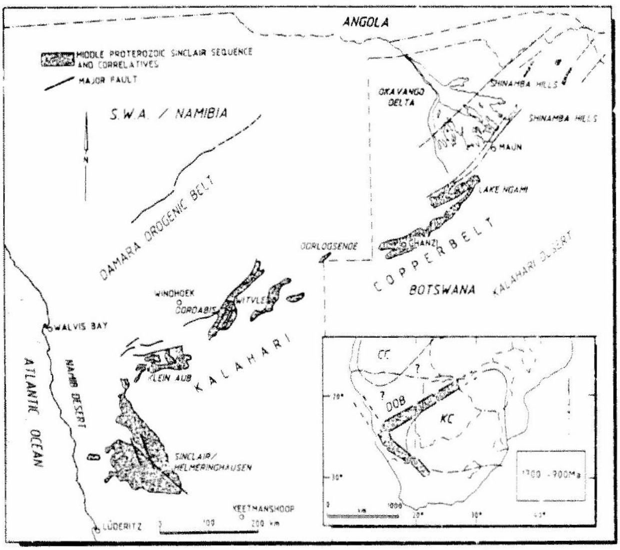

Fig. 2.1: Sketch map showing the regional distribution of the Sinclair Sequence and its equivalents in SWA/Namibia and Botswana. The insert map outlines the branches of a proposed failed rift system of Sinclair age (Borg, in press) in relation to the Kalahari- (KC) and Congo- (CC) Cratons and the Damara Orogenic Belt (DOB).

The main study area of Klein Aub is situated in central SWA/Namibia, some 180 km southwest of Windhoek where the only operating mine was closed in early 1987. Other areas studied were Doeabis, Witvlei and Oorlogsende which are located east-southeast of Windhoek (Fig.2.1) and the regions of Ghanzi, Lake N'Gami, and the Shinamba Hills in central and northeastern Botswana.

2.2 Previous Work

The rocks of the Sinclair Sequence in the different study areas between Klein Aub and Lake N'Gami have been mapped by various authors such as De Kock (1934), Gevers (1935), Martin (1965), Wright (1958), Schalk (1961, 1967, 1970), De Waal (1966), Schalk and Hälbich (1965), Handley (1965), Toens (1975), Fey (1976), Thomas (1973) and Walker (1974). Stratigraphic correlations between the different areas were proposed by Martin (1965), Schalk (1970), Toens (1975), South African Committee for Stratigraphy = SACS (1980), Ruxton (1981) and Williams-Jones (1984). The age and degree of metamorphism in the Klein Aub area was determined by Ahrendt et al. (1978). A study of the Cu-Ag ores at Witvlei was published by Anhaeusser and Button (1973). Tregoning (1977), Maiden et al (1984), Ruxton (1981, 1986), Ruxton and Clemmey (1986), Borg and Maiden (1986b) described aspects of the mineralisation and proposed ore genesis models. Sedimentological studies and environmental interpretations of a limited portion of the stratigraphic successions were undertaken by Ruxton (1981, 1986) and Ruxton and Clemmey (1986). Williams-Jones (1984) carried out a geochemical study on basalts from the Dordabis area. Hughes et al. (1984) and Ruxton (1981, 1986) published data on lead and sulphur isotopes from Klein Aub Mine. Cole and Le Roex (1978) described geobotanical aspects and Killick (1986) gave a brief description of the Cu occurrences within the Sinclair Sequnece. Radiometric age data for a number of intrusive and extrusive igneous rocks from the study areas in SWA/Namibia and Botswana were obtained by De Waal (1966), Van Niekerk and Burger (1969), Harding and Snelling (1972), Burger and Coertze (1973-74), Hugo and Schalk (1974), Key and Rundle (1981) and Hegenberger and Burger (1985).

Watters (1974), Kröner (1977), Reeves (1978, 1979), Mason (1981), Meixner (1983), Cahen et al. (1984) and Porada (1985) made attempts to incorporate the volcano-sedimentary successions of the Sinclair Sequence and its correlatives into the structural framework of southern Africa.

2.3 Objectives of the Study

The present study attempts to describe the sediment-hosted copper mineralization occurring in the segments of the Kalahari Copperbelt of SWA/Namibia and Botswana. The aim is further to relate the localization, character and ore genesis of the stratabound Cu-Ag mineralization within the Sinclair Sequence and its correlatives, to the igneous, sedimentological, metamorphic, and regional and local structural history of the basins. Another objective is to investigate the distribution of Platinum Group Element (PGE) and Au in the formations of the Kalahari Copperbelt in order to localize source and host rocks for mineralization.

2.4 Methods of Investigation

The study focuses mainly on the area of Klein Aub, where good exposure of all stratigraphic units of the Sinclair Sequence and the underground workings at Klein Aub Mine allowed the investigation of the mineralization and its lithological, geochemical and structural setting. The results from the Klein Aub area can be regarded in many ways as a case study for the other Middle Proterozoic basins in central SWA/Namibia and Botswana.

Investigations of other areas of exposed Middle Proterozoic rocks in SWA/Namibia and Botswana was less detailed due to both an overall lack of underground workings or boreholes and the limited exposure due to Kalahari sanddunes to the east. However, studies of the other areas did include lithological logging and sampling of representative boreholes and surface sampling for both geochemical and petrographical investigations.

In order to establish the tectonic and sedimentological evolution of the basins, 20 lithological profiles, that covered some 70 km along strike, were measured in the area of Klein Aub. Since the depositional environment of some of the Middle Proterozoic formations has been the subject of dispute (Mason, 1981, Ruxton, 1981, 1986), a more detailed facies analysis was undertaken for the mineralized portion of the sequence.

Cores from a representative diamond drill hole in the Dordabis area have been logged to demonstrate the relationship between sedimentary and volcanic rocks.

Since the orebodies at Klein Aub Mine are located adjacent to a major fault, the collection of structural data from a selected surface area and a crosscut in mine workings was also undertaken. A total number of 88 rock samples from the study areas have been analyzed by X-ray fluorescence (XRF) analysis for major and trace elements at the Geological Survey of South Africa. CIPW-norms for the felsic volcanic rocks have been calculated.

A geochemical and petrographical investigation of all possible source and host rocks for stratabound mineralization was carried out to study alteration, base metal depletion- and redistribution processes, especially in mafic volcanic rocks. Since PGE and Au are a significant constituent of other sediment-hosted Cu-Ag deposits, 30 samples from all stratigraphic units were analysed for PGE by Neutron Activation Analysis (NAA). The distribution of mineralization was studied on different scales, including ore petrology of polished and thin sections, detailed mapping of mineralized pillars in mine workings, interpretation of reef plans and the lithological and stratigraphical position within the basin. In order to localize further ore mineral phases, selected samples were investigated and analysed by Scanning Electron Microscope (SEM).

Samples of altered basalt, mineralized sediment and ore concentrate were analysed by X-ray diffraction (XRD) to identify metamorphic and ore minerals.

Chemical constraints on possible ore fluids, on pressure and temperature conditions of metal transport, and on ore formation were studied and characteristic parameters were determined,

A comparison was drawn with sediment-hosted Cu deposits of the Permian Kupferschiefer and the Proterozoic Nonesuch Shale after visits to the type-localities in Poland, W.-Germany and Michigan, USA.

3. GEOLOGICAL SETTING

The Middle Proterozoic Kalahari Copper Belt (Fig.2.1) is situated on the northwestern and northern margins of the Kalahari Craton. It is bordered by the Late Proterozoic Damara Orogenic Belt towards the north (insert map of Fig.2.1). A geological map of the Klein Aub area has been established to investigate the relationships between basement- and cover rocks and between the different formations within the Sinclair Sequence

3.1 Pre-Sinclair Basement

In the Klein Aub, Doornpoort and Witvlei areas, the basement to the Sinclair Sequence, is defined by Early to early Middle Proterozoic (1800-1400 Ma) igneous and metamorphic complexes of the Rehoboth Sequence (Fig.3.1, 3.2, Table 1).

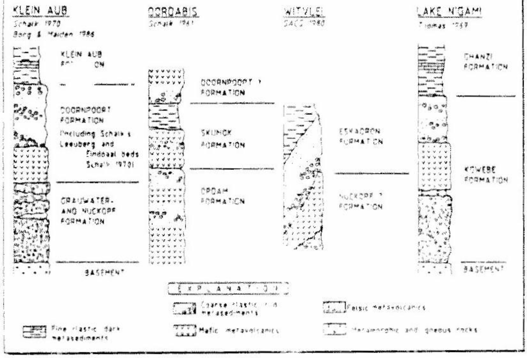

Fig.3.2: Stratigraphy of the Sinclair Sequence and its equivalents in the study areas in SWA/Namibia and Botswana

The Rehoboth Sequence has been subdivided from oldest to youngest into the Marienhof, Elim, Billstein and Gaub Valley Formations (SACS, 1980) and these formations consist of interbedded units of conglomerate, quartzite, phyllite, marble, mafic volcanic rocks and minor quartz porphyry. The various rocks have undergone moderate to strong metamorphism and range from upper greenschist- to amphibolite facies grade. The Marienhof Formation in the Klein Aub area has been intruded by the Swartmodder Granite, which has an radiometric age of 1668 ± 26 Ma (Malling and Reid, in press). A radiometric age of 1423 ± 82 Ma is inferred for the Doornboom Complex, which intruded the Gaub Valley Formation (SACS, 1980; Malling and Reid, in press.). No geological basement contacts are exposed in Botswana but the Okwa basement complex, exposed in several small outcrops some 200 km south of Lake N'Gami, is regarded as the local basement to the Sinclair Sequence (Crockett and Jennings, 1965; Key and Rundle, 1981). The gneisses of the Okwa basement complex have a radiometric age (Rb/Sr) of 1813 ± 68 Ma (Key and Rundle 1981), but units of the Okwa complex have been intruded by granites that yield a Rb/Sr-age of 1004 ± 49 Ma (Key and Rundle, 1981).

(Fig.3.1). This map is essentially based on an earlier, unpublished map (scale 1:100 000) by Schalk (1967) and is in general agreement with his mapping. The present map resulted from field work and an interpretation of aerial photographs.