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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A Dissertation submitted to the Faculty of Science, University of the Witswatersrand, Johannesburg, for the degree of Doctor of Philosophy.

Johannesburg, 1987
DECLARATION

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

[Signature]

[Date] 18.10.18
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 tectonics of the N'uckopf and Gnarlie 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, (D1) syndepositional block faulting, possibly with a dextral strike-slip component, (D2) the main deformational event of the Damara Orogeny, producing large-scale folding and regional cleavage, (D3) 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 Ca, 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 earlier 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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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,
To the endowed with mind and nature's might.

Mephistopheles in Goethe's Faust II. Act I
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, Os, Mo, Re and Bi. Amongst the largest and best documented of these deposits are the Kupferschiefer, Germany and Falun; White Pine, Michigan; Okokan and Dzerzhinsk, USSR; the Central African copper belts, 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 breakup (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 relate to marine transgressions over terrestrial volcanic successions. Deposits of this sub-group include the Kupferschiefer, White Pine and the Central African Copperbelt. 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. Renzsch, 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 an sedimentary 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, 1978; Clemency, 1978; Ruston, 1986). Other sources proposed are underlying red beds and/or mafic volcanics from which the base metals were leached (e.g. Brown, 1978; Badham, 1983; Jowett, 1986; Sawkins, 1986). Annels (1979) and Brown (1986) discussed the possibilities of exhalative and pneumatolitic 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 (Reilly et al., 1984). According to these authors, basement se-
quences, 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 (Bronzgerama-Sanders, 1965) or ground water (Haynes, 1986 a,b) are proposed fluid driving mechanism for syngentic 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 geologic 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 cor-
relatives 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.

![Sketch map showing the regional distribution of the Sinclair Sequence and its equivalents in SWA Namibia and Botswana. The inset 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 190 km southwest of Windhoek where the only operating mine was closed in early 1987. Other areas studied were Do, Jabis, Wivel and Ourlogende which are located east-southeast of Windhoek (Fig. 2.1) and the regions of Ghanzi, Lake Ngami, and the Shinamba Hills in central and northeastern Botswana.](image-url)
2.2 Previous Work


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 sand dunes 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, 201 stratigraphic profiles, that covered some 30 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 significant constituents 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 (inset 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, Table 1).

Fig. 3.1: Stratigraphy of the Sinclair Sequence and its equivalents in the study area of 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 Swartmood Granite, which has a 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 300 km south of Lake Ngami, is regarded as the local basement to the Sinclair Sequence (Crockett and Jennings, 1985; 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.
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