CO.NC1 l SIGNS

The stratabound sediment-hosted Cu deposits of the Sinclair Sequence between the Klein Aub area in SW. Namibia and the Shinamba Hills in Botswana have been studied in their overall geological context and their mineralogical and geochemical composition. Such an attempt required the investigation of the (plate) tectonic setting and aspects of the igneous, sedimentary, structural, metamorphic, and metallogenic history of the Middle Proterozoic formations which extend, in a narrow belt, for more than 1000 km in a northeasterly direction.

The close geographical association with the northern Kalahari Desert, the belt-like shape and the similarities with regard to stratigraphy, lithotypes, and especially an abundance of sediment-hosted Cu mineralization justify a common term for this major feature and the name Kalahari Copperbelt is proposed.

The earliest deposits of the Sinclair Sequence in the Klein Aub area are rhyolitic lavas and pyroclastics and minor clastic sediments of the Nickopf and Grauwasser Formation. The volcanics display the characteristics of explosive siliceous volcanism and volcanic vent breccias which grade into coarse pyroclastics, distal ash fall deposits and locally develop ignimbrites. Coarse clastic sedimentation was subordinate during Nickopf times but became more prominent during deposition of the Grauwasser Formation. Both formations were denuded and are preserved in deep, fault-bounded graben- or half graben structures. The overlying Doornpoort Formation overstepped the graben shoulders and covered local host blocks and basement highs. This formation contains significant amounts of mafic volcanics at the base and successively grades into a thick fining upward succession of continental red beds. The mafic volcanics are subaerially extruded tholeiitic flows with brecciated and sediment-filled flow tops. Metamorphosomation especially affected zones of both original and tectonically re-fledged permeability and caused epidotisation of these domains, a process which was accompanied by the strong remobilization of Cu, Zn, Co, Mg, Na, and K. Red bed sedimentation of the upper part of the Doornpoort Formation first produced only subordinate intercalations within the volcanic pile, but subsequently covered the mafic volcanics. The sedimentation was strongly controlled by syndepositional fault scarps, that occurred mainly along graben shoulders, where alluvial fans developed in front of the fault scarps. These alluvial fan conglomerates graded into braided stream systems locally into playa lakes. Exosparite pseudomorphs of aragonite dune deposits were locally developed suggesting an arid continental climate. Alluvial fan conglomerates are arranged in an en echelon fashion which might indicate syndepositional, dextral strike slip movement on the northern graben bounding faults. The internal phase of tholeiitic bimodal volcanism and the subsequent red bed deposition took place in an extensional crustal regime. The initial phase of tholeiitic bimodal volcanism and the subsequent red bed deposition took place in an extensional crustal regime and is interpreted as a phase of mechanical rifting, possibly triggered by a mantle plume underthrusting thick continental crust.

Both volcanism and block faulting had ceased with the beginning sedimentation of the Klein Aub Formation which consists of a lower, marine part the Ecca Beds and an upper part, the Dikshoom Beds that comprise fluvial sediments. The marine sediments are developed in several fining upward cycles which consist of mature subtidal quartz arenites, intertidal silts and mudstones and subordinate coastal and algal limestones. The sediments display a variety of well-preserved sedimentary structures which are indicative of a tidal environment. The mudstone/carbonate cycles probably developed in a tidal range of meso-macro-tidal proportions and were associated with an unbarred shoreline. After this marine transgression, sedimentation returned to deposition of the upper part of the Klein Aub Formation in braided fan environments. The Klein Aub Formation represents the thermal subsidence or sag phase of the failed rift system. The sedimentary style of the uppermost part of the lower Sinclair Sequence heralds the subsequent deposition of the Damara Sequence which displays similarities with regard to both lithotypes and sedimentary environments.

11. CONCLUSIONS
The area has been affected by three phases of deformation. The earliest is represented by the syndepositional extensional faulting during Nöcker, Grauwasser and Boreenporst times. The second phase of deformation, \( D_2 \), was the regional deformation and metamorphism of the Damara Orogeny (peak at \( 530 \pm 10 \) Ma). A compressional event that produced large-scale open \( F_2 \)-folds, a distinct regional \( S_2 \)-cleavage and was accompanied by metamorphism of lower greenschist facies. A third, \( D_3 \)-event was also compressive and resulted in the development of \( en e c h e l o n \) folds, a locally developed axial planar \( S_3 \)-cleavage and faults, thrusts and veins on a variety of scales. The most prominent fault, the Klein Aub fault, has an oblique-slip component and has probably formed in a transpressive crustal regime, with strongest compression directed towards northwest. The fault dragged and truncated the mine-alized bands of the Klein Aub ore bodies and subordinate faults often defined the rhomboid shape of single ore bands. This \( D_3 \)-fault system has possibly developed in response to plate convergence between the rigid crustal blocks of the Congo and Kalahari Cratons during a late phase of the Damara Orogeny. Strata-bound Cu mineralization is essentially of two types. Minor amounts of native Cu are hosted by amygdales and fractures in altered parts of the basaltic flows. More abundant and economically important is the sediment-hosted Cu-Ag mineralization hosted by dark pyritic sediments at the redox interface with continental red beds. The mineralization at Klein Aub Mine is characterized by an association of Cu, Ag and minor Au and Pt, and the absence of Pb, Zn or Co. The Cu:Ag ratio changes gradually with depth below the present surface with the highest Ag ratios in the upper parts of the ore bodies. Two different styles of mineralization have been distinguished, one of which consists of disseminated mineralization hosted by the coarser, more permeable beds of interlaminated siltstones and mudstones, and the other fracture-hosted but locally penetrating into coarser layers of the wall rocks. Cu grades decrease up dip along the strata from the root zones of the Klein Aub fault and an ore mineral zonation from chalcopyrite to bornite, chalcopyrite and pyrite is developed in the same direction suggesting an ascending flow of the mineralizing fluids. The ore fluids were characterized by a low pH, high F, low S and Cu, Ag and Au were most probably transported as \( \text{Cu}^{+1} \) complexes. PGE and Au are enriched (on a ppb level) in all stratigraphic units of the Sinclair Sequence, when compared with mafic rocks, with the exception of the red beds which are virtually barren of PGE and Au. The basal felsic volcanics show an enrichment of PGE and Au which is probably of magmatic origin. The strata-bound Cu-Ag ores are also enriched in Au and Pt but show a distribution pattern which implies a hydrothermal origin for this enrichment. PGE and Au in the basalts have remained immobile during alteration processes and show no signs of remobilization. Two intrabasinal metal sources for the sediment-hosted mineralization have been located and their metal depletion has been demonstrated. These probable source rocks are the altered basalts which lost most of their base metals, and the red beds which are depleted in their original PGE and Au contents. The ore genesis is explained by a two-phase metal replacement model. During early diagenesis sediment compaction and basin dehydration caused basinal fluids to migrate upwards towards the basin margins. These fluids leached metals at relatively low temperatures from permeable zones of the basalts and the red beds. The metals were precipitated under reducing conditions in the diagenetic pyrite bearing dark sediments where fluid flow was controlled by sedimentary permeability of coarser layers and diagenetic pyrite supplied the sulphur. Preferential pressure solution in the finer clastic sediments and diagenetic quartz cementation sealed the disseminated mineralization during advanced stages of diagenesis. Hot fluids with temperatures between 250 and 350°C, altered and remobilized even larger amounts of metals from the source rocks during metamorphism and deformation. The fluids were channeled by fault structures and permeable layers such as incompletely cemented quartz arenites. The metal-bearing fluids mineralized all permeable zones such as fractures in the pyrite bearing host rock and locally penetrated into permeable wall rocks adjacent to the fractures. The fluids also mineralized diagenetic pyrite cubes in the quartz arenites after deformation of the area had ceased. The mineralization was affected by supergene processes from descending meteoric waters after erosion of part of the overlying units. These supergene processes were active to a depth of more than 600 m in the vicinity of fault structures and poro...
sibly enriched the upper part of the ore bodies in Ag without any apparent changes in the size, shape or mineralogy of the pre-existing hypogene mineralization.
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