Cuaderno Lab. Xeolóxico de Laxe
Coruña. 1989. Vol. 14, pp. 177-200

Importance of regional metamorphism to the formation of stratabound copper mineralizations: an example of the Late Proterozoic Duruchaus in Formation Namibia

La importancia del metamorfismo regional para la formación de mineralizaciones de cobre del tipo «stratabound»: un ejemplo de la Formación Duruchaus en el Proterozóico Superior de Namibia

UHLIG, S.

In rift systems of the Late Proterozoic Damara Orogen, Nosib Group sediments of varied lithology were deposited about 950 Ma ago. The Kamtsas Formation, a more psammitic marginal facies, can be distinguished form the proper basin facies of the Duruchaus Formation which forms a sequence of several hundred meter thick metapelites with frequent intercalations of carbonate-rich and/or quartzitic layers and lenses. Thin evaporitic sequences occur locally in the uppermost parts of the Duruchaus Formation and consist mainly of carbonate rocks and carbonate rich pellites with presumable pseudomorphs of saline minerals. This may suggest that in some restricted subbasins sabkha to playa-lake type environments existed. Stratiform concentrations of tourmaline (up to 1 m thick toumalinities) in metapelites of the Duruchaus Formation are considered to be of synsedimentary origin and were precipitated as a primary silica-tourmaline gel from subaqueous exhalative fluids. Several 2-4 m thick orthoamphibolites of tholeiitic composition provide evidence of the activity of a basaltic magmatism within the Late Proterozoic continental crust between the Congo and the Kalahari Craton.

Along the Southern Margin of the Damara Orogen, copper mineralization occurs frequently within zones of intensively sheared and foliated mica and chlorite schists of the Duruchaus Formation. Mean copper ore grade reaches 2 wt % containing some 10 g/t silver. Normally these stratabound mineralized zones are not thicker than a few meters and their horizontal extent ranges from several hundred meters up to 1-2 Km. The primary sulfides have mostly been completely oxidized to malachite, copper and iron oxides near the surface. Alteration processes resulted in a supergene enrichment of the precious metals. Petrographical and geochemical characteristics differentiate the mineralized rocks of the Duruchaus Formation from these related to typical stratiform copper mineralizations.

Key words: copper mineralization, Late Proterozoic, Namibia, lithology, geochemistry, metamorphic fluids, toumalinites, metabasites.

Hace unos 950 Ma los sedimentos del Grupo Nosib se depositaron en las fosas tectónicas del Orógeno de Damara (Proterozóico Superior) que pertenece al Cinturón Orogénico Panafricano. La Formación Duruchaus representa la facies central del Grupo Nosib: en su mayoría son series pelíticas (con unos cientos de metros de potencia) con intercalaciones carbonáticas y cuarcíticas. La facies marginal, la Formación Kamtsas, se distingue claramente por su carácter psamítico. Estratos evaporíticos se observan en las partes superiores de la Formación Duruchaus y consisten en rocas carbonáticas y en pelitas ricas en carbonatos con posibles pseudomórfosis de minerales salinos. Eso hace suponer que en algunas subdepresiones aisladas existían condiciones de «sabkha» o de «playa». En algunas de las series pelíticas superiores de la Formación Duruchaus se encuentran también estratos ricos en turmalina (turmalinitas). Su origen es sinsedimetario debido a la formación de geles de ácidos silícicos ricos en boro a partir de soluciones exhalativas subacuáticas.
En la zona estudiada el metamorfismo regional de la Orogénesis de Damara alcanzó la zona superior de la facies de esquistos verdes con la formación de metapelitas, mármoles y cuarcita de la Formación Duruchaus. Muy espectaculares son las brechas de cuarzo y carbonatos y las formaciones «pegmatíticas» con megacristales de cuarzo y carbonatos de esta Formación que evidentemente se originan a partir de fluidos metamórficos.
Las intercalaciones de ortoanfibolitas de composición toleítica en las metapelitas de la Formación Duruchaus indican una actividad de magmatismo basáltico en la corteza continental entre el Cratón del Congo y el Cratón de Kalaharí durante el Proterozóico Superior.
A lo largo del margen meridional del Orógeno de Damara, se encuentran con mucha frecuencia mineralizaciones de cobre en las series metasedimentarias de la Formación Duruchaus que sufrieron una tectonización intensiva (cizallamiento y/o plegamiento). El valor medio del contenido en cobre llega a un 2 por ciento, y la plata unos 10 g/t. En general estas zonas mineralizadas del tipo «stratabound» tienen un espesor de unos metros con una extensión horizontal de varios cientos de metros hasta 1-2 kilómetros. En la superficie los sulfuros primarios sufrieron una oxidación más o menos completa formándose malaquita y óxidos de cobre y de hierro. Los procesos de meteorización han ocasionado un enriquecimiento de metales preciosos. Las características petrográficas y geoquímicas de estas rocas mineralizadas se distinguen claramente de las relacionadas con las típicas mineralizaciones estratiformes de cobre.

Palabras clave: mineralizaciones de cobre, Proterozoico Superior, Namibia, litología, geoquímica, fluidas metamórficas, turmalinitas, metabasitas.

In Riftsystemen des oberproterozoischen Damara-Orogens, das zum Panfrikanischen Orogengürtel gehört, lagerten sich vor ca. 950 Ma Sedimente der Nosib-Group ab. Die zentrale Beckenfazies der Duruchaus-Formation, in

die karbonatreiche und/oder quarzitische Folgen eingelagert sind, läßt sich von der psammitischen Randfazies der Kamtsas-Formation unterscheiden. Geringmächtige lokale Einschaltungen von evaporitischen Lagen, die aus Karbonatgesteinen und karbonatreichen Peliten mit möglichen Pseudomorphosen nach Salzmineralen bestehen, weisen darauf hin, daß in isolierten Teilbecken Sabkha -bis Playa-Lake- ähnliche Bedingungen geherrscht haben können. Bis zu 1 m mächtige stratiforme Turmalinanreicherungen sind in Metapelitfolgen der Duruchaus-Formation eingeschaltet. Iher Entstehung wird auf eine synsedimetäire Turma-lin-Kieselsäuregel —Bildung aus subaquatisch— exhalativen Lösungen zurückgefürt. Den Metasedimentfolgen der Duruchaus-Formation sind vereinzelt 2-4 m mächtige Orthoamphibolite eingelagert, die eine tholeiitische Zusammensetzung aufweisen, und auf die Tätigkeit eines basaltischen Frühdamara Magmatismus zwischen dem Kongo- und dem Kalahari Kraton hinweisen.
Entlang des südlichen Damara-Orogenrandes finden sich epigenetische Kupfervererzungen in Zonen intensiv zerscherter und verfalteter Glimmer-und Chloritschiefer der Duruchaus-Formation. Diese vererzten Zonen sind maximal wenige m mächtig und lassen sich im Streichen einige hundert Meter bis maximal 2 Km verfolgen. Ihr Metallagehalt liegt durchschnittlich bei 2 Gew.-% Kupfer und ca. 10 g/t Silber. Die primären Sulfide sind in Oberflächennähe meist wollständig zu Malachit, Kupfer- und Eisenoxiden alteriert. Wäehrnd den Verwitterungsvorgängen kam es zu einer supergenen Anreicherung de Edelmetalle. Petrographisch und geochemisch unterscheiden sich die vererzten Gesteine deutlich von denen typischer stratiformer Kupfervererzungen.

Schlüsselworte: Kupfermineralisation, Oberproterozoikum, Namibia, Lithologie, Geochemie, metamorphogene Fluide, Turmalinite, Metabasite.

UHLIG, S. (Parkstrasse 23, D-7500 Karlsrure 1, F. R. G.)

INTRODUCTION

Since German colonial times, several areas of copper mineralization have been known to exist in metasediments of the Late Proterozoic Duruchaus Formation along the Southern Margin of the SW-NE trending branch of the Damara Orogenic Belt (RIMANN, 1915). Evaporitic intercalations appear locally within the Duruchaus Formation and have recently been considered to be of genetic importance for this copper mineralization (BEHR *et al.*, 1982, 1983; SCHMIDT-MUMM *et al.*, 1987). For this reason it seemed interesting to investigate whether there was any relation between the occurrence of metaevaporites and copper mineralization of the Duruchaus Formation.

Following an earlier lithological and mineralogical investigation of one Duruchaus exposure with presumable evaporitic horizons to the West of the Geelkop Dome (RÖHRS, 1982), see Fig. 1, the object of the present research was to characterize the Duruchaus Formation lithologically and geochemically along the exposed Southern Margin of the Damara Orogen. By detailed mapping and profiling it was possible to establish a model for the depositional environment of the Duruchaus Formation. Comprehensive geochemical investigations of metamorphic rocks (some 180 rock samples of sedimentary and magmatic origin) of the Duruchaus Formation and other stratigraphically related Formations of the Damara Sequence support this model and permit interpretation of the geodynamic framework. Concentrations of major and trace elements have been determined by XRF, REE and boron by AES/ICP at the «Institut für Geowissenschaften und Literjosphärenforschung» in Giessen (detailed description of analytical methods and geochemical data in UHLIG, 1987).

GEOLOGICAL SETTING

The Damara Orogen in Namibia consists of a S-N trending coastal and a SW-NE trending intracontinental branch forming part of the Pan-African network of orogenic belts which surround and dissect the African Continent (KRÖNER, 1977). In this paper, the term Southern Margin Zone applies only to the SW-NE-trending intracontinental branch of the Orogen (Fig. 1). Rocks associated with the Damara Sequence cover most of Central Namibia and are exposed for some 400 Km along its SW-NE strike between the Congo Craton to the north and the Kalahari Craton to the South. The Katanga and the Zambezi Belts are considered to be the continuations of the Damara Orogenic Belt to the NE.

Crustal weakening during mantle updoming between the Congo and Kalahari Cratons initiated intracontinental rifting which began with the formation of at least three rift graben systems (MARTIN and PORADA, 1977) and the deposition of clastic sediments of the Nosib Group between 1000 and 900 Ma ago (Fig. 1). The Damara Sequence consists of four major stratigraphic units (S. A. C. S., 1980). At the base of the Damara Sequence are the rift-phase sediments of the Nosib Group which have been subdivided, in the Southern Margin Zone, into the Kamtsas and the Duruchaus Formation. The Kamtsas Formation, a more psammitic marginal basin facies, is characterized mainly by immature feldspar rich quartzites and can clearly be distinguished from the basin facies of varied lithology, the Duruchaus Formation. Carbonate sequences predominate within the Otavi Group (Central and Northern Zone, Fig. 1 shows the structural zones of the Damara Orogen defined by MILLER, 1983b) and the Lower Swakop Group. In the Southern Margin Zone intercalations of obviously volcano-sedimentary origin (e. g. amphibole schists of the Chuos Formation) occur in addition to associated clastic sequences. More peliticsediments characterize the Upper Swakop Group. In the Southern Zone of the Damara Orogenic Belt, the Matchless Amphibolite Member is interbedded in the Kuiseb Formation of the Upper Swakop Group (Fig. 1). With extensive molasse clastics of the Mulden Group in the Northern Zone and of the Fish River Subgroup in the Southern Platform, sedimentation of the Damara Sequence came to an end between 650 and 550 Ma ago (MILLER, 1983b).

DIAGENETIC AND REGIONAL METAMORPHIC PROCESSES

Damaran regional metamorphism reached its peak about 530-500 Ma ago (HAACK *et al.*, 1980; KRÖNER, 1982) and led to the formation of voluminous granitic melts in the Central Zone of the Damara Belt. Towards the orogen margins temperatures were lower. Within the studied areas of the Southern Margin Zones, P-T conditions correspond mainly to upper greenschist and epidote-amphibolite facies. The partly illite-rich pelites of the Duruchaus Formation became mainly quartz and albite-bearing biotite and chlorite schists. In constrast to the Central Zone, where domal synforms and antiforms predominate, very intensive south vergent upfaulting, over-thrusting and folding characterize late orogenic tectonics along the Southern Margin of the Damara Orogen and produced a pronounced foliation of the Duruchaus metasediments. At least two major foliation planes, parallel and transverse to bedding (35-45°), are preserved.

Due to diagenetic and mainly metamorphic alteration of the Duruchaus sediments (and sediments of the Swakop Group), silica and carbonate-rich fluids of high salinity originated at temperatures up to 500-550°C (based on fluid inclusion data from BEHR and HORN, 1982). By thermodynamic calculations of P-T conditions, KASCH (1981; 1983 a, b) postulated two thermal peaks of regional metamorphism in the Southern Zone and in the Southern Margin Zone. A syntectonic thermal peak reaching 590°C is separated from a 570°C peak by a late-tectonic thermal trough of 485°C.

THE NOSIB GROUP WITHIN THE SOUTHERN MARGIN

Lithology

During the synrift phase thick Nosib Group sediments of varied lithology were deposited in the most southerly of the three parallel graben systems and are presently exposed within the approximately 80 Km wide Southern Margin Zone. The Duruchaus Formation forms a sequence of several hundred meters of feldspar and quartz-rich schists which petrographic study shows to be metagreywackes. Due to intense deformation along the Southern Margin Zone, tectonic duplication of beds cannot be excluded and should be taken into account in interpreting lithological profiles. Mainly greenish to olive-coloured biotite (up to 45 vol %) produce the rock colour. Generally, interbedding of pelitic and psammitic laminae is well preserved.

Very frequent intercalations of carbonatic and/or quartzitic layers and lenses (centimeter to several meter range) are characteristic and cause the varied lithology of the Duruchaus Formation. Lithological profiles near the depocentre can be distinguished from marginal intercalations and thinner and less abundant quartzitic interbeds. Massive carbonatic beds make an exception and still contain marks of detrital «contamination». Locally convolute and lamellar structures characteristic for stromatolites are preserved within these carbonate beds and may indicate temporary low water levels of the sedimentary basin. Quartz and feldspar-rich psammo-pelitic horizons become clearly thicker towards the former graben margins where their transition into the Kamtsas quartzites is well-documented (lithological profiles in UHLIG, 1987). Graded bedding, cross-bedding and ripple marks (cm to dm range) can be observed.

Deformation and metamorphism

Within the metasediments of the Duruchaus Formation structures related to dehydration processes can be observed on a small scale in several Duruchaus outcrops (e. g. west of the Geelkop Dome). Abundant discordant lenticles, nodules and disseminations of chlorite in the Duruchaus metasediments and in quartz-carbonate breccias indicate that the metamorphogenic fluids have also been rich in chlorides. Fluid inclusions of related quartz-grains are highly saline (up to 33-45 wt % eq. NaCl; BEHR and HORN, 1982). These metamorphic solutions increased rock creep and acted as sliding masses during the tectonic activity. During deformation, these fluids left their source rocks and moved upward along faults and other zones of weakness into stratigraphically highs horizons where they cristallized at P-T conditions low enough to form discordant quartz-carbonate breccias and intrusive «pegmatitic» (with typical megacrystals) quartz plugs and veins. Zones of weakness that acted as ascent paths for those metamorphogenic solutions may originate from alternating sedimentary sequences with different rheological properties as demonstrated in the mapped area near Dordabis (UHLIG, 1987). Calcite and dolomite rhombohedrons, up to 0.8 m long and quartz crystals, up to several meters long, are quite abundant in these deposits. Locally, quartz occurrences of this type are mined for optical quartz near Alt Seeis (60 Km E of Windhoek). Typical rock fragments from the Duruchaus Formation (e. g. tourmalinites, albitolites) occur in the discordant quartz-car-bonate breccias and demonstrate a greater distribution of the Duruchaus metasediments within the subsurface along the Southern Margin of the Damara Orogenic Belt.

Geochemistry

Major and trace element chemistry depends on the mineralogy of the studied rocks. In general it seems to be very complex to define and describe sedimentary rocks by their geochemical characteristics. Potash feldspar and quartz rich arkosic sediments show lower Na/K-ratios (< 1) and largely higher Si/Al-ratios than clastic sediments containing higher amounts of mineral and rock fragments in a dominantly clayey matrix (PETTIJOHN, 1975; Fig. 2). Higher alkali concentrations of the Duruchaus metapelites (5-10 wt %), that correspond to detrital mineral fragments such as feldspar and mica, support the petrographical results of a short fluviatile transport of the weathering products of a gneisic basement. Longer transport and more intensive weathering processes would have resulted in a stronger differentiation of the clastic sediments. Low iron and magnesium contents (mean FeO_{tot} + MgO < 7 wt %; Cr < 120 ppm and Ni < 70 ppm, see Fig. 2) are a further criterion for a gneissic hinterland that is indicated by characteristic heavy-mineral assemblages in the Duruchaus metasediments (zircon, magnetite, apatite inclusions in detrital quartz and zircon inclusions in detrital biotite).

Chondrite-normalized REE patterns of Duruchaus metapelites from different lithological profiles show a well pronounced enrichment of lREE and a rather flat distribution of hREE (Fig. 3). Their REE patterns are characterized by Eu depletion. Higher contents of quartz (up to 80 wt % SiO_2) result in congruent patterns with lower absoljute values corresponding to lower REE concentrations.. The metapelites of the Duruchaus Formation exhibit a pattern of REE normalized to chondritic abundance (EVENSEN *et al.*, 1978) that is characteristic for fine-grained Proterozoic quartz-inter-mediate metagreywackes (TAYLOR and MCLENNAN, 1985). Early Archean metagreywackes and metasiltstones do not show a significant Eu anomaly. The depletion of Eu in post-Archean sedimentary rocks is due to chemical fractionation of the source material and is related to the production of potasium rich granitic rocks which are characterized by negative Eu anomalies. REE distributions of carbonate rocks of the Duruchaus Formation is very similar to REE patterns of the Duruchaus metapelites and depends on the «contamination» by detrital mineral parageneses (Fig. 3).

Metaevaporites

Evaporitic intercalations (up to tens of meters thick) occur locally in the uppermost pelitic sequences of the Duruchaus Formation and consist mainly of carbonate rocks and carbonate-rich pelites with apparent pseudomorphs of evaporite minerals (albite after gaylussite, cauliflower quartz after nodules of sulfates, microcline after gypsum, tourmaline after borate, pennine after scapolite; RÖHRS, 1982; BEHR *et al.*, 1982, 1983). In an idealized lithological profile RÖHRS (1982) and BEHR *et al.*, (1983) demonstrated seven evaporitic cycles. This may suggest that in some marginal subbasins and in restricted central parts of the southerly graben system sabkha to playa-lake type environments had existed. However, it must be said that the stratigraphic range of evaporitic facies within the Duruchaus Formation is not as large as expected in the early stages of the investigation. «Up to 1000 m thick metaplaya sequences of partly evaporitic origin» (SCHMIDT-MUMM *et al.*, 1987) could not be observed.

Sodium is a highly mobile element and will be unstable in sodium-rich evaporitic intercalations during diagenesis and regional metamorphism. Therefore, higher sodium contents as an indicator for metasediments of evaporitic origin should be used cautiously. According to MOINE *et al.* (1981) evaporitic rocks show higher Mg concentrations than nonevaporitic sediments and can be differentiated from Mg-rich sediments deriving from eroded basites and ultrabasites by obviously lower concentrations of TiO_2 ($<$ 1wt%), Cr and Ni (Cr + Ni: 50-250 ppm). In addition to higher contents of Ca-rich carbonates and sulfates, carbonate rocks related to evaporitic sequences should present a characteristic Mg/Al ratio that is dependent on the associated Mg-rich minerals such as clays, chlorites and carbonates. In the triangular Al-Ca-Mg diagram, MOINE *et al.* (1981) defined a discrimination field of «sulfate-bearing rocks» (shales, marls and limestones of evaporitic origin) based on geochemical investigations of Triassic, Devonian and Proterozoic metaevaporites. Various carbonate rocks and marbles of the Duruchaus Formation are distributed within the field of evaporite-bearing series (Fig. 4). However, the great majority of the Duruchaus metasediments (quartzites, metapelites and carbonate rocks with CO_2 $>$ 30 wt%) shows a distribution that is characteristic for «nonevaporitic» sediment sequences.

Tourmalinites

Sporadically, stratiform concentrations of tourmalinite (up to 1 m thick tourmalinites) occur in pelitic sequences of the Duruchaus Formation. Only where deformed (e. g. within hinge folds) does thickness exceed 1 m (Fig. 5). The tourmalinites are very fine-grained and consist of granular quartz and Fe-rich and Mg-bearing tourmalines which form thin monomineralic laminations (thickness $<$ 0.5 mm) with a quartz-tourmaline gradational zone. In general, graded bedding is common (Fig. 5). The more quartzitic interlaminate layers also contain small amounts of albite and calcite. In addition to accessory biotite, iron oxides, epidote and allanite, idomorphic to hypidiomorphic apatite occur in concentrations up to 0.5 vol % (chemical analyses see Table 1). In addition to tourmaline this remarkable content of apatite results in the positive cerium anomaly (25 ppm) of the chondrite normalized REE pattern of the analyzed Duruchaus tourmalinite on Farm Stolzenfeld (15 Km NW Dorbabis). Samples of associated pennine-bearing horizons show typical REE values that are characteristic for the nonevaporitic Duruchaus metapelites (Fig. 4).

Formation of tourmaline must predate the tectonization of the tourmalinite and the surrounding sediments of the Duruchaus Formation because the interlaminate quartz-tourmaline layers are are intensely sheared and folded within the associated strata. In stratiform tourmaline-bearing metapelites of the Duruchaus Formation on Farm Tsatsachas (South of Farm Stolzenfeld) increased sodium concentrations (up to 9,7 wt% Na_2O, see also Table 1) led to the formation of strongly pleochroic magnesio- riebeckite during regional metamorphism. These blastophyric minerals are mostly orientated within schistosity (bedding and transverse cleavage) and enclose stratiform tourmaline laminations. Another argument for the pre-metamorphic formation of these Duruchaus tourmalinites can probably be seen in the tourmalinite fragments of the metamorphogenic intrusive quartz-carbo-nate breccias.

The studied tourmalinites are not considered to be of evaporitic origin (in the meaning of a metamorphogenic origin in situ from primary borate rich strata). It is supposed that the Duruchaus tourmalinites were precipitated in restricted subbasins due to syngenetic or early diagenetic processes. Within the water column, above the sediment-water interface, tourmalines could have been precipitated as a primary silica-tourmaline gel from subaqueous exhalative fluids (SLACK *et al.*, 1984). Such fluids probably originated from hot-spring activities and may have been extremely boron-rich as a result of hydrothermal leaching of boron-bearing pelitic sequences (including primary evaporitic precipitates) during diagenesis (PLIMER, 1986, 1987).

METAMORPHIC ROCKS OF VOLCANIC ORIGIN

In the area SE of Omitara (100 Km ENE Windhoek) actinolite- and epidote-rich amphibolites (2-4 m thick) are interbedded with metapelites of the Duruchaus Formation and can be observed for 2 Km along its strike. Due to metamorphic growth of actinolite and epidote, the fine-grained amphibolites look blastophyric. Foliation is pronounced and conceals primary parallel structure. In addition to the above-mentioned minerals, these amphibolites contain albite, chlorite, calcite and quartz (together up to 30 vol. %). Accessory constituents are sphene, apatite and magnetite preserving segregation lamellae of ilmenite.

Fairly common basic igneous rocks of volcanic origin occurring along the Southern Margin of the Damara Orogenic Belt are the metabasalts of the Dordabis Formation (Sinclair equivalents ?, according to the comparison of WILLIAMS-JONES, 1984, the Dordabis Formation shows a similiar age, petrology, petrography, associated sedimentary suites and depositional environment to the Sinclair Sequence) and the amphibole schists of the Chuos Formation. The major element chemistry of these metavolcanics is very similar to the chemistry of tholeiitic basalts and high iron contents are characteristic (10-20 wt % Fe_2O_3tot, Fig. 6).

In particular it was important to determine whether the Duruchaus amphibolites are metabasalts or metamorphosed marly sediments. Certain major and trace element ratios and discrimination diagrams prove to be useful for characterizing sedimentary and magmatic trends in metamorphic rocks. In the AFM diagram higher iron contents of the early Damara metabasites differ clearly from the low iron trend of sedimentary rocks of the Duruchaus Formation (Fig. 7). The aluminium content in basaltic melts may decrease (and titanium increase) during magmatic differentiation. For this reason amphibolites of magmatic origin should present a characteristic Al/Ti ratio which is obviously different in sedimentary rocks (UHLIG, 1987). The Al and Ti concentrations in sediments generally depend on the content of alumino-silicates. Higher titanium concentrations (1-4 wt%) and a smaller range of aluminium concentrations (12-16 wt%) differentiate these early Damaran metabasites from the Duruchaus metasediments which show a greater range of aluminium contents and considerably lower titanium concentrations ($<$ 1 wt%, Fig. 7). In summary the results of the geochemical discrimination of the Duruchaus amphibolites, and the strong chemical resemblance to the Dorbadis metabasalts and Chuos amphibole schists, exclude a sedimentary origin.

TECTONIC SETTING OF THE EARLY DAMARAN METABASITES

The geological and tectonic framework of the investigated Damara metabasites indicates an origin within the continental lithosphere (e. g. the Dordabis metabasalts are interbedded with fluvial protoquartzites). Nevertheless, to complete the information on their geodynamic environment, it is considered important to investigate whether the chemistry of these basic rocks can be compared with continental basalts. In general, basalt discrimination diagrams after PEARCE *et al.* (1975, 1977) and PEARCE (1983) and MULLEN (1983) are provided for oceanic basalt suites but they may also be applicable to continental basalts. Due to their complex chemistry, basalts of continental origin are very often distributed within transition zones of these discrimination diagrams, between characteristic continental and ocean island basalts (Fig. 8). Within destructive continental margins the subcontinental mantle contributes part in the formation of basaltic magmas. Here remelting of the subducted oceanic lithosphere, including the subducted oceanic crust, strongly controls the chemical character of the magma and reduces the influence of the convective upper mantle (PEARCE, 1983). For this reason basalts that originate from continental margins or intracontinental rift and fracture zones show higher Zr/Y ratios than basalts of clear oceanic origin (PEARCE and NORRY, 1979). The Dorbadis metabasalts, the Chuos amphibole schists and the Duruchaus amphibolites have Zr contents and Zr/Y ratios chiefly characteristic of basalts of continental environment (Fig. 8).

The Duruchaus amphibolites, the Chuos amphibolite schists and the Dordabis metabasalts have very similar chondrite-normalized REE patterns showing a relative enrichment of the light REE (Fig. 8). This constant decrease of the chondrite-normalized REE values, from the lREE to the hREE, is characteristic of continent derived basalts (WILSON, 1978) and is very similar to REE distribution of Precambrian continental metabasites from South Africa and China (TAYLOR and MCLENNAN, 1985; WANG RENMIN *et al.*, 1985). The chondrite-normalized REE patterns of the analyzed continental Damara metavolcanis are very similar and confirm a common origin from a basaltic magma source within the continental lithosphere between the stable Congo and Kalahari Cratons. Basic magmatism was possibly initiated by mantle updoming withing today's Central Namibia about 1,000 Ma ago. Early rifting processes of the Damara Orogen enabled the ascent of the tholeiitic melts into the graben systems of the Damar Orogenic Belt where basic volcanic rocks became interbedded with early Damarn rift sediments.

At a later stage in evolution of the Damara Belt, basic sills and lavas were emplaced in the Khomas Trough, producing the Matchless Amphibolite Member of the Kuiseb Formation. BREITKOPF's work (1987) actually prove a more complex situation. The geochemistry of the Matchless amphibolites showed that some were formed in a situation of advanced continental rifting, and some in a situation of initial seafloor spreading. An analogy was drawn with the present-day Red Sea, which is partly floored by thinned continental crust and partly by newly-formed oceanic crust. A continental tholeiitic magmatism which has been active in a graben system to the south of the Khomas Trough during early Damaran time is thought to agree with the posterior evolution and activity of an oceanic tholeiitic magmatism in the central graben (see Fig. 1). Concluding this discussion of the tectonic environment of the early Damaran Matabasalts, it is important to state that metabasalt geochemistry supports the geological interpretation of a rift setting for the Nosib Group.

STRATABOUND COPPER MINERALIZATION OF THE DURUCHAUS FORMATION

Along the Southern Margin of the Damara Orogen, copper mineralization occurs frequently within zones of intensively sheared and foliated mica and chlorite schists of the Duruchaus Formation. In these metasediments stratabound mineralization is obviously controlled by foliation and/or occurs in discordant metamorphogenic quartz lenses. Mean copper ore grade reaches 2 wt% containing some 10 g/t silver and up to 0.2 g/t gold. Normally these mineralized zones are not much thicker than a few decimeters, reaching a maximum of 1-2 meters. Their horizontal extent ranges from several hundred meters up to 1-2 Km. The primary sulfides (chalcocite, bornite, chalcopyrite, pyrite) have mostly been completely oxidized to malachite, copper and iron oxides near the surface. Even in the intrusive quartz-carbonate breccias and «pegmatitic» quartz bodies strongly limonitized iron oxides (up to 2 cm diameter) and copper-bearing sulfides, very often altered to malachite, have repeatedly been observed.

The major element chemistry of the mineralized Duruchaus metasediments varies according to the varied lithology that characterizes the Duruchaus Formation. Besides higher Cu contents (up to 5 wt%), the mineralized metasediments are slightly enriched in H_2O^+, CO_2, F, S, Th, U, Au and Ag. Compared to unmineralized Duruchaus metasediments, concentrations of C_{org}, Ba, Zn, As and Mo reach higher peaks in mineralized rock samples (see data in UHLIG, 1987). The Duruchaus metasediments in general, as well as their mineralized counterparts, show no higher V and B concentrations which could be an indication of a more highly saline environment during sedimentation (POTTER *et al.*, 1963; Fig. 9). Metasediment samples with boron contents higher than 200 ppm show normal low copper concentrations (< 20 ppm). A primary syngenetic relation between the formation of presumable evaporitic horizons or stratiform tourmaline concentrations and the studied copper mineralized strata of the Duruchaus Formation could not be confirmed during the geologic survey nor by geochemical criteria. A significant positive correlation between V and C_{org} and typical concentrations of these trace elements that are characteristic for typical stratiform copper mineralization (e. g. Kupferschiefer, mean values after KULICK *et al.* (1984): 2,17 wt % C_{org} and 407 ppm V) cannot be observed within the mineralized metasediments of the Duruchaus Formation (Fig. 9).

Unmineralized Duruchaus metasediments contain less than 25 ppm cobalt that can normally be expected in pelitic rocks with up to 5 wt % Fe_2O_3. Cobalt concentrations in copper mineralized samples do not exceed 40 ppm. These low Co contents are characteristic for the stratabound copper mineralization of the Duruchaus Formation and obviously differentiate them from stratiform Late Proterozoic copper deposits in Southern Africa which show considerably higher Co contents. In the Duruchaus metapelites sulfur concentrations are very low (< 0.01 wt%) but reach up to 0.18 wt% in copper mineralized strata. Sulfate-bearing carbonate intercalations occur locally within the Duruchaus Formation and are considered to be a possible sulfur source for the formation of sulfur-rich fluids.

As mentioned above, mean copper grade and continuity of stratabound mineralizations is not high or great enough to make these deposits exciting exploration targets in these days of low copper price, but higher amounts of precious metals like gold and silver could make them more attractive. A positive correlation between precious metals and copper is well-documented and Cu/Ag and Cu/Au ratios of about 3,000 and 1,000,000 respectively should be realistic for the primary mineralization (Fig. 10).

METALLOGENESIS

Higher heat flow characterized the depositional environment of the synrift phase and, supported by the arid climate, enabled the formation of saline chloride rich solutions during diagenesis of the Nosib Group rift sediments. These solutions were able to mobilize and transport metal ions from sedimentary and magmatic rocks. During regional metamorphism of the Damara Orogeny those leaching and mobilization processes continued and were intensely reactivated.

Depending on the thickness of overlying rock sequences during diagenesis and continously intensifying regional metamorphism, excess hydrostatic and tectonic pressure was built up in the increasingly metalliferous formation waters. On zones of weakness and fault zones which may have already been intended or active during the synrift phase, tectonic movements started at least due to expanding internal and externmal pressure. These movements culminated with intensive orogenic folding and over-thrust tectonics which characterize the areas where the Duruchaus metasediments are exposed along the Southern Margin of the Damara Orogen. The fluid phases left the overstressed system along the dislocation planes and considerably reduced the internal static and dynamic friction of the sliding planes.

It is presumed that the copper of the stratabound deposits has been transported in saline fluids varying distances from the source rocks. High amounts of Cl^- in metamorphic fluids enhanced metal leaching from metamorphosed rocks as complex ions with chlorine. Basic volcanic rocks of the early Damaran orogenic magmatism have an average copper content of 110 ppm and are considered to be, besides sedimentary rocks, the probable source rocks for the copper in the fluids. In the metasediments of the Duruchaus Formation copper contents are less than 20 ppm.

Copper-rich sulphides precipitated probably where Cu-Fe-chloride-bearing fluids met sulphide sulphur. Traces of the precious metals gold and silver were also incorporated in the primary sulfides. Changes of P-T conditions and redox potential, due to lithological changes of the varied host rock, promoted precipitation of mineralization. At the same time structural traps like fault zones (up- and overthrusts), fold hinges and subordinately also karst-related cavities close to surface were of great metallogenetic importance.

Under later, near surface conditions, after uplift and erosion of the mineralized metasediment zones, primary copper and iron sulphides were altered to copper oxides and carbonates, and iron oxides and hydroxides. Related to these weathering processes partial remobilization and reconcentration of the valuable metals took place and may have continued until recently.

CONCLUSIONS

Sedimentary basins whose origins are related to intracontinental rifting can be characterized by two distinct evolutionary stages: a synrift and a postrift phase (WATTS, 1981). The initial synrift phase results from crustal stretching and creates a graben system that shows characteristic features. Generally these are a higher geothermal gradient, deep listric faults on which melts of a rift-related magmatism may ascend, and a high rate of subsidence (e. g. ILLIES, 1974; MCKENZIE, 1978; WATTS *et al.*, 1982). Sediments that are deposited in subbasins during the synrift phase are normally immature fine- to coarser-grained clastic rocks. Lacustrine and in some cases evaporitic horizons may be intercalated. As a result of the active faulting accompanying rifting, facies changes and variations of thickness are common. The studied metasediments of the Nosib Group are typical metamorphosed graben sediments related to the synrift phase of the Late Proterozoic Damara Orogen.

In contrast to the synrift phase the postrift phase is characterized by crustal recooling down to conditions of thermal equilibrium. Subsidence velocity exponentially decreases and more evolved fine- to medium-grained clastic and carbonate sediments are deposited (LARGE, 1987). Due to the absence of, or only a weak activity of synsedimentary tectonics during the postrift phase, sedimentation is characterized by lateral continuity of the lithofacies and more or less constant thickness of sediments. However, these idealized deposition conditions may become more heterogenous and complicated by paleogeographic and magmatogenetic factors (e. g. deltaic fans, algal reefs, etc. and volcano-sedimentary formations) and/or by epeirogenic processes. Within the studied Southern Marging of the Damara Orogen the sedimentary sequences of the Swakop Group represent sediments of the postrift phase.

Stretching of the continental crust in Central Namibia resulted in its weakening. In the southern graben system of the Damara Orogen deep reaching faults and fracture zones originated from rifting and initiated the ascent of basic melts from a basaltic magma chamber between the Congoand the Kalahari Craton. The Dordabis metabasalts, the Duruchaus orthoamphibolites and the amphibolite-chists of the Chuos Formation show very similar geochemical characteristics and give evidence for an early Damaran tholeiitic magmatism within the continental crust of the SW-NE-trending Damara Orogen.

During diagenesis and regional metamorphism volatile constituents escaped from buried rift deposits of the Damara Sequences and created moderately saline fluids. Lithologically varied sedimentary sequences with isolated evaporitic intercalations, like these of the Duruchaus Formation, are an important source of highly saline solvents. These chloride-enriched fluids leached and mobilized metal as complex metal-chloride ions fron sedimentary and volcanic rocks. Subsequently, sulphide minerals precipitated under favourable conditions in chemical and structural traps.

By enrichment in silica-and carbonate-rich solutions of high salinity, a pore fluid over-pressure built up in the crustal segments consisting of lithologically varied metasediments. Presumably for this reason, horizons within the Duruchaus Formation became weakened zones on which late orogenic movements took place. Locally this resulted in an intensive shearing and folding of the Duruchaus metasediments that can be observed in some areas on Farm Eintracht and Stolzenfeld. At the same time parts of the Duruchaus Formation form less tectonized sections of nappe complexes that be-came overthrust on the southern basement of the Kalahari Craton.

In general Fe- and Cu-sulphides are the most abundant ore minerals of the stratabound mineralization within the Duruchaus Formation. Only locally other ore minerals (galena, sphalerite and uranium-bearing minerals) reach noticeable concentrations. After precipitation of mainly Fe-Cu-sulphides at relatively high temperature, the ore-forming hydrothermal fluids ascended along fracture zones into higher leveles, closer to surface. In the direction of decreasing P-T conditions, a metallogenetic zonation took place and at lower temperature economically interesting mineral parageneses could have been concentrated in higher crustal levels which are now mostly eroded along the Southern Margin of the Damara Orogen. It is suggested that the huge Cu-Pb-Zn deposits of Namibia (e. g. Tsumeb, Kombat) originated from similar ore-forming fluids and processes.

With regard to further exploration programs on stratabound copper mineralization within metasediments of the Duruchaus Formation along the Southern Margin of the Damara Orogen, it appears to be necessary to direct prospectors' attention to structural control of mineralization and to supergene enrichment of precious metals.

ACKNOWLEDGEMENTS

I acknowledge advice and assistance by Prof. Dr. R. Emmermann (Giessen, FRG).

In particular, I am very inbedted to the Geological Survey of Namibia and to the Deutsche Forschungsgemeinschaft for supporting this research work. Furthermore, I want to express my thanks to Dr. K. E. L. Schalk and Dr. K.-H. Hoffmann (Windhoek, SWA) for their assistance in the field. Interesting discussions by Prof. Dr. H.-J. Behr and Prof. Dr. H. Porada (Göttingen, FRG) are gratefully acknowledged. I am also very grateful to Uranerzbergbau GmbH (Bonn, FRG) for facilitating particular trace element analyses. Finally, I am ver indebted to Prof. I. R. Plimer (Newcastle, AUS) for his valuable comments on the draft of this publication.

Recibido, 30/VII/89

Aceptado, 15/VIII/89

REFERENCES

BEHR, H. J. & HORN, E. E. (1982). Fluid inclusion systems in metaplaya deposits and their relationships to mineralization and tectonics. Chem. Geol. 37: 173-189.

BEHR, H. J., PORADA, H., RÖHRS, J. & WEBER, K. (1983). Saline horizons acting as thrust planes along the southern margin of the Damara orogen, SWA/Namibia. Spec. Publ. geol. Soc. S. Afric. 11: 1-20.

BREITKOPF, J. K. (1987). Geochemical evidence for magma source heterogeneity related to plume activity during advanced rifting in the Southern Damara Orogen, Namibia. Abstr. of Contr. to IGCP 217 Lund, 3-6 June 1987.

EVENSEN, M. N., HAMILTON, P. J. & O'NIONS, R. K. (1978). Rare-earth abundances in chondritic meteorites. Geochim. et Cosmochim. Acta 42: 1199-1212.

HAACK, U., GOHN, E. & KLEIN, J. A. (1980). Rb/Sr ages of granitic rocks along the middle reaches of the Duruchaus river and the timing of orogenetic events in the Damara Belt (Namibia). Contr. Min. Petrol. 74: 349-360.

ILLIES, H. (1974). Intra-Plattentektonik in Mitteleuropa und der Rheingraben. Oberrhein. geol. Abh. 23: 1-24.

KASCH, K. W. (1981). The structural geology, metamorphic petrology and tectonothermal evolution of the southern Damara belt around Omitara S. W. A./Namibia. Bull. Precambr. Res. Unit. Univ. Cape Town 27: 333 pp.

KASCH, K. W. (1983 a). Regional P-T variations in the Damara Orogen with particular reference to early high-pressure metamorphism along the southern margin. Spec. Publ. geol. Sc. S. Afr. 11: 243-253.

KASCH, K. W. (1983 b). Tectonothermal evolution of the southern Damara Orogen. Spec. Publ. geol. Soc. S. Afr. 11: 255-265.

KRÖNER, A. (1977). Precambrian mobile belts of southern and eastern Africa - ancient sutures or sites of ensialic mobility? A case for crustal evolution towards plate tectonics. Tectonophysics 40: 101-135.

KRÖNER, A. (1982). Rb-Sr geochronology and tectonic evolution of the Pan-African belt of Namibia, southwestern Africa. Am. J. Sci. 282: 1471-1507.

KULICK, J., LEIFELD, D., MEISL, S., PÖSCHL, W., STELLMACHER, R., STRECKER, G., THEUERJAHR, A. K. & WOLF, M. (1984). Petrofazielle und chemische Erkundung des Kupferschiefers der Hessischen Senke und des Harz-Westrandes. Geol. Jb. D68: 3-223.

LARGE, D. (1987). The evaluation of sedimentary basins for massive sulphide mineralization. Contribution to DMG Aachen 1986.

MARTIN, H. & PORADA, H. (1977). The intracratonic branch of the Damara orogen in South West Africa. Part I: Discussion of geodynamic models; Part II: Discussion of relationships with the Pan-African mobile belt system. Precambr. Res. 5: 311-357.

MCKENZIE, D. (1978). Some remarks on the development of sedimentary basins. Earth and Planetary Science Letters 40: 25-32.

MILLER, R. McG. (1983 a). Economic implications of plate tectonic models of the Damara Orogen. Spec. Publ. geol. Soc. S. Afr. 11: 385-395.

MILLER, R. McG. (1983 b). The Pan-African Damara Orogen of South West Africa/Namibia. Spec. Publ. geol. Soc. S. Afr. 11: 431-515.

MILLER, R. McG. (1983 c). Tectonic Implications of the Contrasting Geochemistry of Damaran Mafic Volcanic Rocks, South West Africa/Namibia. Spec. Publ. geol. Soc. S. Afr. 11: 115-138.

MOINE, B., SAUVAN, P. & JAROUSSE, J. (1981). Geochemistry of evaporite-bearing series: a tentative guide for the identification of meta-evaporites. Contr. Min. Petrol. 76: 401-412.

MULLEN, E. D. (1983). $MnO/TiO_2/P_2O_5$: a minor element discriminant for basaltic rocks od oceanic environments and its implications for petrogenesis. Earth and Planetary Science Letters 62: 53-62.

PEARCE, J. A. (1983). Role of the sub-continental lithosphere in magma genesis of active continental margins. In: C. J. HAWKESWORTH & M. J. NORRY (eds.), Continental basalts and mantle xenoliths, Shiva Publ. Ltd. Cheshire: 230-349.

PEARCE, J. A. & NORRY, M. J. (1979). Petrogenetic implications of Ti, Zr, Y and Nb variations in volcanic rocks. Contrib. Min. Petrol. 69: 33-47.

PEARCE, T. H., GORMAN, B. E. & BIRKETT, T. C. (1975). The TiO_2O_2-K_2O-P_2O_5 diagram: a method of discrimination between oceanic and nonoceanic basalts. Earth and Planetary Science Letters 24: 419-427.

PEARCE, T. H., GORMAN, B. E. & BIRKETT, T. C. (1977). The relationship between element chemistry and tectonic environment of basic and intermediate volcanic rocks. Earth and Planetary Science Letters 36: 121-132.

PETTIJOHN, F. J. (1975). Sedimentary rocks. 3rd edition Harper& Row: 628 pp.

PLIMER, I. R. (1986). Tourmalinites from the Golden Dyke Dome, Northern Australia. Mineralium Deposita.

PLIMER, I. R. (1987). Tourmalinites associated with Australian submarine exhalative ores. Contribution to DMG Aachen 1986.

POTTER, P. E., SHIMP, N. F. & WITTERS, J. (1963). Trace elements in marine and fresh-water argillaceous sediments. Geochim. et Cosmochim. Acta 27: 669-694.

RIMANN, E. (1915). Geologische Untersuchungen des Bastardlandes in Deutsch-Süd-West-Afrika. Ed. Hanseat. Minengesellschaft (D. K. G.). Berlin: 100 pp.

RÖHRS, J. H. C. (1982). Sedimentologische und mineralogische Untersuchungen zur Genese der Nosib Sedimentite im südlichen Damara Orogen. Unpublished Diplom-Arbeit Georg-August-Universität Göttingen: 162 pp.

S. A. C. S. (South African Committee for Stratigraphy, 1980). The Damara Sequence. In: L. E. KENT (Comp.). The Stratigraphy of South Africa Part. 1, Lithostratrigraphy of the Republic of South Africa, South West Africa/Namibia, and the Republic of Bophuthatswana, Transkai, Venda and Ciskai. Handb. Geol. Surv. S. Afr. 8: 415-438.

SCHIMDT-MUMM, A., BEHR, H. J. & HORN, E. E. (1987). Fluid systems in metaplaya sequences in the Damara Orogen (Namibia): Evidence for sulfur-rich brines - General evolution and first results. Chem. Geol. 61: 135-145.

SLACK, J. F., HERRIMAN, N., BARNES, R. G. & PLIMER, I. R. (1984). Stratiform tourmalinites in metamorphic terranes and their geologic significance. Geology 12: 713-716.

TANKARD, A. J.; JACKSON, M. P. A.; ERIKSSON, K. A.; KOBDAY,' D. K.; HUNTER, D. R.; MINTER, W. E. L. (1982). Crustal Evolution of Southern Africa. Springer-Verlag New York: 523 pp.

TAYLOR, S. R. & MCLENNAN, S. M. (1985). The continental crust: its composition and evolution. Blackwell Scientific Publ. Oxford: 312 pp.

UHLIG, S. (1987). Die oberproterozoische Duruchaus-Formation in Namibia und ihre Kupfervererzungen. Dissertation Justus-Liebig-Universität Giessen: 162 pp.

WANG RENMING, HE SHUYAN, CHEN ZHENZHEN, LI PINGFAN & DAI FENGYAN (1985). Geochemical evolution and metamorphic development of the early Precambrian in Eastern Hebei, China. Precambrian Research 27: 111-129.

WATTS, A. B. (1981). The U. S. Atlantic continental margin: subsidence history, crustal structure and thermal evolution. In: Geology of Passive Continental Margins: History, structure and sedimentologic record, American Association of Petroleum Geologists, Education Course Note Series 19: 2/1-2/75.

WATTS, A. B., KARNER, G. D., STECKLER, M. S. (1982). Lithospheric flexure and the evolution of sedimentary basins. Phil. Trans. R. Soc. Lond. A305: 249-281.

WILLIAMS-JONES, J. E. (1984). The petrology of the basalts of the Dordabis Formation, in the vicinity of Dordabis in central S. W. A./Namibia. Unpubl. thesis Rhodes University Grahamstown: 114 pp.

WILSON, A. F. (1978). Comparison of some of the geochemical features and tectonic settings of Archean and Proterozoic granulites with particular reference to Australia. In: B. F. Windley, S. M. Naqvi (eds), Archean Geochemistry, Elsevier: 241-268.

TABLE I. **Major and trace element concentrations of tourmalinites and metapelites with stratiform tourmaline concentrations of the Late Proterozoic Duruchaus Formation in Namibia.**

Farm	Stolzenf.	Stolzenf.	Berghof	Stolzenf.	Tsatsach.	Tsatsach
Sample	ST-12	ST-17	18/9/2D	3/10/29S	5/11/8B	5/11/9A
wt%						
SiO_2	69.1	68.5	65.5	78.9	63.4	64.3
TiO_2	0.78	0.81	0.77	0.41	1.01	1.05
Al_2O_3	14.8	13.2	14.3	7.55	15.4	13.9
Fe_2O_3*	3.75	5.25	3.54	3.17	3.70	6.09
MnO	0.01	0.01	0.01	0.04	0.01	0.01
MgO	2.04	2.77	5.36	0.92	3.19	2.83
CaO	0.33	0.38	1.11	2.16	0.51	0.60
Na_2O	5.59	3.65	1.36	2.92	9.72	9.35
K_2O	0.18	0.07	0.02	1.20	0.11	0.12
P_2O_5	0.20	0.23	0.26	0.11	0.12	0.16
CO_2	0.20	0.14	0.94	2.17	0.19	0.21
H_2O^+	0.80	1.08	1.70	0.55	0.97	0.53
B_2O_3	2.35	3.86	4.51	0.02	1.26	0.10
total	100.13	99.95	99.38	100.12	99.59	99.25
ppm						
Cr	69	70	82	25	70	61
Co	7	7	7	4	3	8
Ni	34	36	36	10	41	38
Cu	2	8	n.d.	n.d.	n.d.	1
Zn	7	7	14	3	6	6
Ga	19	20	19	9	21	19
Pb	2	1	4	2	2	2
Th	7	3	9	4	10	8
Rb	9	1	n.d.	36	1	2
Sr	54	76	111	22	27	10
Y	34	21	24	18	18	33
Zr	250	231	227	126	248	318
Nb	16	8	5	5	16	11
Ba	7	11	16	208	2	10

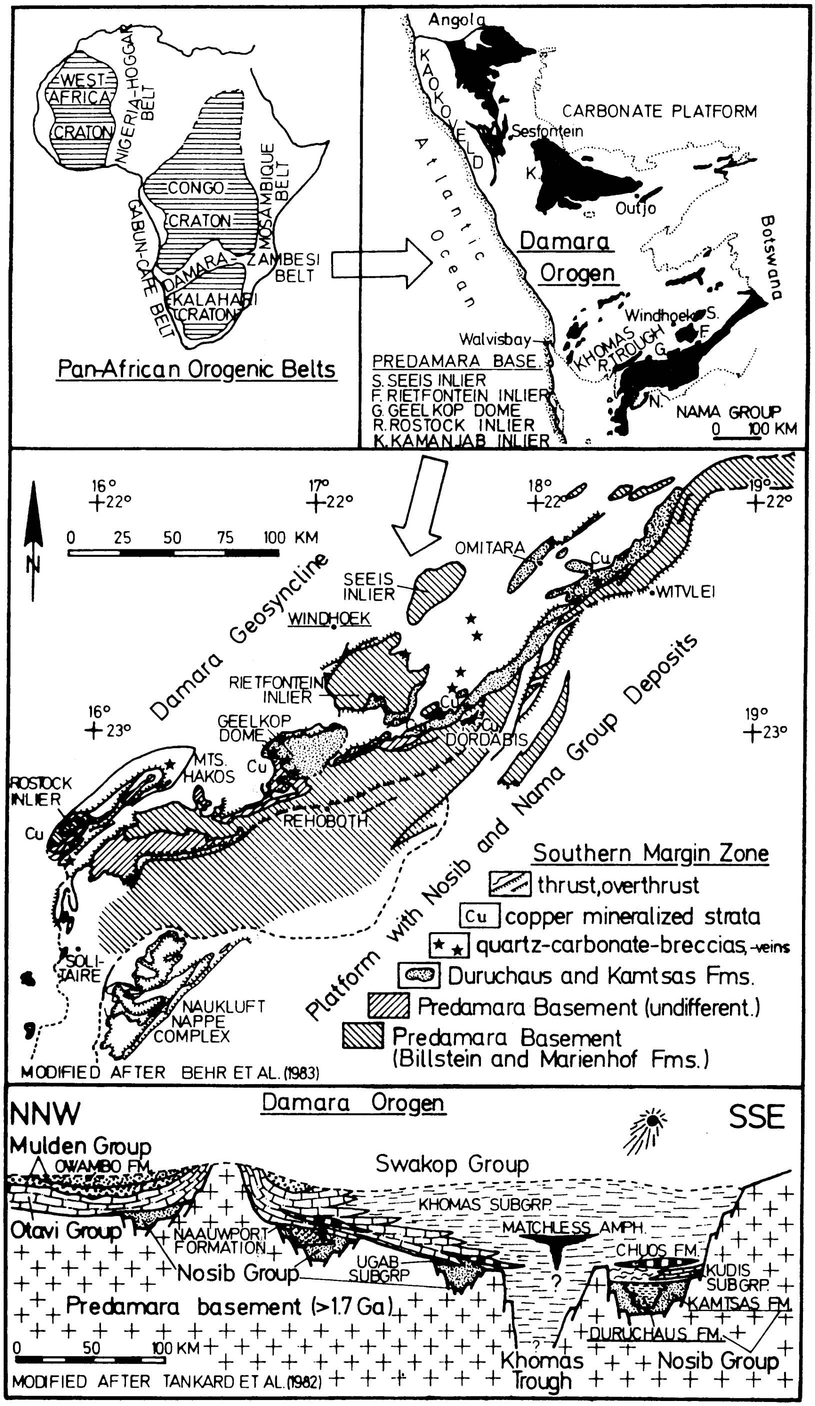
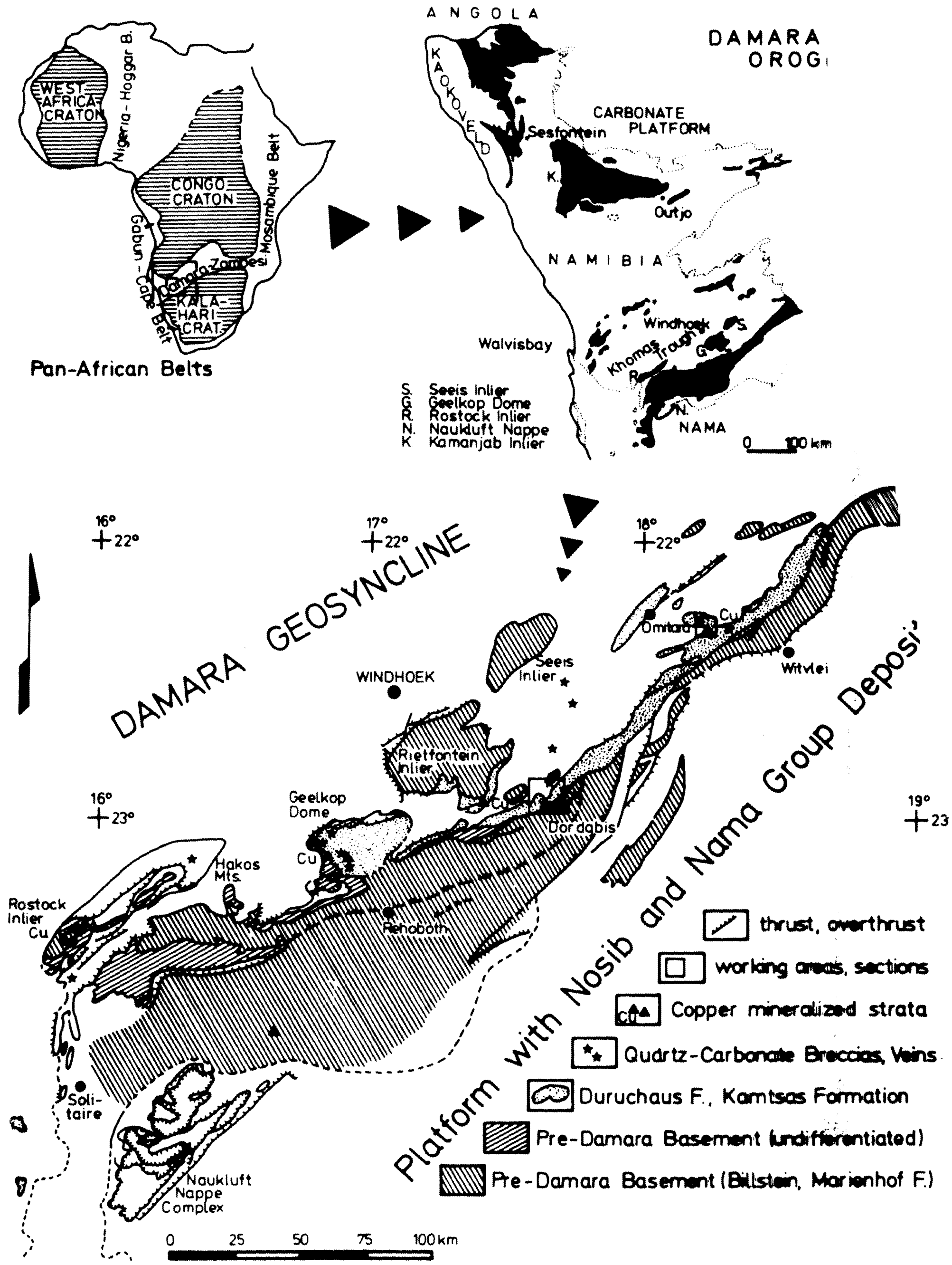


Fig. 1. **Geological setting of the Late Proterozoic Damara Orogen in Namibia and distribution of the Duruchaus Formation along the Souther Orogen Margin.**



Mapa 1. Situación geográfica de la zona estudiada.

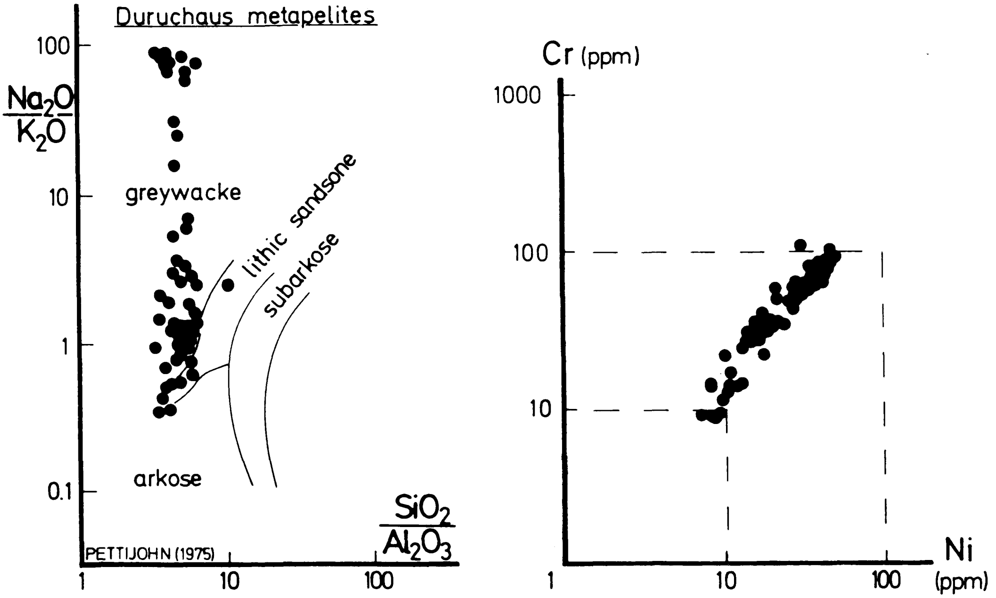


Fig. 2. The metapellites of the Duruchaus Formation show Na_2O/K_2O and SiO_2/Al_2O_3 ratios that are characteristic for greywackes; low Cr and Ni contents support an origin of the detrital weathering products from a gneissic basement.

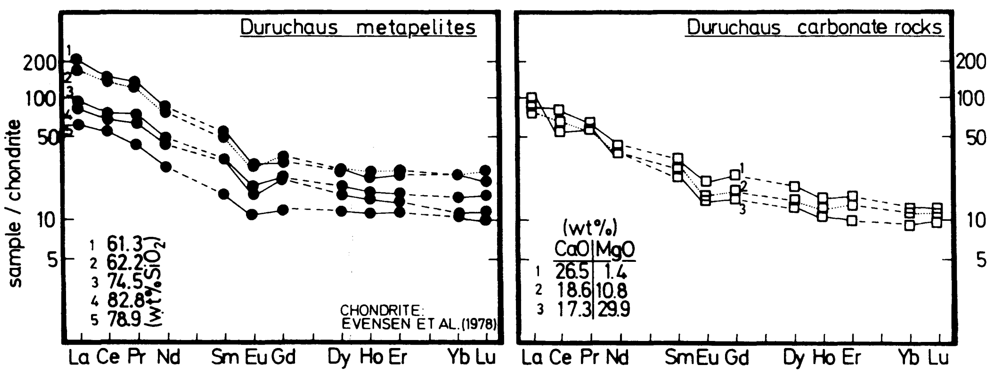


Fig. 3. Metapelites and carbonate rocks of the Late Proterozoic Duruchaus Formation exhibit characteristic patterns of REE normalized to chondritic abunance (EVENSEN *et al.*, 1978) which depend mainly on the detrital mineral parageneses (data see in ULIG, 1987).

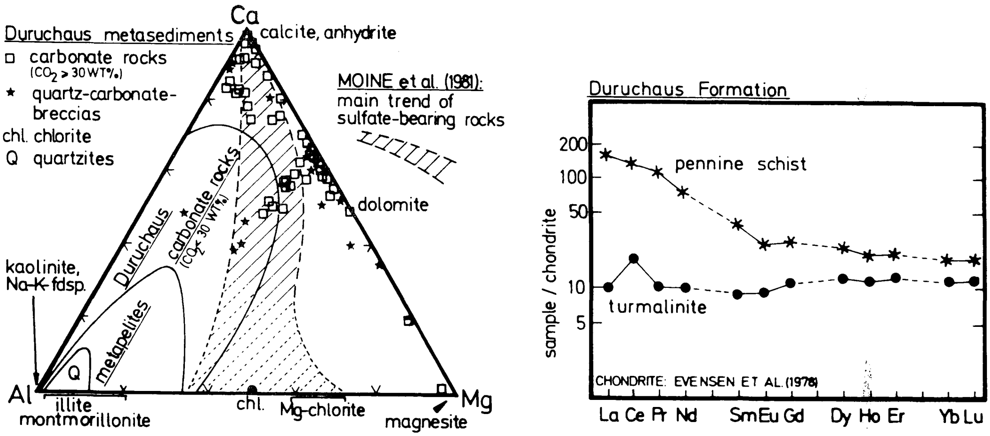


Fig. 4. According to the discrimination diagram of MOINE *et al.* (1981), for metasediments related to evaporitic sequences, the great majority of the Duruchaus metapelites shows a distribution that is characteristic for «nonevaporict» clastic sediments; penninerich Duruchaus metapelites present REE values which are very similar to normal «nonevaporitic» meapelites of the Duruchaus Formation; the remarkable contents of apatite result in the positive cerium-anormaly (25 ppm) of the analyzed Duruchaus tourmalinite on Farm Stolzenfeld.

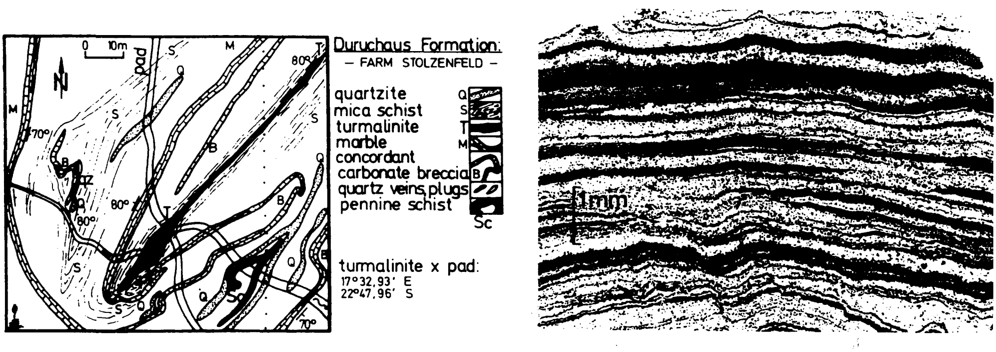


Fig. 5. Geological setting of one tourmalinite of the Late Proterozoic Duruchaus Formation; due to tectonization within a hinge fold thickness exceeds 1 m; interlaminate layers of quartz (white) and tourmaline (black) show graded bedding and are thougt to have been precipitated as a primary silica-tourmaline gel from subaqueous exhalative fluids (vertical section of figure = 6 mm).

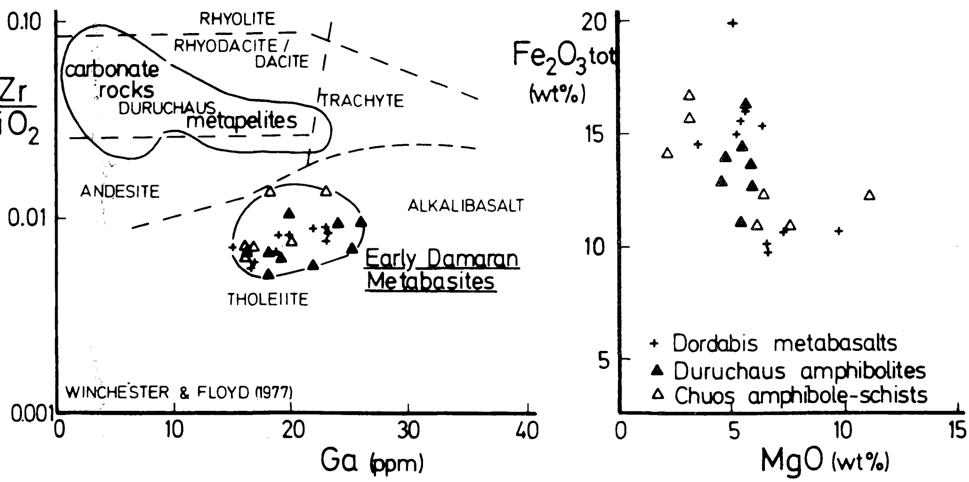


Fig. 6. Tholeiitic metavolcanics occur along the Southern Margin of the Damara Orogen and are characterized by high iron contents.

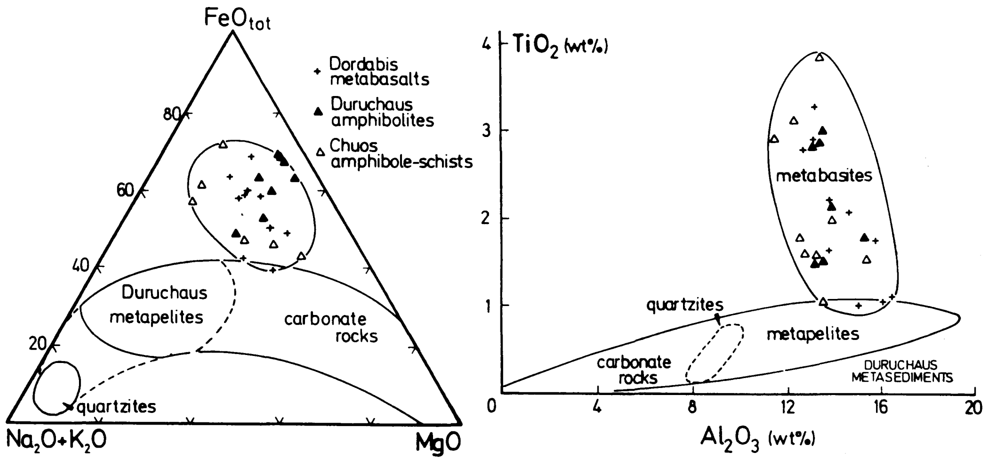


Fig. 7. Major and trace element ratios and discrimination diagrams differenciate the Duruchaus amphibolites from the Duruchaus metasediments and underline the strong chemical resemblance of the Duruchaus amphibolites to the Dordabis metabasalts and Chuos amphibole-schists.

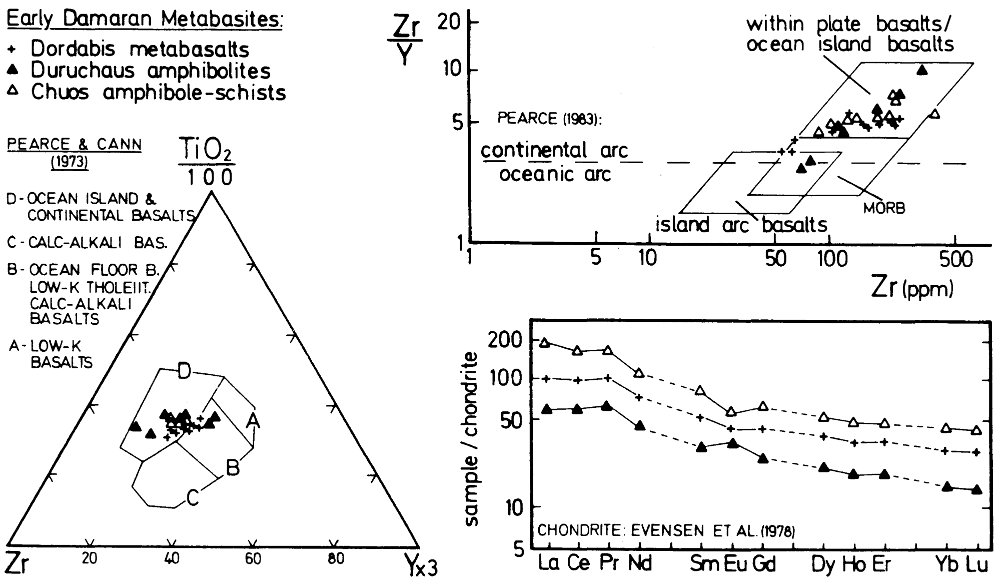


Fig. 8. Due to their complex chemistry the tholeiitic metavolcanics, which originated from a basaltic magma source within the continental lithosphere between the Congo and Kalahari Cratons, are distributed in a transition zone of the discrimination diagram of PEARCE & CANN (1973) and exhibit Zr/Y ratios and REE patterns that are characteristic of basalts of continental environment.

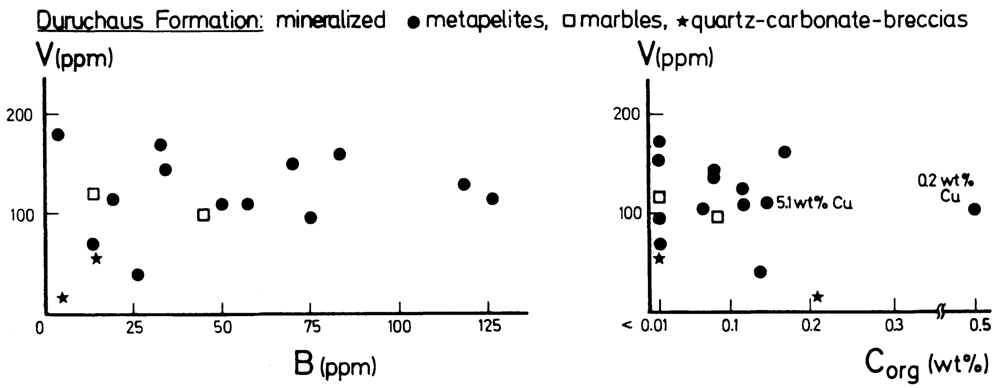


Fig. 9. Boron contents in copper mineralized Duruchaus metasediment samples do not exceed 120 ppm; higher concentrations of V and C_{org} and a positive correlation between these elements what is characteristic for stratiform copper mineralizations cannot be observed in the mineralized Duruchaus metasediments.

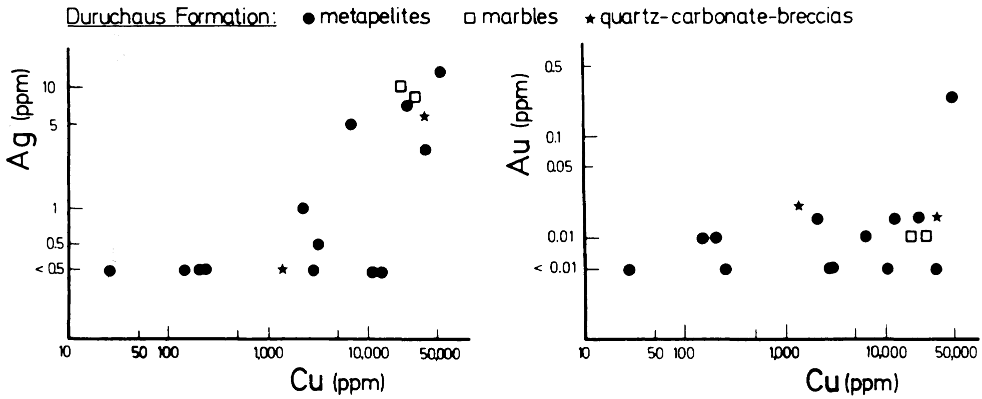


Fig. 10. **The positive correlation between precious metals and copper is well-documented in the stratabound mineralizations of the Duruchaus Formation.**