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ALPINOTYPE THRUST TECTONICS AND BASEMENT-COVER RELATIONSHIPS IN THE SOUTHERN MARGIN ZONE OF THE PAN-AFRICAN DAMARA OROGEN, ROSTOCK AREA

N. Pfürr, K. Wissmann, H. Ahrendt, R.S. Hill and K. Weber
Institut für Geologie und Dynamik der Lithosphare, Universität Göttingen, Goldschmidtstr. 3, D-3400 Göttingen, West Germany

ABSTRACT

The Southern Margin Zone of the Damara Orogen exhibits alpinotype thrust and nappe tectonics. Three nappe complexes are identified in the Rostock area: the Rostock Basal Nappe Complex (RBNC), the Rostock Cover Nappe Complex (RCNC) and the Ubib Nappe Complex (UNC). Nappe movements were intensely influenced by fluids and intrusive dolomites (Fault Dolomite), which originated from playa-type sediments. Up to five different phases of deformation are distinguished. The tectonic framework of the RBNC is compared to that of the external massifs of the Alps (Aar Massif, Gotthard Massif).

The probably oldest rocks of the Damara Sequence are included in the lowermost nappe complex (RBNC), where they conformably overlie red orthogneisses of the Gamsberg-type, which possibly constitute the pre-Damara basement. The Damara Sequence consists of a succession of felsic and basic volcaniclastics that interfingers with alluvial to fluvial quartzites and conglomerates and playa-type sediments, characteristic of deposits in rifted areas. Accordingly, we consider these rocks to be Nosib Group (basal Damara) and not Gaub Valley Formation (> 1.5 Ga) of the Rehoboth Sequence, as previously mapped.

1. INTRODUCTION

The preliminary results till the end of 1986 of a mapping project (to a scale of 1:10 000) in the Rostock area are presented. This area is situated in the Southern Margin Zone (SMZ), one of the main structural zones of the 400 km wide, north-east trending intracontinental branch of the Pan-African Damara Orogen (Fig. 1). According to Hoffmann (1983), the Southern Margin Zone is defined as a 25 to 55 km wide belt of low-angle thrust sheets and south-east vergent fold nappes that consist essentially of multiply deformed Damara cover rocks and intensely refoliated basement rocks. The Southern Margin Zone delimits a zone of deep-level thrusting and crustal shortening. The present understanding of the geology of the Rostock area is based on the unpublished reconnaissance mapping (1:50 000) of Hill (1975) and mapping of areas immediately to the north and east of the study area by De Waal (1966) and Hälbich (1970).

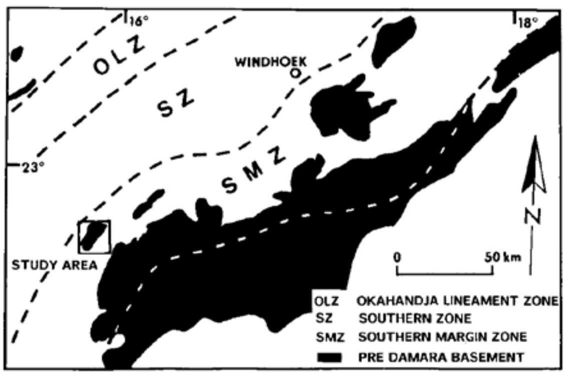

Fig. 1: Locality map showing the location of the study area (outlined) within the SMZ of the north-eastern branch of the Damara Orogen (adapted from Miller, 1983).

The project was initiated in 1984, with the aim of elucidating the structure and the basement-cover relationships of the Upper Proterozoic sequences in the Rostock area. The project includes geological and structural mapping, accompanied by macro- and microstructural analysis, investigations of metamorphism, geochemistry and age dating of the rocks concerned.

Until now the fieldwork has concentrated mainly on the central, south-eastern and eastern parts of the Rostock area. The purpose of this paper is to give a short account of the current results of these investigations and to modify the model of early Damara depositional and structural development in this part of the Southern Margin Thrust Belt.

2. GEOLOGY

A simplified geological map of the Rostock area is shown in Fig. 2. The mapping allows identification of 3 major tectonic units within the Rostock area, which are tentatively called the Rostock Basal Nappe Complex (RBNC); the Rostock Cover Nappe Complex (RCNC) and the Ubib Nappe Complex (UNC).

The RBNC cons its of pre- or early-Damaran orthogneisses and their autochthonous to parautochthonous cover of Damara Rocks. The contact with the overlying RCNC, consisting of Kudis Group rocks, is characterized by intense mylonitization. The UNC consists of Damaran rocks, which are separated from the underlying RBNC by the so called Fault Dolomite, which is believed to be of intrusive origin.

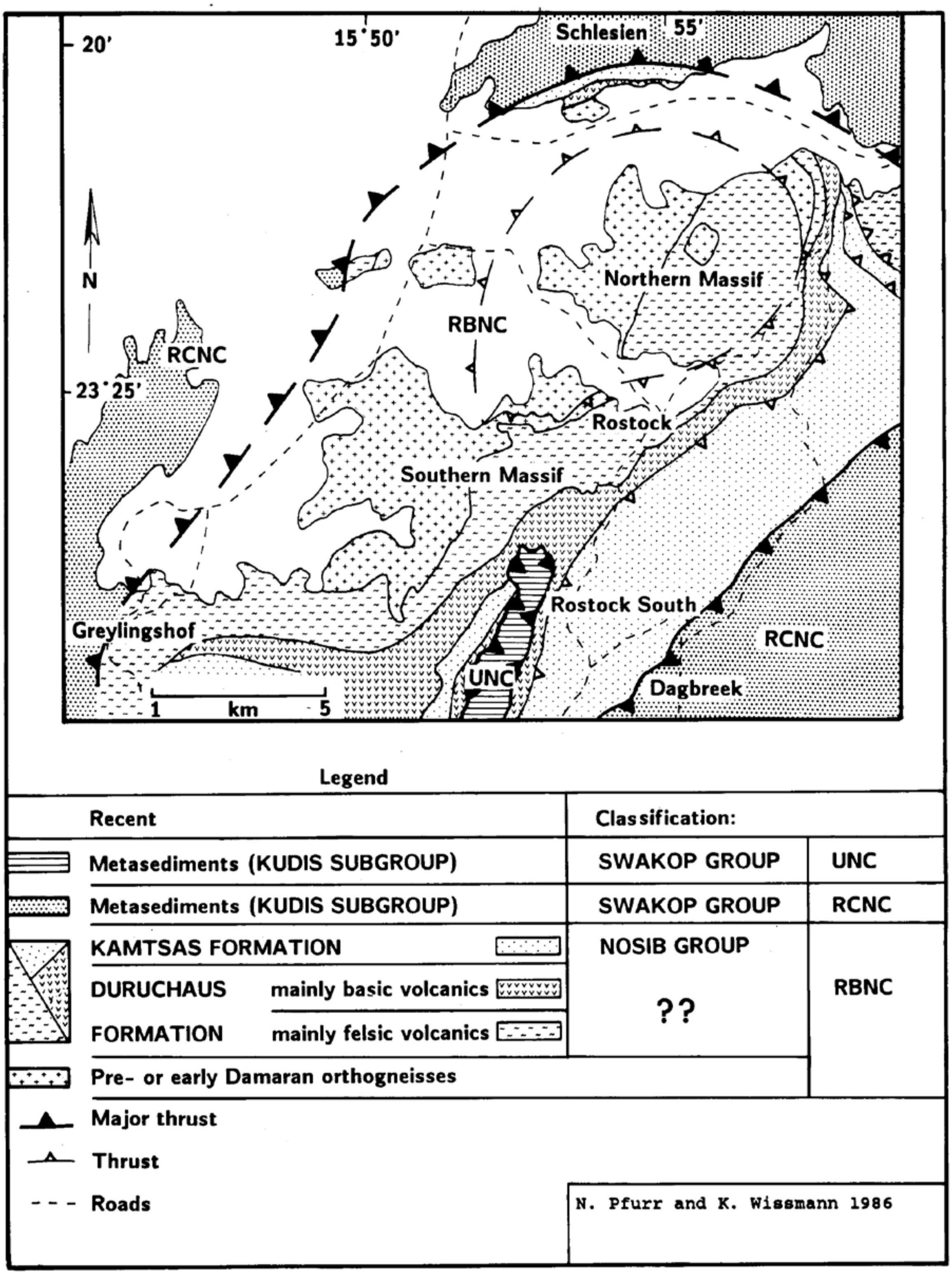

Fig. 2: Simplified geological map of the Rostock area; north-western part partly adapted from Hill (1975).

2.1. Rostock Basal Nappe Complex

Within the RBNC four major lithotypes are distinguished (see Fig. 2): pre- or early-Damara orthogneisses and three partly interfingering sedimentary and volcaniclastic sequences of the Nosib Group. The latter are subdivided into a sequence of conglomerates and quartzites of the Kamtsas Formation with some volcaniclastic intercalations and two sequences of playa-type sediments, representing the calcareous pelitic and sabkha-playa facies of the Duruchaus Formation, as described by Behr *et al.* (1983a) from the Southern Margin Zone. In addition, large amounts of mainly felsic volcanics in the lower and mainly mafic volcanics in the upper parts of the sequence are included.

The association of the volcanics with the sediments of the Duruchaus and the Kamtsas Formation indicates that they are of Nosib age and therefore have to be interpreted as rift volcanics.

Intensive folding and thrusting during an early stage of deformation produced large recumbent folds and at least two thrust sheets, a basal orthogneiss complex and an upper orthogneiss complex, both with their sedimentary cover, now forming the RBNC.

The orthogneisses contain a variety of weakly to well-foliated alkali-granite gneisses. According to Hill (1975) they resemble the pre-Damaran Gamsberg granite and are considered to be its equivalent. Granites of the Gamsberg Suite from the Rehoboth and Maltahohe districts were dated at 1090 Ma (Hugo and Schalk, 1974).

The basal orthogneiss complex is autochthonously covered by rocks of the lower Duruchaus sequence, a conglomerate with a schistose matrix containing abundant pebbles of the underlying granites and rare black quartzite. The conglomerate grades upward into albite mica schists with local Cu mineralization and segregation nests of tremolite. Intercalations of dolomites, albitites and metavolcanics occur at many sites. In portions of the schists, underformed scapolite of mizzonitic to dipyritic composition occurs abundantly. It forms light grey, rounded porphyroblasts up to 1 cm and has a poikiloblastic structure with inclusions of quartz, biotite, albite and clinozoisite.

The albitites may resemble quartzites in the field, but they consist mainly of albite with minor quartz, carbonate and mica. In thin section a mylonitic fabric with equilibrated grain boundaries is found.

In the upper thrust sheet a subvolcanic complex is found, which consists of the upper orthogneiss and overlying volcanic rocks. In most parts, the volcanics form the cover of the orthogneiss, but in places are intruded as well.

The volcaniclastic sequence consists of acid volcanics, amphibolites and biotite-albite schists forming alternating layers from 10 cm to 10 m thick. Their boundaries are very sharp (Fig. 3). The lithotypes often thin out, which shows the flow character of these rocks.

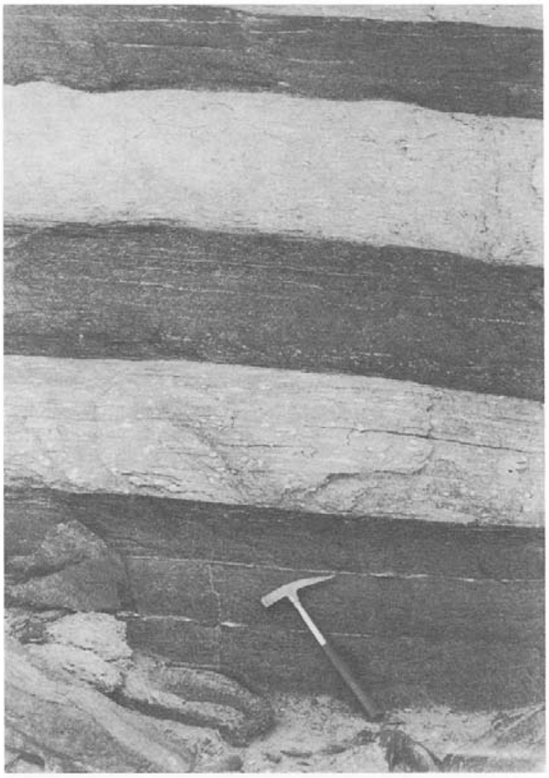

Fig. 3: Alternation of mafic and felsic metavolcanic flows and tuffs; farm Greylingshof.

Intercalations of albitites and dolomitic layers occur at scales of cm to m.

The felsic volcanics within the sequence have been distinguished according to their mineralogical composition into Na- to K-rich volcanics. Red-grey to red layers are intermediate to K-rich volcanics. They show a laminated porphyroblastic texture. The porphyrobalasts are microcline, albite and quartz. They can be interpreted as remaining volcanic phenocrysts, because in thin section traces of the corrosion of mineral grains by resorption are visible. The fine- to medium-grained matrix consists of irregular to polygonal grains of quartz. Na-rich volcanics are grey in color and consist mainly of albite and minor quartz. They display a fully recrystallized granoblastic texture. Intergrowths of biotite and muscovite as well as xenomorphic Ca epidotes are arranged parallel to the foliation. Accessories of all these felsic volcanic rocks are ore minerals, single garnets, titanite, apatite and short- to long-prismatic zircons.

Mafic volcanics are represented by compact, fine-textured amphibolites. They consist mainly of a tschermakitic hornblende of the barroisitic type, albite and biotite. Schistose varieties show higher contents of biotite than the massive layers, and some layers contain albite porphyroblasts. Various thick layers of almost completely recrystallized biotite-albite schists may be derived from tuffitic material.

A major part of the upper Duruchaus sequence is formed by amphibolites, probably basic metavolcanics. Further components are albite-biotite schists, garnetiferous feldspar gneisses, garnet- amphibole bearing chlorite-mica schists, phyllites, garnet-bearing calcsilicates, ferruginous quartzites, albitites and thin layers of brown dolomite. The characteristic fabric of these rocks in thin section is a mylonitic layering with complete recrystallisation and equilibrated grain boundaries.

Lower amphibolite facies conditions are indicated by the paragenesis of biotite, chlorite, muscovite, quartz and almandine and in some of the basic volcanics by the paragenesis of barroisitic hornblende and albite.

Almandine-rich garnet is the dominant component of the rocks (Fig. 4). Many of the first generation garnets have snowball structures. Late- to post-tectonic garnets show well developed helicitic internal fabrics due to the overgrowth of the crenulation cleavage.

These rocks also contain large amounts of post-tectonic “hornblendegarben”, up to 10 cm in size, of hastingsitic to tschermakitic composition (Fig. 5). The internal metablastesis of garnet and ampibole as well as the origin of irregularly distributed veins of quartz, calcite and brown dolomites, formed by hydraulic fracturing, may be the effect of intrusion of metasomatic fluids derived from underlying Duruchaus sediments.

The lower part of the Kamtsas Formation comprises metaconglomerates attaining a maximum thickness of about 200 m. The clasts consist of quartzites, amphibolites and a variety of granite types. The foliated matrix is yellowish to grey in color, contains quartz, feldspar and biotite and in places is calcareous. Within the sequence the conglomerate grades into quartzite. Thin layers of dolomite and acid volcanic tuff are intercalated.

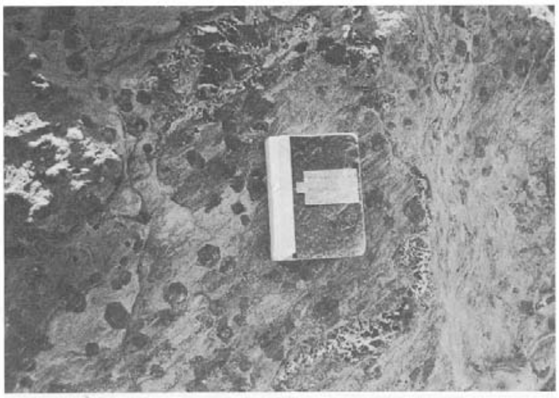

Fig. 4: Post-tectonically grown garnet blasts within chlorite-bearing schists. The formation of veins composed of quartz and dolomite is related to hydraulic fracturing; farm Rostock South.

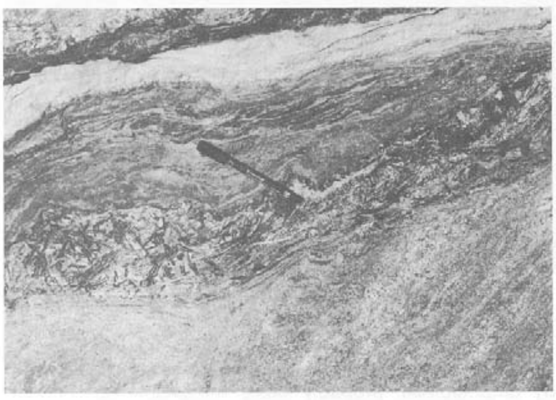

Fig. 5: Post-tectonic “hornblendegarben” within chlorite-bearing shists near a dolomitic layer; farm Rostock South.

Upward the conglomerates grade into yellowish quartzites consisting of quartz, feldspar and mica. Cross-bedding is marked by thin layers of green biotite. Channel casts contain pebbles of granite and quartzite. The quartzite pebbles are of the same type as the wall rocks and seem to be of intraformational origin. Locally the quartzites contain small patches of copper sulfides associated with veins of quartz and dolomite.

The rocks of the Kamtsas Formation are the psammitic-psephitic-facies rocks of the Nosib Group, which were deposited in an environment ranging from alluvial to fluvial.

2.2 Rostock Cover Nappe Complex

The south-eastern part of the RCNC is formed by rocks of the Blaukrans Formation, mainly dark-grey graphitic schists, which are associated with dark marbles, carbonate-rich schists, black quartzites. Sericitic schists with albite porphyroblasts and phengitic schists may be metavolcanic intercalations. Dark grey schistose conglomerates contain clasts of granites and quartzites, graphitic schists, black quartzites and marbles of intraformational origin.

According to Hoffmann (1983) the presence of such mass-flow deposits within a mainly pelitic black shale facies sequence indicates a relatively deep water slope environment for the deposition of the Blaukrans Formation.

The rocks of the Blaukrans and the Hakos Formation, forming the western and northern parts of the RCNC, have not yet been studied in detail.

2.3 Fault Dolomite

Intrusive dolomites occur mainly at the base of the UNC and on thrust planes within this nappe complex and to a lesser extent in most of the other rocks as well. These dolomites are considered to be equivalent to the Sole Dolomite, as has been described from the Naukluft Nappe Complex in the Southern Foreland by Behr *et al.* (1983) and Weber and Ahrendt (1983).

Main components of the brown, compact rocks of the Fault Dolomite are sparitic dolomite and talc, albite, quartz and sericite. The minerals display no primary recrystallization and no crystal-plastic deformation. Thin foliated layers are very rare and have not yet been microscopically investigated. Many of the intrusive dolomites, which vary in thickness from a few centimetres to tens of metres contain numerous fragments of wall rock. Large quartz veins are associated with the Fault Dolomite. Some of these quartz veins contain up to 1 dm large crystals of quartz, dolomite and calcite. The

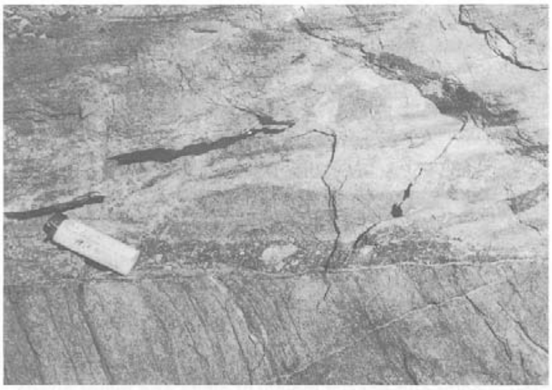

Fig. 6: Fault Dolomite containing fragments of wall rock, forms a discordant thrust plane; farm Greylingshof.

TABLE 1: Regional classification of the structural features

Compression Phase	Deformation Stage	RBNC	RCNC	UNC
K_1	D_1	mylonitic foliation thrusting large scale (?) isoclinal folds		
K_2	D_2	large scale closed to isoclinal SE-vergent folds / slaty cleavage thrusting / imbrication		
	D_3	open folds NW-dipping slaty cleavage		
K_3	D_4	NW-vergent backfolding (kink bands and open folds)		
	D_5	regional updoming		

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base of the Fault Dolomite forms a sharp boundary to the underlying rock sequences (Fig. 6). According to Behr *et al.* (1983) and Weber and Ahrendt (1983) this type of rock may be interpreted as a discordant intrusion under pore-fluid pressure into thrust planes and along the base of nappe complexes, where it acts as a lubricant.

2.4 Ubib Nappe Complex

The UNC with the Fault Dolomite at its base, discordantly overlies the rocks of the RBNC. Internally the UNC is strongly faulted and imbricated into several thrust sheets. The thrust planes contain intrusive dolomites of the Fault Dolomite type and numerous quartz veins. The whole sequence is overturned.

The stratigraphic base is formed by a grey metaconglomerate of 200-300 m thickness, the stratigraphic classification of which is still problematic. The nature of the pebbles indicates that it may be an equivalent of the Kamtsas Formation. The clasts consist of white and pink, coarse-grained granites, light fine-grained granites, acid and basic volcanics as found in the RBNC, biotite-bearing quartzites and albite-biotite schists. The matrix is schistose to quartzitic. The metaconglomerate grades upward into dark quartzites fining up into dark schists. These rocks are overlain by the typical Chausib Member turbidite sequence. (H. Porada, pers.comm.) with regular alternation of distinctly graded quartzite and dark graphitic schists, as described by Porada *et al.* (1976). The whole succession, including the metaconglomerates at the base, may reflect the development of a basinal margin with the formation of a submarine fan.

3. STRUCTURAL FEATURES

In all of the above mentioned nappe complexes, the same generations of deformation (D_1-D_5) could be distinguished, based on fold and cleavage fabrics and therefore allow a regional classification as shown in Table 1. During D_1 and D_2 a mylonitic foliation and isoclinal folds were produced under ductile conditions at a deeper crustal level, whereas the D_3 folding, the D_4 backfolding and the D_5 updoming were mainly brittle-type deformation at a higher crustal level.

3.1 D_1 and D_2 deformations

3.1.1 Rostock Basal Nappe Complex

The D_1 deformation created a first foliation in the massive orthogneisses, mainly a gneissosity, but in places a schistosity as well, and thrustplanes, S_1 foliation and isoclinal folds in their sedimentary cover. The B_1 axes plunge gently south-east or north-west.

The oldest folding in the orthogneisses isoclinally refold the S_1 foliation, where schistosity is developed. Therefore these folds represent a second generation of deformation, D_2. In parts of the orthogneisses, showing a weaker gneissosity, open SE-vergent B_2 folds at a scale ranging from 5 m to 1 km and a slaty S_2 cleavage are found. This cleavage forms a distinct intersection lineation by crossing S_1 at acute angles.

In the metasediments, isoclinal B_1 folds refolded by isoclinal B_2 folds, are found. The SE-vergent B_2 folds (Fig. 7) with gently SSW or NNE plunging axes are very prominent. Their sizes range from cm to more than 1 km. Some dm-scaled noncylindrical isoclinal folds are found. They refold the S_1 foliation and are therefore recognized as B_2 folds.

The S_2 foliation in the metasediments is often found as mylonitic layering, which on the limbs of the folds runs parallel to the bedding and transversely cuts the bedding at the hinges of the folds. The Further development of the large-scale isoclinal B_2 folds is represented by the late D_2 thrust planes in the lower limbs of the folds (Fig. 8). Boudinaging and extensive imbrication on a scale ranging from m to km have taken place during the later D_2 deformation and do not show evidence of possible large-scale B_1 folds.

3.1.2 Rostock Cover Nappe Complex

All upper nappe units within the RCNC show homo-

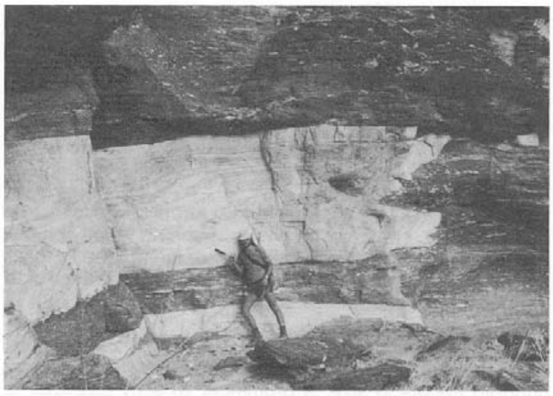

Fig. 7: Adventive fold of a large isoclinal B_2 fold in albite-dolomite rocks of the Duruchaus Formation (RBNC); Northern Massif, farm Rostock North.

Fig. 8: D_2 shear zone within the RBNC; farm Rostock South.

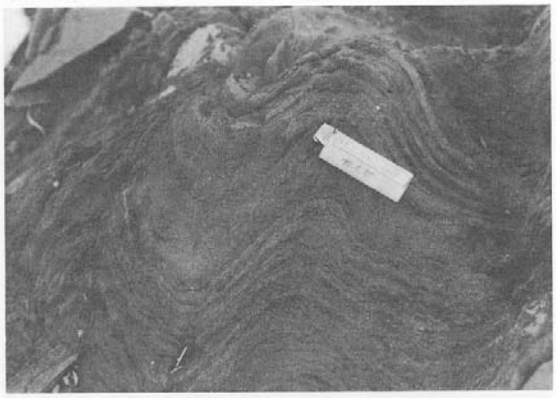

Fig. 9: S_2 crenulation cleavage in pelitic layers of the Chausib turbidites (UNC); farm Rostock South.

tactic fabrics at thrust planes dividing them. The oldest fabrics, correlated with the regional D_1 deformation, are a prominent mylonitic foliation and some isoclinal B_1 folds with NW-SE-trending, gently plunging axes.

The regional appearance of the RCNC is dictated by the B_2 folds. They are SE-vergent, closed to isoclinal, with gently SW or NE plunging axes and appear at a scale of cm to km. Their slaty cleavage is very prominent. The large-scale B_2 synclines are found at a km-scale, whereas the anticlines are only found at a 100 m-scale. The lower limbs of the overturned B_2 folds are often sheared, which causes a D_2 imbrication and thrusting with a S_2 mylonitic foliation.

3.1.3. Ubib Nappe Complex

In the UNC the mylonitic deformation is less intense than in the RBNC and the RCNC. The main characteristics of the UNC are the very in homogeneous strain distribution and the prominent intrusion of Fault Dolomite within the nappe complex and at its base and structural discordances to the underlying RBNC.

In the pelitic layers of the Chausib turbidites, isoclinal B_1 folds of mm to cm size with NW-SE-trending, gently plunging axes and a mylonitic S_1 foliation are found. The S_1 foliation normally runs parallel to the bedding, but in places cuts the bedding at acute angles.

The D_2 deformation produces NE-SW-trending, SE-vergent, closed to isoclinal B_2 folds of decimetre to several hundred metres in size. A prominent S_2 slaty cleavage is related to these folds as well as a crenulation, which is found in places (Fig. 9).

Large amounts of intrusive dolomites are found brecciating the adjoining rocks. The Fault Dolomite in places shows a weak foliation parallel to the base of the complex. The generally prominent S_2 cleavage is lacking in the Fault Dolomite. Therefore, the dolomitic intrusions and the foliation in the Fault Dolomite are related to the late D_2 deformation.

The S_1 cleavage planes dip at a lower angle than the bedding which indicates that the whole sequence is in an overturned position relative to D_1. The normal position of the S_2 slaty cleavage indicates that the sequence is in a normal position relative to D_2. Therefore the structure of the UNC is interpreted as the remaining lower limb of a great overturned B_1 anticline, which is refolded by B_2 and now occurs as the normal hinge of a B_2 syncline.

3.2 Open folding

All units are affected by an open folding, D_3, at a scale of 50 to 500 m. It produced a S_3 slaty cleavage, frequently connected with the new formation of biotite on the S_3 cleavage planes. In the lower units of the RBNC this cleavage is only weakly developed, whereas in the upper units of the RCNC and UNC it is very prominent.

3.3 Backfolding

The D_4 deformation is represented by an open NW-vergent backfolding around mainly SW or NE-trending, gently plunging axes. The B_4 folds appear in sizes ranging from metres to more than fifty metres. In the internal parts of the RBNC, which are shown in Fig. 2, in the RCNC and UNC, B_4 folds are seldom found. A crenulation related to B_4 folds occurs in places. In the more external, not yet mapped, parts of the RBNC in the northern area of farm Donkerhoek, the backfolding becomes very prominent in places and occurs as kink-bands, passing gradually into open folds.

3.4 Updoming

The final D_5 deformation led to a regional updoming of the whole Rostock area. It causes the fold axes to undulate around the centre of the dome, while the planes of bedding and mylonitic layering tend to dip away from the centre of the dome. As a result of the updoming the Rostock area attained its structure as a tectonic window with the centroclinal striking of the thrust planes.

4. INTERPRETATION OF THE STRUCTURAL DEVELOPMENT

At least three compressional phases K_1-$_3$ are to be distinguished (see Table 1), from which the K_1 and K_2 compressional phases have to be correlated with two different nappe thrusts.

During K_1 the RBNC and the RCNC have been piled up internally and the RCNC and UNC have been piled on the RBNC. Overthrusting took place from a northern direction and produced a thrustbelt, which was overprinted by all later deformations.

The second phase of overthrusting from NW to SE took place as a Further development of D_2 folding during K_2 and is found as a large scale imbrication of the nappe piles. Because the S_2 cleavage has not affected the Fault Dolomite at the base of the UNC, the movements at the base of this nappe complex must have taken place partly during the very late second phase of overthrusting.

During progressive compression the upper units were affected by D_3 folding, which led to a widespread S_3 slaty cleavage.

During the uplift a weak third phase of compression, K_3, caused the antivergent backfolding and finally led to the updoming of the whole area.

5. CONCLUSIONS

The main preliminary results of the investigation in the Rostock area are:

1. Red orthogneisses and Damaran metasediments overlying them autochthonously, form the basal complex.
2. A bimodal volcanic sequence was found in the autochthonous cover of the orthogneisses.
3. This bimodal volcanic sequence interfingers with rocks of the Kamtsas Formation and rift-type sediments of the Duruchaus Formation.
4. The structure in the Rostock area is the result of intense folding and thrusting. Two separate thrust phases and five phases of deformation occurred. No pre-Damara deformations are found.
5. At least three nappe complexes consisting of lithotypes of different environments are stacked.
6. The thrust tectonics were intensely influenced by fluids and dolomitic intrusions.
7. New occurrences of Duruchaus rocks and Chausib turbidites were found.

Based on these results, the geodynamic evolution in the Rostock area may be interpreted with the help of the following model:

The deposition of clastic sediments and evaporitic playa sediments of the Nosib Group was closely related to the formation of continental rift structures and to the initial subsidence of this continental rift, as Porada (1985) proposed. The discovery of bimodal volcanics in association with the rift sediments in the Rostock area shows that even in the southern part of the orogen the formation of a continental rift caused volcanic activity, as is described by Miller (1983) for the northern Damara Orogen and as Porada (1983) claimed for the rifting stage in conjunction with evaporitic playa sedimentation in the southern Damara Orogen.

By dating the volcanics it should be possible to determine the onset of deposition in the Southern Damara Orogen. The age of the volcanics could finally defeat the concept of Hill (1975) that this sequence belongs to the more than 1.5 Ga old Gaub Valley Formation.

The tectonic position of the RBNC might resemble that of the external massifs of the Alps (Aar Massif, Gotthard Massif), where the Helvetic Nappes overthrusted these massifs. Within the external massifs of the Alps relics of the autochthonous sedimentary cover are still preserved below Alpine thrust planes.

North of the RBNC, deposited rocks of distal, deeper water units like the sequences of the Kudis Subgroup have overridden the external massif with its sedimentary cover of Duruchaus rocks. Metamorphism of the Duruchaus rocks caused by the overthrusting of Swakop Group rocks generated a highly saline, dolomite-charged fluid-solid mush (Behr *et al.* 1983; Weber and Ahrendt, 1983). This may be applicable to all basement complexes in the Southern Margin Zone (Rostock, Nukurus-Natas, Gamsberg, Rietfontein, Seeis).

It is necessary to confirm this interpretation with geochemical and isotopic data, which are still being carried out. One purpose of geochemical analysis is the definition of the chemical composition and genetic relations of the igneous rocks. With U-Pb zircon ages of the acid volcanics, as well as Rb-Sr whole rock ages and mineral ages obtained by the Rb-Sr and K-Ar method of felsic and basic volcanics, it should be possible to determine the age of effusion and to elucidate the metamorphic history of this region. Sr^{87}/Sr^{86} initials of felsic and basic rocks may give Further information on the genetic relationships of these rocks.

6. ACKNOWLEDGEMENTS

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