

STRATIGRAPHIC SUBDIVISION AND SEDIMENTARY FACIES OF THE DURUCHAUS FORMATION IN THE GEELKOP DOME AND NAUASPOORT-WORTELPOORT AREA NORTH OF REHOBOTH, SOUTHERN DAMARA BELT

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ABSTRACT

The Duruchaus Formation in the type area north of Rehoboth comprises a thick sequence of mixed clastic sediments and minor carbonates and meta-evaporites exposed in a large tectonic half-window below allochthonous nappes of the internal, metamorphic zones of the Southern Damara Thrust Belt. The thickness of the sequence is estimated to be at least 6700 m.

Arenaceous and coarse, rudaceous rocks within the sequence of mainly fine-grained, argillaceous clastic sediments are more widespread and make up a considerably greater proportion of the Duruchaus Formation than previously reported. The arenaceous beds form prominent, laterally continuous stratigraphic marker units and allow the subdivision of the sequence into formally defined lithostratigraphic units of member rank. In contrast, conglomerates form lenticular lithosomes enclosed by fine-grained facies associations of the thick, dominantly argillaceous members. Meta-evaporitic rocks present in the area are confined to only the highest preserved, argillaceous unit, the Gurumanas Evaporite Member, in the upper part of the sequence.

Fine-grained clastic sediments of the thick argillaceous members and associated thin carbonates and meta-evaporites are interpreted as lacustrine and playa-lake sediments deposited in a deep, essentially non-marine, continental rift basin. The regular, cyclic alternation of consistently westward thinning, fluvial and fluvio-deltaic arenaceous members with the fine-grained lacustrine sediments, is ascribed to repeated, cyclic progradation of coarse sandy, braided fluvial systems of the Kamtsas Formation quartzites from east to west, parallel to the long axis of the Duruchaus basin. These probably formed in response to long-term periodic variations in the regional subsidence rate. The lenticular, coarse conglomeratic units interlayered in the thick argillaceous members are believed to have been deposited by gravel-dominated alluvial fans derived from the steep, fault-bounded, southern graben margin of the Duruchaus basin, in response to more local, fault-controlled subsidence.

1. INTRODUCTION

Continental clastic sediments of the Nosib Group in the southern Damara Belt comprise two distinct, lateral facies associations represented by coarse, mainly arenaceous, clastic sediments of the Kamtsas Formation and predominantly fine-grained, clastic sediments of the Duruchaus Formation (Martin, 1965; Schalk and Hälbich, 1965; Hälbich, 1970; Schalk, 1970; Fey, 1971, 1975; SACS, 1980; Hegenberger and Seeger, 1980; Kasch, 1981).

The most extensive and best preserved development of the Duruchaus Formation is in the Geelkop Dome area and adjoining area south of the Nauaspoort and Wortelport Mountains to the north of Rehoboth (Fig. 1) where it forms a very thick, essentially undisrupted, conformable sequence exposed in a tectonic half-window below nappes of the internal metamorphic zones of the Southern Damara Thrust Belt. It was previously mapped and described by Hälbich (1970) who revealed the presence of mappable sandstone and conglomerate units within the sequence of mainly argillaceous clastic sediments and thin carbonates. However, no formal subdivision of the thick succession was attempted.

This report describes a first detailed lithostratigraphic subdivision of the Duruchaus Formation exposed in the Geelkop Dome (Fig. 2) based on new regional mapping in the area (Hoffmann, 1986a,b; Hoffmann and Schalk, 1986; Hoffmann, 1987a). Emphasis is placed on pointing out the regular, cyclic development of arenaceous

and rudaceous intercalations in the dominantly fine-grained clastic sequence and on elucidating the stratigraphic position of meta-evaporitic rocks which have been the subject of recent very detailed sedimentological and mineralogical studies by Röhrs (1982) and Behr *et al.* (1983a,b). In addition, aspects of sedimentary facies are discussed. The work forms part of detailed investigations into the tectonostratigraphic and struc-

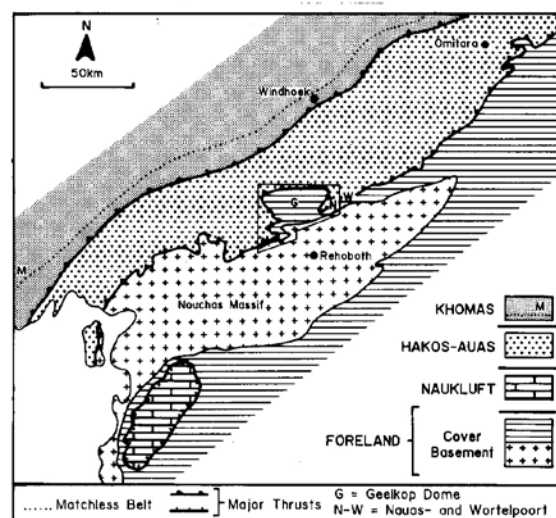


Fig. 1: Tectonostratigraphic zones of the Southern Damara Thrust Belt (after Hoffmann, 1987b) and location of the Geelkop Dome and Nauaspoort-Wortelport area north of Rehoboth.

tural development of the Southern Damara Thrust Belt by the author.

2. REGIONAL SETTING

Within the tectonic framework of the southern Damara Belt the thick succession of metasediments of the Duruchaus Formation in the Geelkop Dome and Nauaspoort-Wortelpoort area are part of the extensive autochthonous to parautochthonous sedimentary cover sequence of the external, southern foreland zone of the Southern Damara Thrust Belt (Fig. 1; Hoffmann, 1987a,b). It unconformably overlies diverse middle Proterozoic metamorphic and plutonic, intrusive rocks belonging to the large, external Rehoboth-Nauchas Basement Massif. Both the basement and its foreland cover are overlain along a very marked structural discordance in the north by tectonic units of the Hakos-Auas Mountain Zone, which comprises a complex sequence of far-travelled, allochthonous nappes and thrust sheets of the internal, metamorphic zones of the thrust belt (Hoffmann, 1987b; Hoffmann and Schalk, 1987).

The regional structure within the large Geelkop halfwindow is dominated by two major, open, doubly plunging antiforms, which are the large Geelkop Dome in the central parts of the area, and the smaller, elongate Gurumanas Dome in the north-west (Fig. 3). These are separated by a major synclinal structure, the Narais Synform. The Nauaspoort-Stalhart Synform, and the Kwakwas and Tweerivier Antiform-Synform pair form corresponding large-scale fold structures in the southern portions of the area.

The base of the sequence is well exposed in the Tweerivier-Kwakwas area in the south-west and locally in the Nauaspoort-Wortelpoort area in the eastern parts of the area, resting with very marked angular unconformity on basement. The uppermost preserved parts of the sequence are exposed in the northern, western and south-western flanks of the Gurumanas Dome. East- and westward around the Geelkop Dome, the thrusts at the base of the overlying Damara nappes cut down stratigraphy, resting on progressively lower stratigraphic parts of the Duruchaus Formation. West of the Geelkop Dome the Duruchaus sediments are entirely absent.

The large nappes and thrust sheets of the Hakos-Auas Mountain Zone comprise intensely and multiply deformed, metamorphic Damara cover, mainly of the Swakop Group, and pre-Damara basement (Schalk, 1982; Hoffmann, 1981; Hoffmann and Schalk, 1987). Basement rocks present in the nappes consist largely of metasediments which were previously mapped by Hälbich (1970) as part of the Duruchaus Formation, with thick prominent white basement metaquartzites and conglomerates which form a series of high ranges around the Geelkop Dome, representing local facies developments of the Kamtsas Formation. Different parts of the basement nappes are now correlated with the Billstein (or Marienhof) Formation, parts of the

Hohewarte Metamorphic Complex and the Grauwater and the Opdam Formations (Schalk, 1982; Hoffmann, 1986a,b).

Thickly bedded, reddish brown, feldspathic quartzites and local conglomerate of the Kamtsas Formation are locally present within the nappes on Oamites and Tsebris, unconformably overlying basement in places (Fig 3). Field evidence indicates that the prominent Kamtsas quartzites and conglomerates forming the high ranges of the Nauaspoort and Wortelpoort Mountains also structurally rest on the underlying Duruchaus Formation and thus are not part of the stratigraphic sequence as mapped by Hälbich (1970). These thrust units of quartzites of the Kamtsas Formation probably represent facies equivalents of the Duruchaus Formation derived from the northern marginal portions of the Duruchaus basin which lies covered beneath the nappes of the Hakos-Auas Mountain Zone.

Deformation of the Duruchaus succession consists of early, southward verging folds (e.g. Nineis Anticline-Syncline pair and Arovley Syncline) and associated penetrative fabrics in a relatively narrow zone below the nappes, and later, upright or steeply northerly or southerly inclined, open folds which essentially post-date the emplacement of the overlying Damara nappes over the Duruchaus Formation and are represented by the Geelkop and Gurumanas Domes and related, large synforms and antiforms in the south-west.

On the north-eastern, western and south-western side of the Gurumanas Dome, meta-evaporitic rocks and overlying clastic units of the upper Duruchaus Formation have been intensely disrupted and fragmented, and in places form chaotic mega-breccias consisting of very large, several hundred metre to kilometre-sized, angular blocks engulfed by fractured and contorted sediments and 'intrusive' carbonate-cemented, lithic breccia. Formation of this chaotic breccia is ascribed to the mobilisation of evaporitic material during and after tectonic burial beneath the overriding allochthonous Damaran nappes of the Hakos-Auas Mountain Zone. On the west side of the Geelkop Dome, imbricated and in places internally disrupted and brecciated strip sheets consisting of rock units correlated with the upper Duruchaus succession in the Gurumanas area occur directly below and in places imbricated into the base of the overlying basement nappes.

Preliminary results from metamorphic studies (Hoffmann, 1987a) indicate that the Duruchaus Formation was metamorphosed under moderately high-pressure conditions ranging from middle greenschist in the south, to lower amphibolite facies (garnet-staurolite-kyanite grade) in the north. However, in view of the relatively undeformed nature of the rocks and for the purpose of applying consistent terminology to describe the Duruchaus sediments in the following passages, use is made of sedimentary rather than metamorphic terms only.

3. LITHOSTRATIGRAPHIC SUBDIVISION

The Duruchaus Formation in the Geelkop Dome and adjoining Nauaspoort and Wortelport area comprises a very varied sequence of fine-grained, predominantly argillaceous, clastic sediments (shales, siltstones and fine-grained sandstones accompanied by thin carbonates) which make up most of the sequence, and subordinate coarse-grained, arenaceous and rudaceous rocks.

The arenaceous units form several laterally continuous, mappable lithosomes representing regionally important, stratigraphic marker units. They are therefore defined as formally named members of the Duruchaus Formation. In contrast, most of the coarse-grained ru-

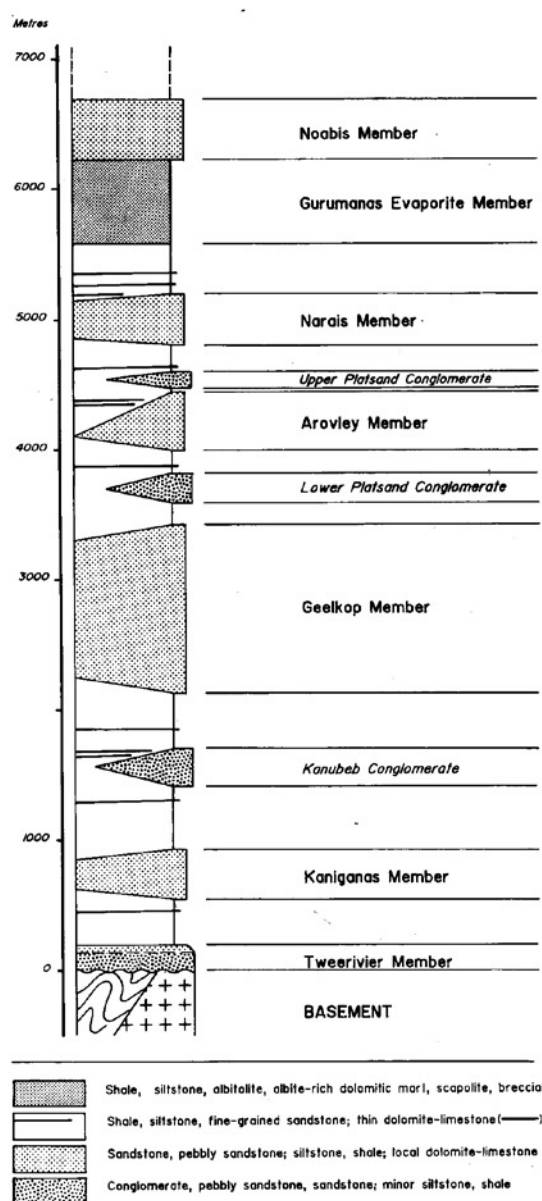


Fig. 2: Standard lithostratigraphic section of the Duruchaus Formation.

daceous units, with the exception a basal conglomerate unit, form discontinuous, lenticular units within the thick, argillaceous members. Because of their essentially local development, these lenticular conglomeratic units are only informally named.

Meta-evaporitic rocks on Gurumanas-Wes and Gurumanas-Oos in the north-western parts of the area occur between the two uppermost preserved, arenaceous stratigraphic units. In order to establish this sequence, which shows the most complete and best preserved development of meta-evaporites recognized so far in the Duruchaus Formation as a type section, it is accorded separate stratigraphic status from the non-evaporitic argillaceous units of the lower and middle parts of the succession as the Gurumanas Evaporite Member.

The complete subdivision of the sequence is shown in the standard profile in Fig. 2. The distribution of the various members is shown in a simplified map of the area in Fig. 3. With few exceptions, contacts of the arenaceous and also of the rudaceous units with the fine-grained argillaceous units are transitional, reflecting lateral and vertical interfingering on both local and regional scale. Therefore, lower and upper stratigraphic boundaries are placed at the first and last appearance of the major sandstone or conglomerate beds interlayered with siltstone and shales.

The total true stratigraphic thickness of the sequence is conservatively estimated to be at least 6700 m and may have been in excess of 7000 m. This estimate is based on measured profiles across different parts of the sequence west of Duruchaus Spitskop, the north-west flank of the Geelkop Dome and in the Gurumanas Dome. In view of the shallow attitude of bedding in parts of these profiles and the inherent large error involved in estimating true thickness for sub-horizontal or shallow inclined strata using single instead of averages of number of dip measurements, this figure can only be regarded as approximate.

Although confined largely to ephemeral stream beds, outcrops are generally good in most parts of the area. However, the eastern and south-eastern parts of Geelkop Dome and parts of the area below the slopes of the Nauaspoort Mountain in the east and especially south of Wortelport, are extensively covered by unconsolidated surficial deposits and soil. This presents problems for exact correlation of lower stratigraphic members of the sequence in the Tweerivier-Kwakwas area in the south-west with those developed in the Nauaspoort-Wortelport area in the east.

4. LITHOLOGY AND FIELD RELATIONSHIPS

4.1 Rudaceous Units

4.1.1 Tweerivier Member

The Tweerivier Member forms a relatively thin but persistent unit of fairly constant thickness at the base

of the sequence. It thins around the large west-closing Kwakwas Antiform, pinching out entirely on the south side of the antiform. The lower part consists of coarse, massive to crudely layered, boulder-bearing, polymict conglomerate which passes upward into stratified pebble and granule conglomerate interbedded with grit and sandstone. The upper part consists of thin, regularly bedded, micaceous sandstone which is interlayered at the top with shales and siltstones of the overlying argillaceous member. Clasts consist mainly of reddish, unfoliated granite and gneissic granite accompanied by various types of metaquartzites, angular phyllite, fine-grained quartz-sericite schist, mica schist and minor felsic porphyry and greenschist.

4.1.2 Matrix-supported conglomerate (diamictite)

In the Tweerivier-Kwakwas area, the lowermost argillaceous unit contains several thin units of matrix-supported conglomerate, or diamictite. They are best developed on the south-side of the Tweerivier Synform, where they form two mappable units of up to 50 m in thickness. Both thin laterally to the east and west, but appear to be almost continuous around the Kwakwas Antiform, close to the base of the sequence. The lower unit may pinch out in places. They are absent in the sequence south of Duruchaus Spitskop, indicating that they finger out somewhere in the northern part of Kwakwas. However, similar matrix-supported conglomerates also occur south of Nauaspoort to the east, where they are interbedded with sandstones in the basal part of the Kaniganas Member (see section 4.2.1)

The thicker, upper of the two units on the south side of the Tweerivier Synform consists of very poorly sorted, massive or non-stratified, matrix-supported conglomerate containing clasts of very variable size and shape, including rare large boulders, set in a dark grey, schistose, phyllosilicate-rich matrix. The clast assemblage is similar to that of the basal Tweerivier Member consisting also of polymict basement material, mainly of reddish pink granite and granite gneiss. Interbedded light grey, calcareous and feldspathic pebbly sandstone, pebbly grit and small pebble conglomerate are present in the upper part of the unit. The unit passes laterally into interbedded schistose pebble and granule conglomerate, gritty sandstone and sandstone alternating with fine-grained argillaceous rocks.

4.1.3. Kanubeb conglomerate

The Kanubeb conglomerate forms a major, up to 300 m thick unit of coarse conglomerate and minor sandstone and pebbly sandstones in the lower part of the sequence in the Nauaspoort area. Similar coarse conglomerate occurs in the Wortelport Mountains to the east, directly overlying the thick quartzites of the Kaniganas Member.

In the Usib River south of Nauaspoort, the conglomerate

overlies shales, siltstones and interbedded sandstones with a very sharp, abrupt contact. It appears to thin out on Kaniganas, east of the Usib River. Westward, the conglomerate extends up to the eastern parts of Naruchas where it is truncated by the regional sole thrust of the Damara nappes. Although the contact with the underlying fine-grained succession is not exposed here, a distinct angular discordance between the base of the conglomerate and the general strike of bedding in the underlying rocks is revealed by vegetation lines. The unit is entirely absent in the Duruchaus Spitskop section and further west in the Kwakwas Antiform and in the Tweerivier Synform. However, a very thin pebbly horizon present within the sequence of mainly argillaceous rocks overlying the Kaniganas Member in the centre of the Geelkop Dome (Fig. 3), may represent the thin, distal equivalent of the Kanubeb conglomerate.

In the Usib River, the lower part of the Kanubeb conglomerate consists of stratified, clast-supported conglomerate with a sandy or gritty matrix interlayered with very irregular, lenticular, brown, sandstone and pebbly sandstone layers. These grade into very massive, unstratified and very coarse, clast-supported conglomerate which makes up most of the unit. Clasts are mainly pebble- and cobble-sized material accompanied by boulders of white and light grey metaquartzite, sericitic quartzite, grey and light yellowish grey, fine-grained quartz-sericite schist and phyllite. In contrast to the basal Tweerivier Member, there are no granitic clasts. It contains no or little matrix, consisting in places of interstitial, pale yellowish brown, sparry calcite.

East of the Usib River, the Kanubeb conglomerate consists of pebble conglomerate with feldspathic, sandy or gritty matrix and interbedded sandstone and pebbly sandstone. In the western parts of Kanubeb and adjoining parts of Naruchas in the west, it consists of generally well-stratified schistose, coarse- and fine-grained pebble and granule conglomerate interbedded with cross-bedded micaceous grit, pebbly sandstone and a few minor, but locally rather thick shale and siltstone beds.

4.1.4 Lower Platsand conglomerate

The lower and upper Platsand conglomerate units comprise conglomerates and pebbly sandstones interlayered with finer grained rocks in the middle parts of the sequence on the north-west side of the Geelkop Dome. They are separated by the thin, western extension of the Arovley Member. The lower unit reaches a maximum thickness of approximately 250 m in the southern part of Kamzwas where it shows a gradational, upward transition from underlying finer grained sediments. The whole unit thins laterally, with the upper part extending as a thin horizon of small pebble conglomerate into the north and west side of the Geelkop Dome. In the latter area, it increases in thickness further south, forming a group of stacked lenses of pebble conglomerate and

pebbly sandstone interlayered with fine-grained lithologies in the Stalhart Synform.

The lower part of the unit consists mainly of interbedded small pebble conglomerate and pebbly sandstone alternating with soft micaceous sandstones, siltstones and shales. These are followed above by several metres thick layers of massive or poorly to well stratified, commonly graded pebble and cobble conglomerate containing a poorly sorted, polymict assemblage of basement clasts accompanied by angular fragments of grey and pinkish grey, micaceous sandstone representing reworked, intraformational material. The whole sequence becomes again finer grained and thinner bedded upward.

4.1.5 Upper Platsand conglomerate

The upper Platsand conglomerate is only locally exposed on the scree-covered slopes of Billstein Mountain. It is cut out in the east by thrusts at the base of the Billstein basement nappes which directly overlie it. Like the lower Platsand conglomerate, it follows transitionally on underlying fine-grained facies but does not appear to continue into the west side of the Geelkop Dome. However, pebbly sandstones present in the centre of the Gurumanas Dome (Fig. 3) probably represent the distal part of this unit extending into the basin centre.

The unit is similar to the lower Platsand conglomerate, but contains a larger proportion of sandstone and pebbly sandstone. The lower part comprises massive or graded, sand-matrix supported, polymict pebble conglomerate interbedded with pebbly sandstones, massive or crossbedded, pinkish brown sandstone and micaceous sandstone with minor shales and siltstones. Massive or crudely stratified, clast-supported but matrix-rich pebble and granule conglomerate which reaches a thickness of several tens of metres, is followed by an upward fining and thinning succession of interbedded conglomerates and sandstones similar to that below. The thick, main conglomerate unit contains only rare granite clasts and compositionally resembles the Kanubeb conglomerate.

4.2 Arenaceous Units

4.2.1 Kaniganas Member

The Kaniganas Member forms a prominent unit of quartzites and sandstones in the lower part of the sequence in the Nauaspoort-Wortelpoort area. It is locally exposed again south of Duruchaus Spitskop and in the centre of the Geelkop Dome. On Wortel, in the extreme eastern part of the area, it comprises up to 1000 m thick resistant quartzites which form the high ridge south of the main ranges of the Wortelpoort Mountains. It follows almost directly on the basal Tweerivier Member, being separated from the latter by a thin sequence of

interbedded micaceous sandstones and siltstones. The thick quartzites rapidly thin westward to about 300 m south of Nauaspoort Mountain. It is of similar thickness south of Duruchaus Spitskop but is absent from the sequence in the Kwakwas Antiform and the Tweerivier Synform.

The very thick eastern-most part of the Kaniganas Member on Wortel is made up entirely of very thick bedded quartzite, pebbly quartzite and minor, thin conglomerate bands. The coarse- to very coarse-grained, pinkish or reddish brown feldspathic quartzites show massive or large-scale trough cross-bedded bedforms and are essentially identical to the quartzites of the Kamtsas Formation. South of the Nauaspoort Mountains, the Kaniganas Member consists of more variable, thinly to thickly bedded and generally finer grained, light pinkish brown or grey, horizontally and cross-bedded feldspathic and micaceous sandstones, pebbly sandstones and thin pebble bands. Two beds of matrix-supported pebble conglomerate which are similar to the ones interbedded with fine-grained lithologies in the Tweerivier-Kwakwas area described above occur in the lower part of the sandstones in the Usib River.

4.2.2 Geelkop Member

The Geelkop Member comprises a thick, laterally persistent sequence of mainly sandstone and pebbly sandstone alternating with fine-grained rocks. It is exposed continuously around the entire northern and western flank of the Geelkop Dome and again on the north and south flanks of the Stalhart Synform in the south-west (Fig. 3). It reaches a total thickness of at least 1300 m on the south limb of the Stalhart Syncline but then thins over a distance of only three to four kilometres into a thin group of micaceous sandstones Further west.

On the north and west side of the Geelkop Dome, it consists of mostly very soft and very impure micaceous, feldspathic sandstone, pebbly and gritty sandstone, micaceous grit and minor pebbly grit alternating in groups of beds with fine-grained facies and defining an overall upward thickening and coarsening sequence. The top layer of these very poorly sorted, impure sandstones and grits is a thin, persistent conglomerate layer. In the Stalhart Synform the sandstones are much better sorted, consisting of pinkish brown, cross-bedded feldspathic sandstones and pebbly sandstones.

4.2.3 Arovley Member

Of all the arenaceous members, the Arovley Member shows the most pronounced changes in thickness from east to west. It is of maximum thickness (up to 400 m) on the steeply dipping, northern limb of a large, southward overturned early fold structure, the Arovley Syncline, on the north-east side of the Geelkop Dome. The unit thins rapidly around the hinge and on the south limb of the syncline, passing into thinner bedded sand-

stones alternating with fine-grained lithologies Further westward where they are only very poorly exposed in the largely scree-covered lower slopes of the Billstein-Nuaub Mountains. The distal equivalent of the Arovley Member appears to be a very thin unit of only a few tens of metres thickness present in the same stratigraphic position above 3

and silty shales which in places contain thin dolomite-limestone layers. The sandstone units consist of resistant (quartzitic) light to medium pinkish brown or pale grey, medium- to coarse-grained, cross-bedded, feldspathic sandstone and quartzite, in places carrying pebbles and thin pebble bands. Except for the presence of interlayered fine-grained rocks, these are similar to typical reddish or pinkish brown Kamtsas quartzites. West of Arovley, they consist of more thinly bedded, soft, light greyish or pinkish grey, micaceous sandstones interbedded with siltstone and shales.

4.2.4 Narais Member

The Narais Member is the main arenaceous unit of the upper Duruchaus sequence exposed in the north-west parts of the area. It emerges from underneath the west side of the Billstein basement nappe, extending westward through the Narais Synform in which it forms wide outcrops due to repetition by open folding, and around the Gurumanas Dome. It forms a local outlier in a small syncline structure close to the nappe front on the farm Duruchaus in the south of the area.

The sandstones of this unit are very similar to those of the Arovley Member, also showing abrupt lateral transition from thick bedded, quartzitic, pinkish brown Kamtsas-typesandstones, pebbly sandstones and local thin conglomerate in the thick, eastern-most part of this unit exposed below the western slopes of Billstein Mountain, into softer, more micaceous, light pinkish grey and grey, cross-bedded sandstone and pebbly sandstone alternating with fine-grained clastic sediments and thin, interbedded dolomite-limestone. The sandstones define a very distinct, overall upward thickening sequence followed by an upward thinning sequence.

4.2.5 Noabis Member

Overlying the Gurumanas Evaporite Member, the Noabis Member represents the highest preserved arenaceous unit of the Duruchaus Formation. It is preserved only locally below the overlying Damara nappes in the west and south-west side of the Gurumanas Dome and as several large, tectonic blocks in the mega-breccia zone on Haakscheen on the north and north-east side of the Gurumanas Dome. Contacts with underlying and overlying rocks are usually tectonic, especially in the large discordant blocks in the north-east. However, on the south-west and west side of the Gurumanas Dome, the sandstones of this unit overlie the evaporitic rocks of the Gurumanas Member with a sharp, intact con-

formable boundary. In one of the large tectonic blocks on Hakscheen, they are conformably overlain by finer grained facies units which contain evaporitic rocks similar to those of the Gurumanas Member.

The Noabis Member consists essentially of pinkish brown, cross-bedded, feldspathic sandstone and pebbly sandstone with only minor interbedded fine-grained rocks. Lithologically, it resembles the more proximal parts of the arenaceous members of the lower and middle parts of the Duruchaus Formation.

4.3 Argillaceous Units

4.3.1 Clastic Sediments

The fine-grained clastic units of the Duruchaus Formation comprise thick sequences of interbedded shales, calcareous shales or marls, silty or sandy shales, siltstones and fine-grained, silty (micaceous), feldspathic sandstones and subordinate interlayered carbonate beds consisting of thinly bedded and laminated crystalline dolomites and limestones.

As a result of upper greenschist to lower amphibolite facies metamorphism, the clastic sediments consist entirely of fine- to medium-grained metamorphic mineral assemblages comprising essentially quartz, microcline, albite, muscovite, biotite and minor chlorite (mostly secondary after biotite), epidote, and rare garnet. Both biotite and microcline are common as porphyroblasts, the latter forming conspicuous, pale, subhedral crystals in originally shaly and more silty or sandy layers. Rare almandine garnet occurs in a few layers of suitable composition in the middle and upper sequence on the north-west side of the Geelkop Dome and in the Gurumanas Dome. Limonite pseudo-morphs after pyrite are widespread in shaly and silty layers indicating originally reducing conditions. The high feldspar content of some parts of these metamorphosed, fine-grained rocks makes it likely that they may prove to contain fine-grained, reworked volcanoclastic material, or even tuffs, if studied in proper detail.

The fine-grained clastic sediments show a great variation in lithology and sedimentary structures. The most common facies comprises thinly bedded sequences of intercalated, finely laminated shales, siltstones and thin, cross-laminated and ripple-marked sandstones. Groups of thinly bedded sandstone beds, some alternating with, or laterally transitional with, thin carbonates are common but subordinate. Mudcracks in shales and silty shale beds are common in parts of the sequence, especially in fine-grained facies interdigitating with sandstones in the thin, western parts of the arenaceous members. Thin, regularly alternating, graded or laminated siltstone-shale couplets may represent thin turbidites. Some parts of the sequence consist of thick units of entirely massive or poorly laminated shales or mudstones.

Soft-sediment deformation structures ascribed to

physical disturbance of unconsolidated sediments are common and include sand-filled dykelets, convolute bedding, various load cast structures and fluid-escape channels.

4.3.2. Dolomite-limestones

Thin carbonate layers consisting of fine- to medium-grained, crystalline dolomitic limestones and dolomite occur intercalated with the fine-grained clastic sediments in all the argillaceous members from the base upwards and in fine-grained facies interfingering with the arenaceous members. They form either thin, usually micaceous limestone layers and lenses of less than a centimetre to a few centimetres in thickness in calcareous, marly sediments, or up to two metres thick groups of thinly layered and finely laminated dolomite and limestone beds with thinly interbedded, hard, siliceous, or 'cherty', layers. The dolomite-limestone units are best developed in the western and north-western, more distal parts of the sequence, forming persistent marker horizons which continue for long distances of several tens of kilometres on the west side of the Geelkop Dome and in the Gurumanas Dome. They consistently decrease in thickness and frequency eastward. They are mainly developed in the upper portion of the argillaceous members comprising the lower and middle parts of the sequence but also in thicker units of fine-grained clastics interdigitating with sandstones of some of the middle and upper arenaceous members (Arovley and Narais Members). In the Gurumanas Dome, they occur throughout the sequence of fine-grained clastic sediments under- and overlying as well as alternating with the thin, distal parts of the Narais Member.

The typically dark coloured carbonate layers vary from brown, dark reddish brown or maroon, to yellowish brown and yellow and more rarely light brownish grey and greyish pink. Individual layers vary in composition from calcite-rich to dolomite-rich. Thin, finely laminated, grey or dark, reddish brown silicic layers and lenses in the dolomite-limestone units are composed of quartz or very fine-grained or microcrystalline albite, quartz and minor dolomite and calcite.

The characteristic, thinly laminated structure of the carbonates and especially of the interbedded, cherty quartz- or albite-rich layers probably represents crypt algal layering, or stromatolites, formed through sediment-binding activities of non-skeletal algal mats. Small, rounded quartz structures are commonly present in the carbonate layers and resemble 'cauliflower chert' which are believed to represent replacements of nodular diagenetic gypsum (compare Behr *et al.*, 1983b, Plate 3f). Desiccation cracks have been observed in the thin carbonate beds. Several of the dolomite-limestone marker units in the middle part of the sequence in the north-west and west side of the Geelkop Dome contain disseminated copper.

4.4 Gurumanas Evaporite Member

The Gurumanas Evaporite Member as defined in this paper comprises fine-grained clastic sediments associated with meta-evaporitic rocks which are exposed on the northern, western and south-western sides of the Gurumanas Dome and at several places on the west side of the Geelkop Dome and in the Tsebris area Further south-west. For a detailed lithological and mineralogical description of the meta-evaporites, the reader is referred to Röhrs (1982), Behr *et al.* (1983a,b) and Miller and Hoffmann (1981).

In the Gurumanas area, the meta-evaporites form a conformable to para-conformable sequence between the two uppermost sandstone units, the Narais and the Noabis Members. Being located close to thrusts of the overlying Damara nappes, the sequence has been affected to varying degrees by disruptive deformation related to overthrust movements. The sequence is relatively undisrupted around the west and south-west side of the Gurumanas Dome where the base of the sequence of meta-evaporitic rocks is placed along the lowermost, paraconcordant carbonate breccia horizon present in fine-grained clastic sediments and interbedded, thin dolomite-limestone overlying the Narais Member. Field evidence indicates some relative movement, or decollement, along this horizon. The upper boundary coincides with the base of the overlying Noabis Member which is preserved in a few places only. The sequence has been severely disrupted in the north and north-east where it is either missing or occurs as tectonic blocks and fragments in the large megabreccia zone on Hakscheen and on adjoining parts of Nineis. Of interest is the fact that in one of the large tectonic blocks, sandstones of the Noabis Member are conformably overlain by fine-grained facies units containing evaporitic rocks similar to those in the Gurumanas Member.

Two different lithological associations indicating the former presence of evaporitic rocks are developed in the Gurumanas Member: 1) Stratiform carbonate-cemented solution breccias believed to be derived from originally bedded evaporites which have been lost from the sequence through dissolution and mobilisation. 2) Pseudomorphs of replaced evaporite minerals, mainly of sodium-bearing carbonates, which had grown in strongly, diagenetically altered (albitised and dolomitised), waterlain, fine-grained clastic sediments from trapped, concentrated saline brines. For the fine-grained, albite-rich sediments, Röhrs (1982) has suggested that they may represent altered volcanic tuffs.

5. INTERPRETATION OF SEDIMENTARY FACIES

The close association of alternating and interfingering, very coarse- to fine-grained clastic sediments accompanied by carbonates and evaporitic rocks of the Duruchaus Formation in the Geelkop Dome area indi-

cates very complex sedimentary facies relationships.

Arenaceous units within the dominantly fine-grained argillaceous succession typically consist of horizontally and trough cross-bedded, fluviatile sandstones and pebbly sandstones with thin pebble bands. These form a number of laterally continuous lithosomes which consistently thin from east to west, interdigitating laterally and vertically with fine-grained sediments. Some of the arenaceous units finger out entirely in the more distal parts of the basin. Nearly all of them display very distinct overall, upward thickening and coarsening sequences followed by upward thinning and fining sequences, which suggests deposition by prograding and retrograding sandy fluvial systems. Good, lateral continuity of the sandstones in the more proximal parts is consistent with depositional models of predominantly braided river systems corresponding to braided alluvial plains, or braidplains (Rust, 1979), rather than strongly meandering systems which are characterized by more lenticular, or elongate, sand bodies stratigraphically bounded by fine-grained facies (Walker and Cant, 1979). Oversteepened and locally overturned cross-bedding, convolute lamination and beds with large slumps folds are common in all the sandstone units and imply deposition in a tectonically active environment (Collinson and Thomson, 1982).

The lateral facies transition from the proximal, sand-dominated braided river facies of the Kamtsas Formation developed outside the area to the east and south (Martin, 1965; Schalk, 1970) is clearly displayed by most of the arenaceous units, especially the Kaniganas Member which on Wortelpoort, in the extreme eastern part of the area, consists of typical very thick-bedded,

coarse-grained, pinkish brown Kamtsas quartzite passing into thinner bedded and finer grained, sandstone and quartzitic sandstone in the west. This transition takes place over only several hundred metres, indicating a very abrupt facies boundary between the coarse clastic Kamtsas facies and the finer grained sandy facies of the Duruchaus Formation in the eastern margin of the Duruchaus basin. Further west, the sandstones thin more gradually, implying gentle depositional gradients within the Duruchaus basin itself. Interdigitation of the fluvial sandstones - even in the more proximal reaches as seen in the eastern parts of the Arovley Member - with fine-grained clastic facies containing thin lacustrine dolomite-limestones, indicates deposition close to a perennial lake, thus implying a deltaic setting for the distal parts of the arenaceous members. The depositional environment of the arenaceous members of the Duruchaus Formation is thus interpreted as corresponding to braided, or low-sinuosity, meandering rivers in the more proximal reaches to river-dominated, fluvio-deltaic in the more distal, interior parts of the Duruchaus basin (Fig. 4).

Although less widespread than the arenaceous units, conglomerates and related coarse-grained, clastic sediments also make up important parts of the sequence, being present in the basal Tweerivier Member and in the argillaceous members of the lower and middle parts of the sequence. In the latter instance, the conglomerates form lenticular units of very variable thickness and lateral extent and, like the sandstone of the arenaceous members, interfinger both laterally and vertically with fine-grained facies of the argillaceous members. However, in contrast to the arenaceous members, the con-

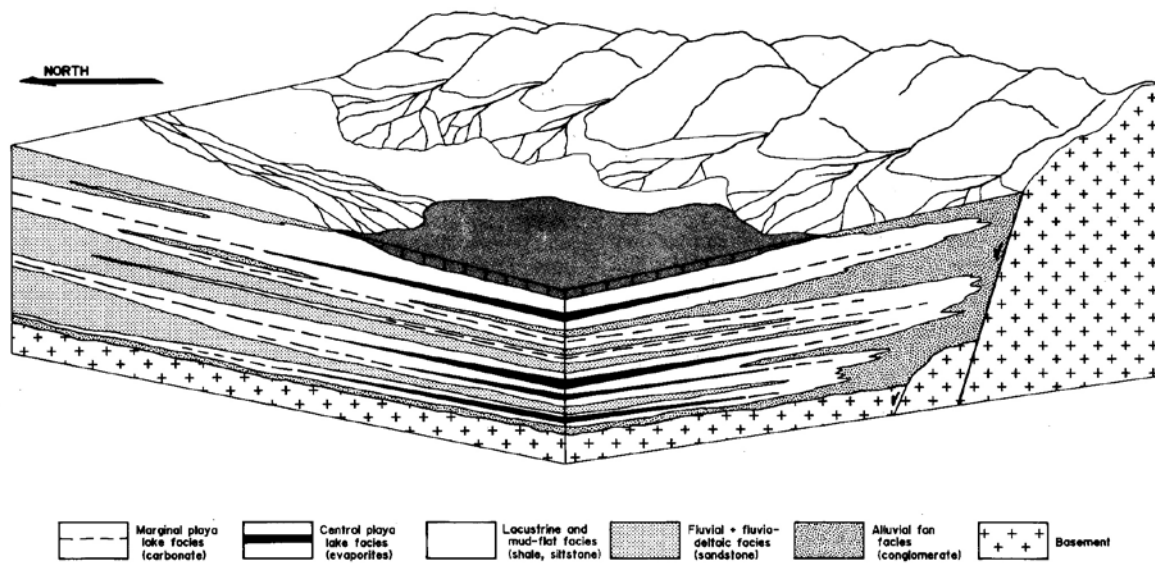


Fig. 4: Schematic block diagram illustrating the tectonic setting and sedimentary facies of the Duruchaus basin during the early Damara rift phase.

glomerate units thin out to the west as well as to the east. Thin, pebbly layers representing the thin distal ends of the thick Kanubeb and the upper Platsand conglomerate recurring in the Geelkop Dome and in Gurumanas Dome respectively, indicate progressive thinning to the north-west, into the basin centre as well, and thus imply a source for the conglomerates lying to the south. The rudaceous units therefore represent an entirely separate, coarse clastic facies to the more continuous, westward thinning, fluvial arenaceous members. On the basis of this evidence, and especially the characteristic rapid lateral decrease in bed thickness and grain size indicating a wedge- or fan-shaped morphology, the rudaceous units are interpreted as mostly distal parts of coarse, gravel-dominated, alluvial fan deposits fringing the eroded southern margin of the Duruchaus basin (Fig. 4).

Major differences in composition and facies between the various rudaceous units can be ascribed to factors related to source area and distance from the basin margin. The basal Tweerivier Member shows a distinct upward fining and thinning sequence from coarse, unstratified conglomerate in the lower part to interbedded small pebble conglomerate and sandstone in the upper part. This, together with the abrupt transition of thinly bedded sandstones at the top of the member into directly overlying fine-grained facies, indicates establishment of shallow-water, basinal conditions immediately following rapid initial subsidence.

Relatively thin but laterally extensive, mud-matrix supported conglomerates interlayered with fine-grained basinal facies on Tweerivier and Kwakwas in the southwestern most part of the area, may represent diamictites deposited by subaqueous debris flows originating from fan-deltas reaching directly into the shallow-water basin following the initial subsidence. In the eastern part of the area, very coarse, massive, clast-supported conglomerate with little or no matrix material, in the thick, central portion of the Kanubeb conglomerate south of Nauaspoort, most likely represents coarse gravel deposited in the proximal, inner parts of an alluvial fan (Rust, 1979; Collinson, 1978). Lateral transition into stratified, finer grained conglomerate and pebbly sandstone reflects the down-slope change from the inner to the middle parts of the fan. The sharp contact and distinct angular discordance observed between the base of the conglomerate and underlying fine-grained facies is evidence for possible major intraformational erosion, thus indicating a position close to the faulted basin margin. In contrast to the basal Tweerivier conglomerate and also the lower and upper Platsand conglomerate units, which contain polymict material with abundant clasts of basement granite, the Kanubeb conglomerate displays a more restricted clast assemblage of mainly quartzite, indicating derivation from local source areas in the Rehoboth-Nauchas Massif.

Both the lower and upper Platsand conglomerates comprise alternating, generally well-stratified, clast-supported and sand-matrix supported conglomerates,

pebbly sandstones, sandstones and fine-grained lithologies, representing gravel- and sand-rich material deposited in the middle and outer regions of alluvial fans interfingering with basinal facies. The gradual transition of these conglomerates and sandstones from underlying fine-grained facies and the upward fining and thickening is characteristic of fans prograding into the basin, covering fine-grained sediments in the basin centre (Rust, 1979). The presence of abundant intraclasts in the lower Platsand conglomerate indicates reworking of the Duruchaus sediments and thus supports the evidence for major, probably fault-induced, intraformational erosion near the margin of the basin inferred for the Kanubeb conglomerate.

The fine-grained clastic sediments of the argillaceous units of the Duruchaus Formation show a very large variation in lithology and sedimentary structures and hence sedimentary facies. Thinly bedded sequences of intercalated, finely laminated shales, siltstones and thin, cross-laminated and ripple-marked sandstones indicate shallow-water, current-influenced environments. Groups of thinly bedded sandstone beds, some alternating with, or laterally transitional with, thin carbonates may represent wave influenced shoreline facies. Mudcracks in shales and silty shales indicate sub-aerial desiccation in a marginal lake mudflat environment during emergence (low lake levels) and in delta plain facies. Thin, regularly alternating, graded or laminated siltstone-shale couplets may have formed by turbidite flows in a pro-delta plain setting during high-level lake stand. The presence in some parts of the sequence of thick, massive or poorly laminated shale beds probably represents fine-grained, distal components of coarse alluvial fan deposits (Rust, 1979).

Abundant soft-sediment deformation structures in the argillaceous rocks, as in the intercalated fluvial sandstones, indicate syndepositional disturbance of rapidly deposited, waterlogged, loosely packed sediments, implying high sedimentation rates accompanied by tectonic unrest during deposition.

Dolomite and limestone interbedded with fine-grained facies form prominent, thin and laterally persistent marker beds thinning eastward and thus closely reflect the lateral facies changes recorded in the clastic sediments. Interbedding of these thin carbonate layers with, and lateral transition into, thinly bedded, fine-grained sandstones which most likely represent littoral sandy facies, and presence in fine-grained facies interdigitating with the distal, fluvio-deltaic sandstones of some of the arenaceous members, indicates deposition close to a lake margin. Deposition in a shallow lake is also indicated by the presence of desiccation cracks and crypt algal lamination. Chert nodules which may be pseudomorphous after diagenetic gypsum indicate saline conditions during or soon after the deposition of at least some of the carbonate layers.

A major problem of the fine-grained clastic facies and associated thin carbonates of the argillaceous units

concerns their interpretation as shallow marine or non-marine. In the absence of absolutely diagnostic criteria, deposition in closed, lacustrine basins with no marine connections appears most likely from the composition of the fine-grained clastic sediments consisting dominantly of siltstones, shales or mudstones with subordinate fine-grained sandstones and the regional-scale interfingering of these fine-grained facies with coarse-grained alluvial and fluvial sediments fringing the Duruchaus basin in the south and east (Collinson, 1978). A shallow lake, rather than shallow marine environment is also evident from the compositionally very immature nature of the fine-grained sediments, in particular the absence of more mature, quartzose sandstone, which indicates limited reworking and, hence, low wave activity in the shoreline facies (Collinson, 1978).

Sedimentological and mineralogical studies by Röhrs (1982) and Behr *et al.* (1983a,b), showing that the meta-evaporitic rocks in the Gurumanas area have formed in alkaline playa lake environments, is in accordance with an essentially non-marine, continental setting inferred from the sedimentary facies of the associated, under- and overlying clastic sediments. The meta-evaporitic rocks occur stratigraphically between the two highest arenaceous members and thus appear to be confined to only this one stratigraphic horizon, the Gurumanas Member, in the uppermost part of the Duruchaus Formation exposed in the Geelkop Dome area. However, similar evaporitic rocks, which have also been noted as conformably overlying sandstones of the Noabis Member in one of the large tectonic blocks in the north-eastern parts of the area, indicate the possible former existence of another, stratigraphically higher but tectonically fragmented and brecciated evaporitic unit. Strongly disrupted thrust slices present directly below the Damara nappes in the west side of the Geelkop Dome and containing similar evaporitic rocks, represent parautochthonous strip sheets of the Gurumanas Member and possibly of this higher evaporite unit.

From one of the parautochthonous thrust units occurring on the eastern parts of Naos, Röhrs (1982) and Behr *et al.* (1983a) have described pseudomorphous replacements of microcline after gypsum occurring in a sequence of interbedded dolomites and dolomitic sandstone. They regard this local, sulphate-dominated sequence as being younger than the Gurumanas Member and hence representing a younger, marine sabkha facies. However, field evidence (Hoffmann, 1987a) suggests that these rocks as well as the sequence of fine-grained clastic sediments and interlayered sandstones in which they occur, are essentially similar to parts of the clastic sequence stratigraphically underlying the Gurumanas Member in the Gurumanas Dome and further east in the Geelkop Dome, which also contain evidence for replaced gypsum associated with thin dolomitic layers. In view of this evidence, the interpretation of the former presence of gypsum indicating a marine incursion in the Duruchaus basin (Behr *et al.*, 1983b) appears doubtful.

6. CONCLUSIONS

Mapping of the thick sequence of mainly clastic sediments of the Duruchaus Formation in the type area in the Geelkop Dome and Nauaspoort-Wortelpoort area shows that it comprises a regular, regional-scale alternation of thick units of mainly fine-grained, argillaceous, clastic sediments with thin carbonates and meta-evaporites and a number of persistent, but thinner, arenaceous units and local, lenticular units of conglomerate. The arenaceous and rudaceous rocks are more widespread and make up a greater portion of the succession than previously known. The arenaceous units form a number of laterally continuous marker horizons and allow the complete subdivision of the up to 6700 m thick sequence exposed in the area.

The thick, fine-grained, dominantly argillaceous units which make up most of the sequence are interpreted as essentially shallow-water lake sediments containing playa lake evaporite beds in the uppermost preserved parts of the sequence. The widespread presence of coarse, arenaceous and rudaceous clastic sediments alternating and interfingering with these fine-grained lake sediments is important as they provide a record of the subsidence history of the Duruchaus basin during the early Damara rifting stage. The arenaceous units appear to have been deposited by repeated, cyclic incursions of sandy braided fluvial systems of the Kamtsas Formation into the Duruchaus basin, controlled by oscillating, regional subsidence of the developing Nosib rift system. Conglomerates in the sequence interfinger with the fine-grained clastics and form separate coarse clastic facies related to gravel-dominated alluvial fans derived from metamorphic and granitic basement in the south. The presence of these alluvial fan deposits as indicators of sharp terrestrial relief produced by active uplift and faulting (Rust, 1979) implies a steep, fault-bounded graben margin in the south of the Duruchaus basin. Their presence, even in the upper parts of the Duruchaus Formation indicates that local, fault-controlled subsidence accompanied by considerable tectonic unrest has strongly influenced the deposition of the clastic sediments and associated carbonates and evaporites of the Duruchaus Formation throughout its history.

The composition of the coarse clastic sediments consisting of feldspathic sandstones and arkoses and polymict conglomerates indicates derivation from mixed granitic and metasedimentary and -volcanic, continental basement sources. The absence in these coarse clastic sediments of a major volcanoclastic component other than that derived from older meta-volcanic units found in the Rehoboth-Nauchas Massif and of interlayered volcanic rocks implies that the southern Duruchaus rift margin was not accompanied by major volcanic activity. However, a minor, largely fine-grained, pyroclastic or reworked volcanoclastic component mixed with the fine-grained, basinal sediments originating from the hidden, northern rift margin nevertheless appears likely

in view of the presence of volcanic rocks associated with Nosib metasediments, which have been recognized in parts of the upper nappe units 'of the Hakos-Auas Mountain zone (Hoffmann, unpubl. data), indicating that volcanic activity accompanied rifting in the more internal zones of the southern Damara Belt.

From the stratigraphic and sedimentary evidence presented it is concluded that the tectonic setting of the Duruchaus basin most likely corresponds to that of a deep, active continental rift basin in which fine-grained, basinal sediments interfingering with coarse clastic sediments derived from the east and the south accumulated. This clearly dispels speculations by Behr *et al.* (1983a) that the Duruchaus Formation in the Geelkop Dome area may have been deposited in a foredeep basin of the developing Damara Orogen.

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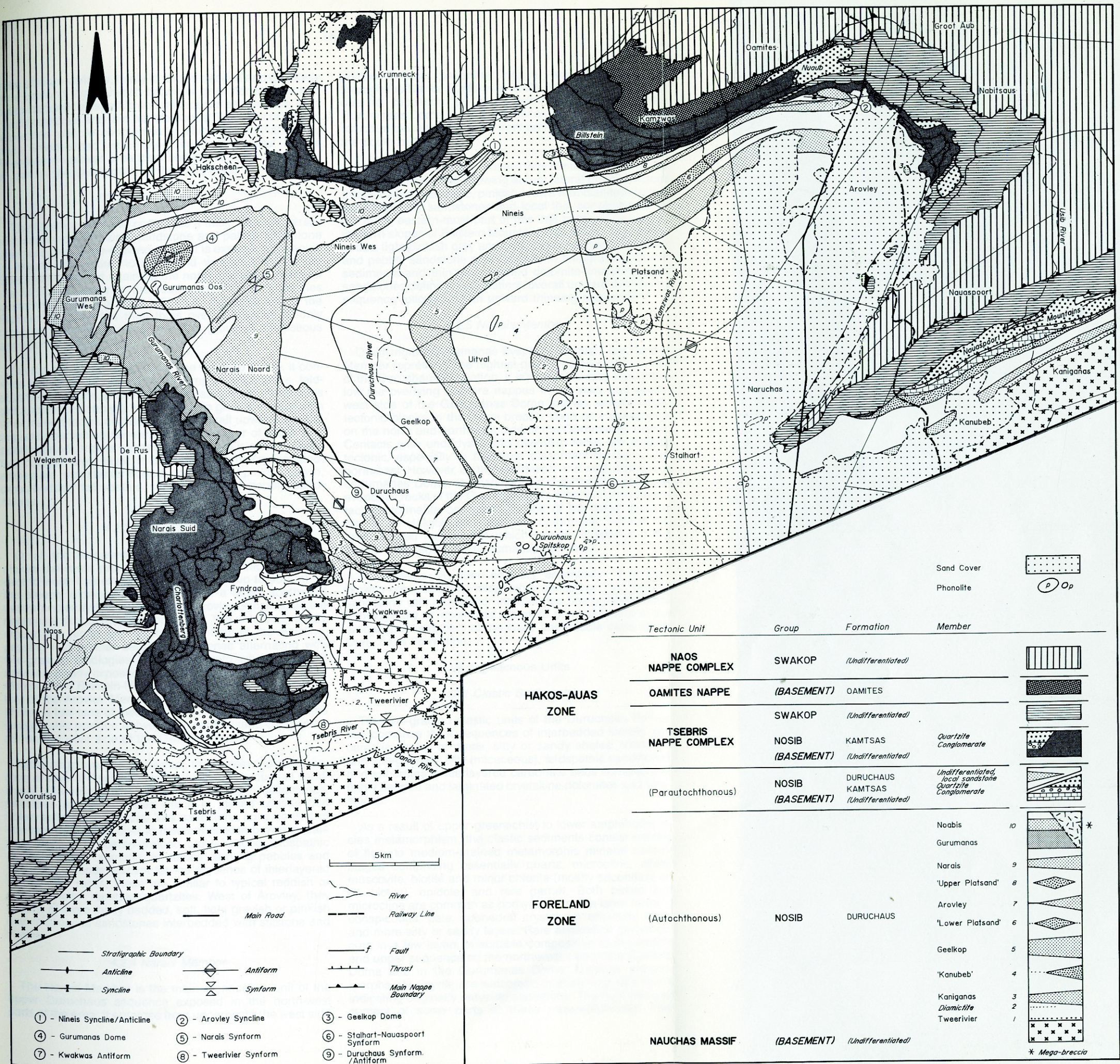


Fig. 3: Geological map of the Geelkop Dome and Nauaspoort area (based on Hälbich (1970) and latest available information by Hoffmann (1986 a,b) and Hoffmann and Schalk (1986).