

# Notes on traverses across the Khorixas-Gaseneirob Thrust, Southern Khorixas and Outjo Districts, Namibia

Roy McG. Miller

Consulting Geologist, P.O. Box 11222, Windhoek, 11009, Namibia (e-mail: roymm36@mweb.com.na)

**Abstract** : Local algalaminites in the pre-Chuos Saturn Formation suggests deposition of parts of this unit in shallow water south of the northern boundary fault of the deep Nosib-age rift of the Northern Zone but mass-flow carbonate layers with stromatolitic reef debris and sandstone layers with transported oolites interbedded with the Chuos diamictites point to much deeper water during Chuos times. Mass flows and rhythmites in the Tsumeb Subgroup rocks on the Fransfontein Ridge are indicative of slope deposition that passed southwards into numerous mass flows and rhythmites of the coeval Karibib Formation in much deeper water of the deepening Northern Zone rift. Quartzites interbedded with the schists of the Kuiseb Formation west of Khorixas show evidence of small-scale regressions and transgressions.

D1 was intense in the Kaoko Belt and folded the northern margin of the Damara Belt. Erosional debris was deposited in intramontane valleys along this margin as the molasse of the Mulden Group. Intense D2 deformation, however, folded the Swakop Group succession into a series of NE-SW to ENE-WSW folds which were then thrust up and over the northern boundary fault of the deep Nosib-age rift of the Northern Zone and onto the Mulden molasse as a series of thrusts successively overstepping each other from west to east to form the front of the Khorixas-Gaseneirob Thrust, the floor thrust of a duplex system of thrusts. Nappes of Swakop Group and deep-water Otavi Group rocks were thrust onto the Mulden phyllites. D2 produced the E-W foliation in the Mulden phyllites and caused north-verging folding and thrusting in the Otavi rocks of the Fransfontein Ridge. In the Kuiseb schists west of Khorixas, zones of intense bedding-parallel D2 deformation and quartzite disruption suggest the presence of several thrusts within the schists. D2 stretching lineations point to a thrust transport direction between 320° and 360° (magnetic).

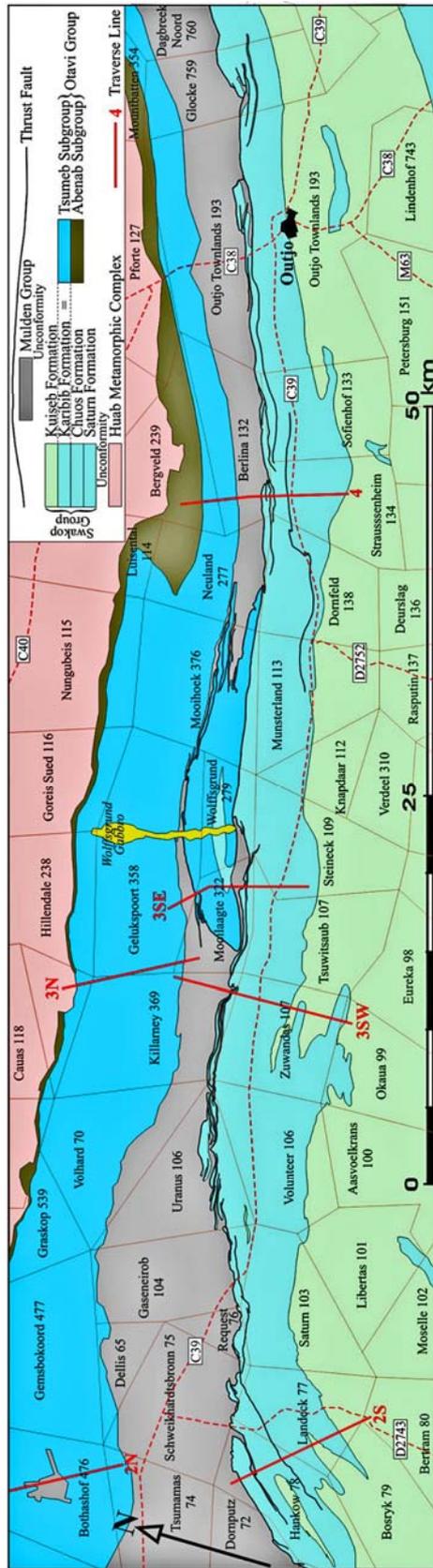
**Key Words** : Otavi Group, Swakop Group, Mulden Group, Fransfontein Ridge, Khorixas-Gaseneirob Thrust, nappes, thrust duplex, stretching lineations, mass flows, grainstone turbidites.

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## Introduction

The notes that follow have been extracted from a programme of observations made in 2010 along seven traverses that started at the base of the Damara succession in the Fransfontein Ridge and continued through to the top of the Karibib Formation or into the Kuiseb Formation a few

kilometres south of the Khorixas-Gaseneirob Thrust. The locations of Traverses 2-4 are shown in Figure 1 and that of Traverse 1 in Figure 1.1. The observations have built on the work of Frets (1969) and Clifford (2008).



**Figure 1.** Simplified map of the geology east of Outjo (superficial cover omitted) showing the stepped D2 thrust front of the Khorixas-Gaseneirob Thrust along which the lower and middle Swakop Group (Saturn to Karibib formations) has been thrust onto Mulden Group phyllites. A nappe of deep-water Otavi Group carbonate rocks with an overlying nappe of Swakop Group rocks was also thrust onto the Mulden phyllites during the same D2 event. The locations of Traverses 2-4 are shown. Based on mapping by Clifford (2008) and the compilation by Schretter (2004).

## Definitions and Methods

In the descriptions that follow, a **grainstone** is a carbonate sandstone or siltstone (i.e. all carbonate grains) which can be limestone or dolomite; a **ribbonite** is a carbonate grainstone deposited below wavy base but having a thin, wavy, flaser-like bedding that can have internal, cross-bed-like laminations; a **rhythmite** is a stack of laminated or thicker, identical looking grainstone beds, generally graded and turbiditic in nature, that accumulated on the continental rise. Rhythmites can consist of limestone alone, dolomite alone, silici-

clastics alone or combinations of these. Thickness of rhythmite layers can vary from a few millimetres to one metre.

All dip readings listed are followed by the reading of dip direction; readings are magnetic and uncorrected to true north, e.g. 45/160, dip 45°, dip direction 160°. These notes will hopefully encourage remapping of the sedimentology and structure of the Damaran rocks in Figure 1 in order to provide a better understanding of depositional conditions and post-Mulden structural evolution.

## General Summary of Geology, Stratigraphy, Sedimentary Structures and Structure

### Stratigraphy

Otavi Group rocks build the Fransfontein Ridge east of the farm Bothashof 476. The Abenab Subgroup at the base is thin. Not all formations are present. The Tsumeb Subgroup forms the main unit with a thickness of 7 km. The Ghaub Formation at the base is only locally preserved as is the tan-coloured Keilberg Member dolostone, its cap carbonate that forms the basal unit of the overlying Maieberg Formation limestones. The thickest unit by far is the Elandshoek Formation which followed by the Hüttenberg Formation at the top of the succession.

The Swakop Group occurs south of the Khorixas-Gaseneirob Thrust. It consists of the Saturn Formation at the base followed

by the Chuos Formation with a prominent iron formation layer in the upper half. Thin equivalents of the Okonguarri and Ghaub Formations may be present at the top of the sequence assigned to the Chuos Formation by Clifford (2008). Limestones, dolomites and thin interbedded schists of the overlying Karibib Formation are followed by the thick schistose metagreywacke succession of the Kuiseb Formation. Post-Kuiseb Mulden Group phyllites fill the valley and plains between the Fransfontein Ridge and the Swakop Group rocks as well as some karst structures in the Elandshoek Formation. Red, Kalahari-age sandstones containing solution-collapse carbonate fragments fill a few small dolines in the Fransfontein Ridge.

### Sedimentary Structures

Between the Summas Mountains and Outjo, sedimentary structures are poorly preserved in the pre-Chuos Saturn Formation (Basal Swakop Group) mainly as a result of the intense D2 deformation. The Chuos Formation is generally poorly exposed and is extensively covered by calcrete. However, mass-flow carbonate and sandstone layers, the former with stromatolitic reef debris in places and the

latter with transported silicified oolites, do form better outcrops than the interbedded diamictites and schist layers. Mass flows, some with fibrous isopachous cement surrounding carbonate clasts, and rhythmite in the Tsumeb Subgroup of the Fransfontein Ridge suggest deposition on the continental slope as it deepened southwards. The coeval Karibib Formation, deposited south of the northern boundary fault of the Northern

Zone rift in still deeper water starts with 2 m of tan dolostone of the Keilberg Member, the cap carbonate to the Ghaub Formation diamictite. Above that are two carbonate facies of the Karibib Formation separated south of the roof thrust of the Khorixas-Gaseneirob Thrust duplex thrust complex by a schist horizon. The lower carbonate facies is intensely foliated but Clifford (2008) records local mass-flow layers (his intraformational breccias) and some graded bedding. The upper carbonate facies contains numerous mass-flow layers with grey limestone and pale brown dolomite

### Structure

*Fransfontein Ridge:* No clear evidence of pre-Mulden D1 deformation was found but post-Mulden D2 deformation was intense, particularly south of the Khorixas-Gaseneirob Thrust front. The southward dip of the Fransfontein Ridge is variably steep to moderate with minor open folds with E-W axes and local, small-scale north-recumbent folds in the Hüttenberg Formation. Bedding-parallel shear zones, interpreted as thrusts, occur locally at or near the base and top of the Otavi Group succession in the Fransfontein Ridge. Traverses 2N and 3N encountered flattened stromatolite columns the orientation of which point to a northward transport direction of the thrust. Down-dip orientation of the axes of minor folds in or close to shear zones suggest small-scale sheath folding in the same northward transport direction. These indicators suggested transport in the direction between 340° and 360° (magnetic).

*Swakop Group:* D2 N-S compression folded the Swakop Group succession into upright to steeply north-vergent isoclinal folds which have a NE-SW orientation just NE of the Summas Mountains but gradually swing around to an ENE orientation towards the east. This change in orientation is believed to be controlled by the orientation of the huge, buttress-like scarp of northern boundary fault of the Northern Zone rift which had a

clasts in a limestone or pale brown dolomite grainstone matrix. The limestone clasts are often highly flattened where bedding and the  $s_2$  foliation are parallel. The dolomite clasts do not deform as easily. Additionally, some mass-flow layers contain clasts of silicified oolites. The mass-flow layer at the top of the Hüttenberg Formation in the Fransfontein Ridge and that at the top of the Karibib Formation appear to be one and the same layer, both having the largest, least deformed clast suite which includes fragments of silicified oolite layers.

throw of almost 7 km on it during eruption of the late-Nosib Naauwpoort volcanics just to the southwest (Miller, 2008). This fault was the boundary between the Otavi Group succession and a much thicker Swakop Group to the south. It was against this buttress that the Swakop Group rocks were initially compressed and then thrust up and over it as a thrust duplex complex onto the Mulden phyllites along the Khorixas-Gaseneirob Thrust. The fault is now deeply buried beneath the Swakop Group rocks and may not be too far south of the thrust front. The axial planar  $s_2$  foliation is intense in the limbs of folds but is less strongly developed in fold closures. Clifford (2008) recognised some north-directed thrusts and younger strike-slip faults. Rather than being a single thrust, the Khorixas-Gaseneirob Thrust is a complex of thrusts that successively overstep each other from west to east (Fig. 1). Most of the thrusts are vertical or dip steeply to the south. On the farm Neuland 277 and east thereof, Clifford (2008) mapped a zone of what he called “rib rock” (Fig. 4.7) at the thrust front with some parallel stringers extending into the Karibib Formation carbonates just behind the front. This so-called “rib rock” consists of long, parallel, rib-like cleavage mullions of chert in the thrust-front carbonates. Each thrust forming the thrust front is a massive sheath fold in which the cleavage mullions have been rotated into parallelism with the

transport direction of the thrust (transport direction 320° magnetic). Stretching lineations in the Karibib carbonates close to the thrust further west point to a 330° (magnetic) transport direction (Traverse 3SE).

D2 also thrust a nappe consisting of the Chuos Formation and intensely foliated Karibib dolomite (the Wolffsgrund Nappe) onto a less deformed nappe of deep-water

Tsumeb Subgroup rocks consisting of the Maieberg, Elandshoek and Hüttenberg Formations (the Mooilaagte Nappe). This stack of two nappes was then thrust onto the Mulden phyllites ahead of the Khorixas-Gaseneirob Thrust. A similar nappe system may be present further east on the farms Nettleton 355, Neins West 178, Sitrusdal 723 and Neins 179, and possibly still further east under calcrete on Valhal 331.

### **Traverse 1: Huab Metamorphic Complex, Kuiseb Formation; farms Kaoko Kroon 487, Inhoek 482**

#### **Summary of the Geology**

The traverse is located on the southern edge of the Welwitschia Inlier southwest of Khorixas and extends from the Khorixas-Gaseneirob Thrust southwards

through the Kuiseb Formation (Fig. 1.1). Mapping of the area was carried out by Frets (1969).

#### **Stratigraphy**

Only the gneisses of the Huab Metamorphic Complex and schists and

minor quartzites of the Kuiseb Formation occur along the traverse

#### **Sedimentology of the Kuiseb Formation**

Graded metagreywacke turbidites form the bulk of the Kuiseb Formation. Most of the interbedded quartzites were deposited during

small-scale regression and transgression cycles.

#### **Structure**

The gneisses of the Huab Metamorphic Complex are intensely sheared as a result of overthrusting of the Kuiseb Formation along the Khorixas-Gaseneirob Thrust. The gneiss is highly brecciated for about 100 m north of the thrust. The main thrust is vertical or dips steeply southwards, strike 110°.

F1 structures in the Kuiseb Formation are not obvious (known from the wider regional context to have been open and orientated E-W (Miller, 1980)) but the Kuiseb schists have a subtle bedding-parallel s1 foliation dated at ~590 Ma (Lehmann *et al.*, 2015). Regional tight to isoclinal F2 folds with a well-developed,

axial planar s2 foliation follow the curvilinear trend of the contact with the Welwitschia Inlier. The s2 mineral fabric is coarsest close to the thrust where bedding has been totally disrupted. The intensity of s2 is variable further south but is generally most intense where bedding and cleavage are parallel. D2 ductility contrast between the quartzites and the enclosing schist is apparent such that the schist can be intensely foliated and the quartzite layers totally disrupted suggesting thrusting in the schist succession. Autobrecciation of the schist or transposition of thin quartzite layers into relatively isolated fold mullions or even into totally isolated lumps of quartzite has taken

place. Numerous small-scale drag folds in the quartzites have resulted in thickness of individual layers varying considerably. F2 folds are overturned towards the NE with the axial planar s2 foliation dipping mainly between 55° and 65° to the SW. D3

produced a gentle buckling along a NE-trending axis and a spaced s3 fracture cleavage. Along the traverse, the main trend of bedding and foliation was WNW with fold structures defined by the main quartzite layers.



**Figure 1.1.** Google image of the region covered by Traverse 1, mainly farms Kaoko Kroon 486 and Inhoek 482. Localities numbered. The line of the schematic section of Figure 1.6 is shown in red.

*Huab Metamorphic Complex*

Locality 1 (UTM 33k0488714, 77483227), Farm Kaoko Kroon 487: The Khorixas-Gaseneirob Thrust. The gneisses against the thrust are intensely sheared, foliated and finely comminuted but with small drawn-out pods in which the originally gneissic texture and mineralogy is still recognisable. There are a few thin (10 cm

thick) lenses of yellow or brown carbonate in the shear zone. The gneiss is highly brecciated for about 100 m north of the thrust but also contains thin (5-30 cm thick) phyllitic shear zones subparallel to the main thrust plane. The main thrust is vertical or dips steeply south, strike 110°.

### ***Kuiseb Formation***

Locality 2 (UTM 33k0489686, 77485742), Farm Inhoek 482: Intensely foliated chlorite-muscovite Kuiseb schist, dip of foliation 75/200 (Fig. 1.2). Bedding in the single s0/s2 fabric is indicated by rare, short lenses of sheared out white quartzite up to 1 cm thick. There are also laminae up to 1 mm thick of brown carbonate parallel to

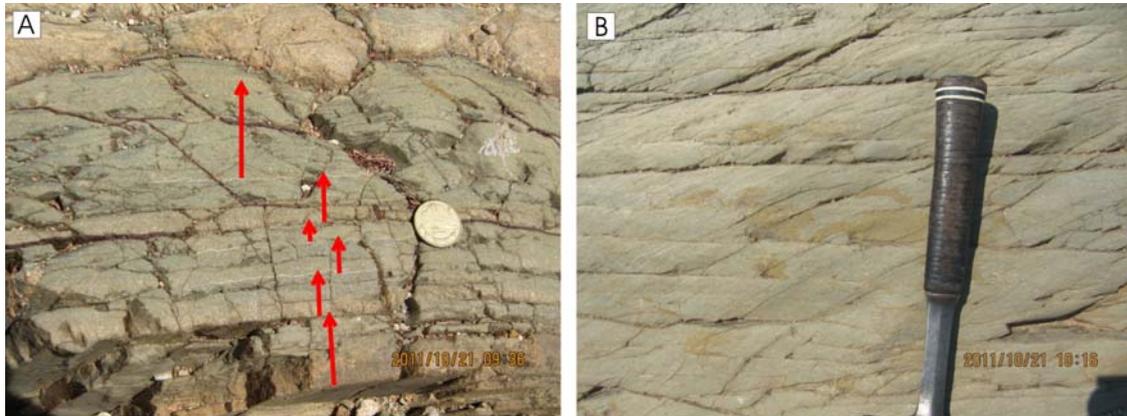
the foliation as well as rare foliation-parallel quartz veins up to 1 cm wide. Local quartz veins up to 1 m wide are parallel to and cross cut the foliation. The locally developed fracture cleavage (s3), dip 85/345, has a red, ferruginous staining which is not present on the s2 cleavage.



**Figure 1.2.** Intensely foliated Kuiseb schist with an s3 fracture cleavage associated with gentle buckling of the s0/s2 foliation. Farm Inhoek 482.

Locality 3 (UTM 33k0489731, 7744899) (Fig. 1.3): Graded beds in Kuisieb

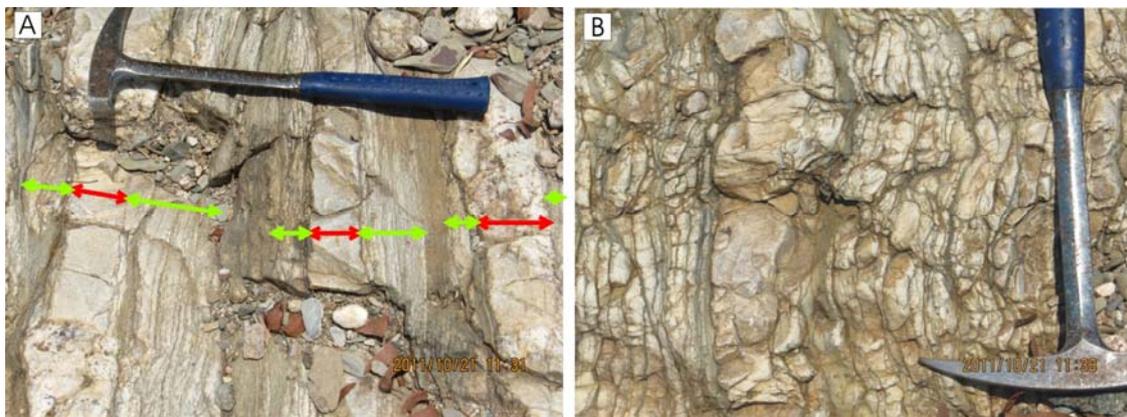
schist.



**Figure 1.3.** Turbidite layers in the Kuisieb schist: (A) Turbidite couplets: thin light brown quartzite base, up to 7 cm thick with grey fine-grained tops between 1 cm and several cm thick, each layer marked with a red arrow; coin diameter 22 mm; (B) Subtly graded beds; beds 0.5-5 cm thick; bedding perpendicular to hammer handle. Farm Inhoek 482.

Locality 5 (UTM 33k0489312, 7744574) (Figs. 1.4, 1.5): Ridge of light brown quartzite. The main quartzite layer is 3 m thick, dip 48/208. Above and below the main layer are several thinner layers of quartzite interbedded with the schist. Most of these thinner layers have many very thin quartzite layers immediately above and below them (Figs. 1.4A, B). The packages of very thin quartzite layers with a single thicker layer (4-12 cm thick) in the middle probably represent small-scale regression and transgression cycles. Several such

cycles occur above and below the main, ridge-forming quartzite layer. Some thin quartzite layers were totally disrupted during deformation and consist only of pebble-like pieces of quartzite floating in tectonic mélange of schist fragments (Fig. 1.5) in which the s2 foliation is well developed. The intensity of s2 varies across the outcrop. The B2 lineation plunges 38/268. s3 is also well developed at this locality as are disharmonic minor folds of the quartzites; fold axes plunges 43/305.



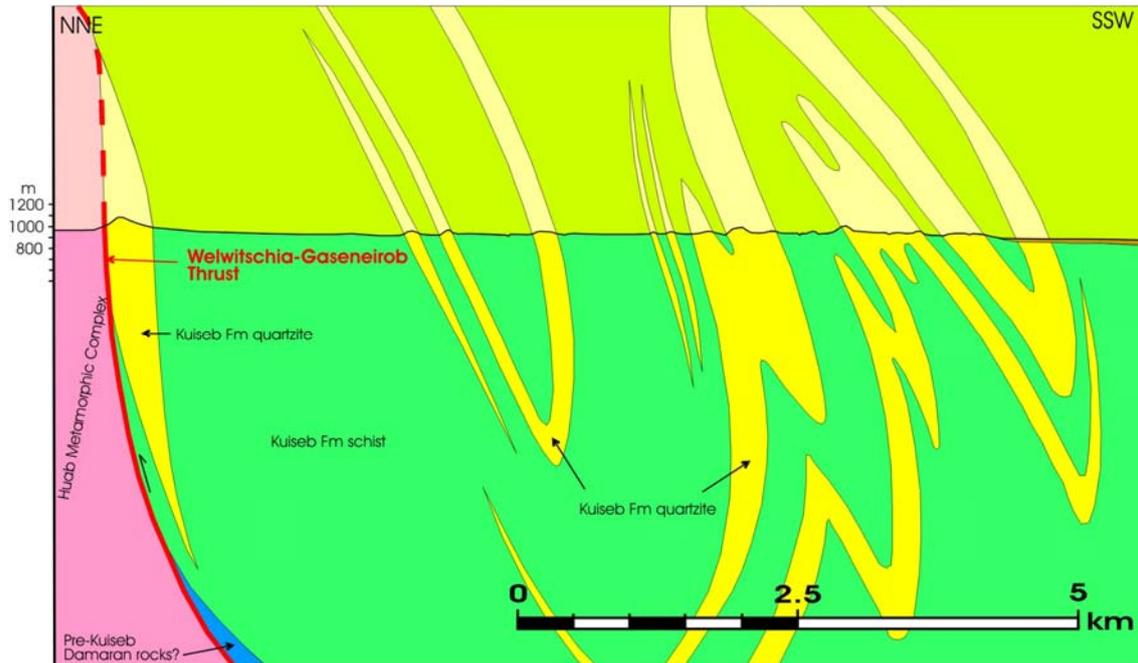
**Figure 1.4. (A)** Single thin layers of quartzite (red arrows) sandwiched between packages of very thin layers of quartzite (green arrows) suggesting cycles of regression and transgression; **(B)** Close-up view of a cyclical quartzite package as shown in 'A'. Farm Inhoek 482.



**Figure 1.5.** Intense dismemberment of quartzite layer during D2 deformation such that the quartzite layer is represented only by pebble-like blobs of quartzite floating in a tectonic schist mélange. Farm Inhoek 482.

Locality 6 (UTM 33k0489568, 7740179): Thick ridge-forming quartzite layer. Complex minor folds and ductility contrasts between the quartzite and the enclosing schist have caused the thickness of

this quartzite layer to vary between 0 m and 10 m with an average of about 5 m. Parts of the quartzite are gritty but no grading was observed. There are a few thin quartz veins in the quartzite.



**Figure 1.6.** Schematic section along Traverse 1 incorporating structural data from Frets (1969).

### Traverse 2N, Otavi Group; farms Danube 59, Bothashof 476

#### Stratigraphy

The traverse starts near the southern border of the farm Danube 59 at the base of the Otavi Group of the Fransfontein Ridge in a thin section of the Gruis and Ombatjie Formations of the Abenab Subgroup. It continues through Tsumeb Subgroup rocks on Bothashof 476 and ends in calcrete-covered Mulden rocks. Although most recent publications refer to the carbonate

succession above the Abenab Subgroup on the southern flank of the Fransfontein Ridge as the Karibib Formation, the lithology is similar to that of the Tsumeb Subgroup and the formation names from this subgroup are used for this section. For detail of the Abenab Subgroup at this locality, the reader is referred to Hoffman (2010).

#### Sedimentology

The Abenab Subgroup contains photic zone stromatolite layers as well as deeper water slope deposits of alternating phyllites and graded carbonate grainstone rhythmites.

A thin, tan dolostone of the Keilberg Member, the cap to the Ghaub Formation, forms the base of the Maieberg Formation of the Tsumeb Subgroup. The Maieberg Formation passes upwards from massive grey limestone with white jaspilite (coarse-grained chert) veins and lumps into slope

deposits of laminated, turbiditic grey limestone rhythmite with cappings of pale grey, very fine-grained, pelagic dolomite. One mass-flow layer containing only Maieberg fragments occurs near the top of the Maieberg Formation. The overlying Elandshoek Formation consists largely of whitish to very pale grey, massive to thickly bedded dolomite with a few thin zones of thin to laminated bedding. There are patches of intense white jaspilite veining which is typical of the Elandshoek Formation.

Thinner bedding generally prevails in the upper 1/3<sup>rd</sup> of the Elandshoek Formation but zones of massive dolomite, deep-water laminated rhythmites and mass-flow breccias alternate. Fragments in the mass-flow breccias are usually enclosed in a veneer of white chert outboard of which is a 4-7 mm thick rim of white, fibrous isopachous cement (Fig. 2.8). This texture is typical of the Gauss Formation in the Otavi Mountainland. The Hüttenberg Formation consists of grey thin- to medium-bedded limestone with thin bedding-parallel layers of brown-weathering chert in the lower part

### Structure

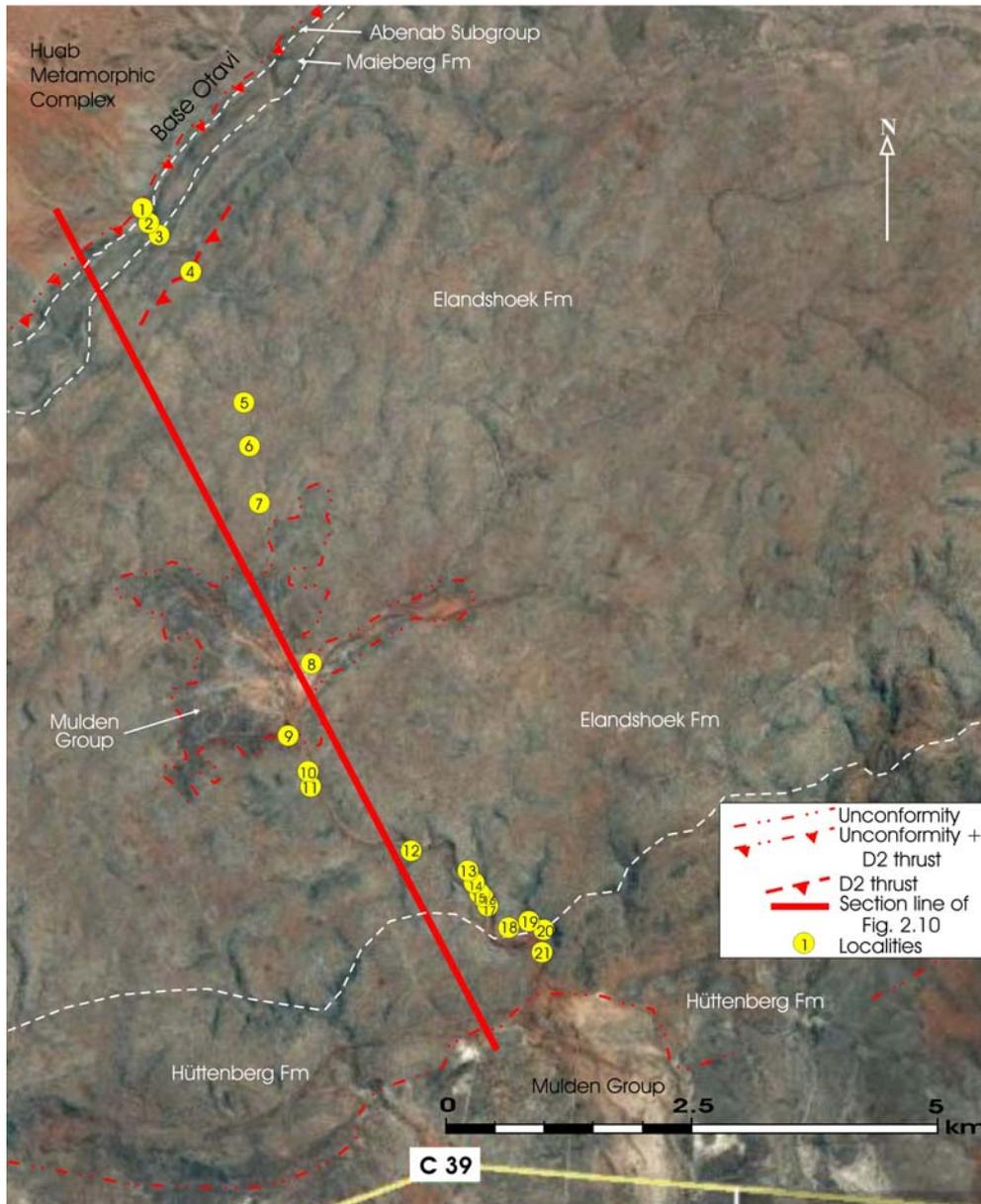
The whole Otavi Group succession on the Fransfontein Ridge was thrust northwards on two thrusts during regional D2. Adjacent to that at the base of the succession, stromatolites have been deformed into bedding-parallel lozenges (Fig. 2.2). Axes of minor folds associated with the other near the base of the

and laminated grey grainstone rhythmites with some very thin, pale grey pelagic dolomite cappings in the upper part.

The Mulden Group cuts unconformably into the top of the Hüttenberg Formation and fills a large post-D1 karst cavity in the Elandshoek Formation. The Mulden is post D1 and pre D2. The basal conglomerate of the karst fill is overlain by layers of grey, foliated phyllite and brown siltstone.

A few younger dolines are filled with structureless, brown to reddish, fragment-filled sandstone of Kalahari age.

Elandshoek Formation have been rotated by the thrusting and plunge down the SSE dip direction of nearby bedding. These suggest the transport direction of the thrust was 340° (magnetic). Minor folds near the top of the Hüttenberg Formation have been overturned to the north. The foliation in the Mulden phyllite is D2 in age.



**Figure 2.1.** Google image of the region covered by the Traverse 2N, mainly farm Bothashof 476. The line of the section in Figure 2.10 is also shown (red line).

***Abenab Subgroup, Gruis Formation, 5 m thick***

Locality 1 (UTM 33k0536323, 7772659), Fig. 2.1: Base of the Otavi Group on farm Danube 59. Basal brown-weathering dolomite with numerous very thin stringers of muscovite-chlorite phyllite.

Thrusting has strongly deformed the columnar stromatolites adjacent to phyllite layers into elongate lozenges ± 10 cm thick (Fig. 2.2). Bedding dip 50/150.

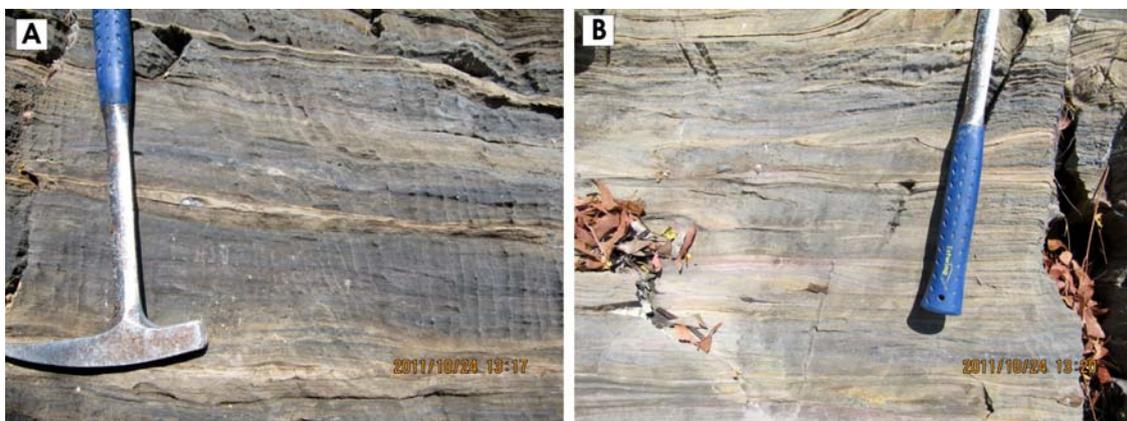


**Figure 2.2.** Stromatolites intensely transposed and deformed into bedding-parallel lozenges. Thin jaspilite veins (coarser grained than chert but finer grained than vein quartz - TCL terminology) in the stromatolites.

***Ombaatjie Formation, true thickness 130 m***

This consists of alternating layers of variable thickness of intensely foliated phyllite, foliation 72/130 with foliation steeper than bedding, and grey dolomite ribbonite (grainstone with flaser-like

bedding, deposited below wave base - Fig. 2.3) with local stromatolites and thin, laminated, brown-weathering, calcareous sandstone layers. Detail of this section is given by Hoffman (2010).



**Figure 2.3.** Dolomite ribbonite grainstones of cycle b7 (?) of the Ombaatjie Formation near the boundary between the farms Danube 59 and Bothashof 476. Some of the units in (A) are slightly argillaceous.

***Tsumeb Subgroup, Maieberg Formation***

Locality 2 (UTM 33k0536434, 7772561): Layer of tan dolostone about 0.5 m thick (Fig. 2.4) at the base of the Maieberg Formation, which is the cap

dolostone to the Ghaub Formation (Keilberg Member - nowhere near as thick as shown by Hoffman, 2010). No Ghaub Formation is present on this farm but it is present further

east on Bergveld 239. The tan dolostone is overlain by about 27 m of grey, massive Maieberg limestone, which is cut by numerous white jaspilite veins and contains irregular lumps of massive white jaspilite up to 2 m across. Above this is typical grey, laminated, deep-water Maieberg rhythmite (laminae of grey limestone turbidite

alternating with thinner, light grey laminae of very fine-grained pelagic dolomite). This contains much fewer white jaspilite veins. Bedding dip 74/140. One 50 cm-thick mass flow unit, containing only Maieberg fragments, occurs near the top of the Maieberg. Bedding dip at top of Maieberg 52/130.



**Figure 2.4.** 0.5 m-thick tan dolostone of the Keilberg Member at the base of the Maieberg Formation.

### ***Elandshoek Formation***

Locality 3 (UTM 33k0536458, 7772445): Contact between grey laminated Maieberg Formation and typical whitish massive to thickly bedded Elandshoek Formation. Bedding dip near base, 35/135, i.e. bedding becoming less steep. A few zones with very thin bedding. Irregular pods of massive white jaspilite and zones with intense veining by white jaspilite - a typical feature of the Elandshoek Fm.

Locality 4 (UTM 33k0536787, 7772009): A 12 m thick (true thickness) shear zone in the Elandshoek Fm, dip of shear zone foliation 48/136, probable thrust. Bedding just below the shear zone 42/160 but undulating, axes of minor folds within

the shear zone plunge down the bedding, plunge direction 160°.

Locality 5 (UTM 33k0537338, 7770735): Elandshoek Fm. Massive but some zones 2 m thick with thin bedding, bedding dip 63/165 but undulating southerly.

Locality 6 (UTM 33k0537407, 7770180): Elandshoek Fm. Broad open synclinal axis, bedding dip 34/260.

Locality 7 (UTM 33k0537472, 7769613) (Fig. 2.5): Elandshoek Fm. Typical thick to massive bedding of the whitish upper Elandshoek Fm with faint, discontinuous, internal bedding laminae in places, some silicified. Some thin beds totally silicified.



**Figure 2.5.** Typical thick to massive bedding of the whitish upper Elandshoek Formation. Dark layers are thin silicified beds. Farm Bothashof 476.

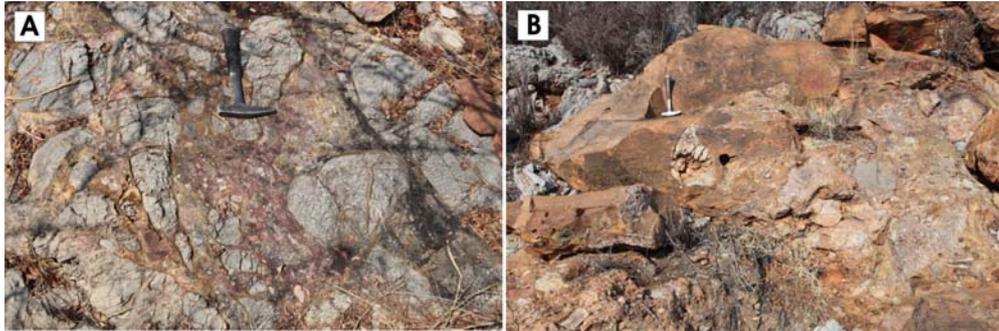
Locality 8 (UTM 33k0538026, 7767981): Basal conglomerate of the Mulden Group filling post-D1 - pre-D2 karst cavity in Elandshoek Fm; Bothashof house located within this inlier.

Locality 9 (UTM 33k0537817, 7767345): Basal conglomerate of the Mulden Group karst fill just south of Bothashof house (Fig. 2.6). The basal conglomerate is overlain by cleaved Mulden phyllite. Within the karst, the basal part of the conglomerate contains numerous angular

to subrounded blocks of Elandshoek dolomite (Fig. 2.7A) but the clasts in the top of the conglomerate are mainly quartz with very few of dolomite; brown to reddish sandy to silty matrix to the conglomerate. Parts of the conglomerate look like a solution-collapse breccia. The uppermost part of the karst fill consists of brown, very thinly bedded to laminated siltstone with some small dolomite and quartz fragments (Fig. 2.7B).



**Figure 2.6.** South side of the Mulden-filled depression surrounding the farm house on Bothashof 476. Brown areas in the lower slopes are comprised of the Mulden basal conglomerate, whitish Elandshoek dolomite higher up hill.



**Figure 2.7.** Close up views of the basal Mulden lithology filling the large karst structure shown on Fig. 2.1. **(A)** Basal conglomerate: clasts of Elandshoek dolomite in a brown sandy to silty matrix; **(B)** Brown, thinly bedded to laminated siltstone at the top of the Mulden karst fill.

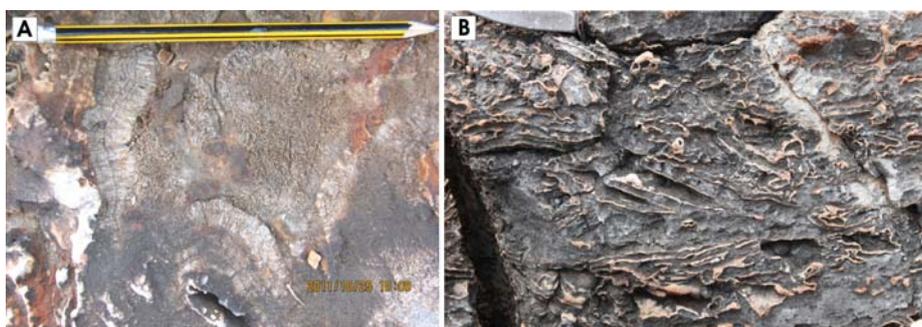
Locality 10 (UTM 33k0537998, 7766781): Elandshoek Fm with thin brown layers of silicified oolites or grainstone; bedding dip 36/195. Plunge of minor fold axes 14/278.

Locality 11 (UTM 33k0538014, 7766718): Elandshoek Fm; bedding dip same as previous locality. Elongate karst filling about 10 m wide of highly silicified red-brown siltstone with a few siltstone and quartz clasts in the centre and dolomite clasts along the margin. Elongate in direction 260°. Possibly of Kalahari age.

Locality 12 (UTM 33k0539064, 7766028): Elandshoek Fm; bedding dip 24/300. Bedding dips mainly gently south but undulates about the horizontal with some gentle northerly dips.

Locality 13 (UTM 33k0539726, 7765682): Towards the top of the

Elandshoek Fm; medium grey weathered surface but very light grey fresh surface. Extensive area of small-fragment slump breccia with platy Elandshoek fragments. Fragments have a very thin silica (jasperoid?) coating enclosed in an outer coating of a fibrous isopachous cement 4-7 mm thick (Fig. 2.8A). In places, the platy fragments were deposited subparallel to bedding so that the layers of fibrous isopachous cement are roughly parallel to bedding in adjoining undeformed layers (Fig. 2.8B). These slump breccias occur between layers of typical massive, unbrecciated Elandshoek dolomite. This texture is very similar to that described for the Gauss Formation in the Otavi Mountainland.



**Figure 2.8.** Small-fragment slump breccia with Elandshoek fragments enclosed in thin veneers of silica and an outer rim of fibrous isopachous cement. **(A)** Close up view showing the radiating fibers of the outer rim; **(B)** Platy fragments of Elandshoek dolomite lying subparallel to bedding. Fragments are enclosed in weather-resistant rims of isopachous cement. Towards the top of the Elandshoek Formation on Bothashof 476.

Locality 14 (UTM 33k0539664, 7765771): Elandshoek Fm; Laminated, very light grey Elandshoek rhythmites, i.e. deep water. Many small-scale, tight chaotic folds which may be due to slumping.

Locality 15 (UTM 33k0539706, 7765733): Elandshoek Fm; Base of a zone of medium to dark grey weathering Elandshoek dolomite breccia with abundant fibrous isopachous cement.

Locality 16 (UTM 33k0539706, 7765733): Elandshoek Fm; Same grey-weathering Elandshoek dolomite but thickly bedded to massive, overlies the main breccia zones with fibrous isopachous cement. Still some small patches of fibrous isopachous cement. Bedding dip 10/250.

Locality 17 (UTM 33k0539852, 7765453): Elandshoek Fm; Top of grey-weathering Elandshoek dolomite. Consists entirely of rhythmite with some minor mass flow layers. Overlain by rhythmite that weathers to a very light grey colour. Deep-water deposit on continental rise.

Locality 18 (UTM 33k0540070, 7765215): Elandshoek Fm; rhythmite, bedding dip 17/150. 20 cm-wide fault filled with abundant white calcite, fault dip 77/210.

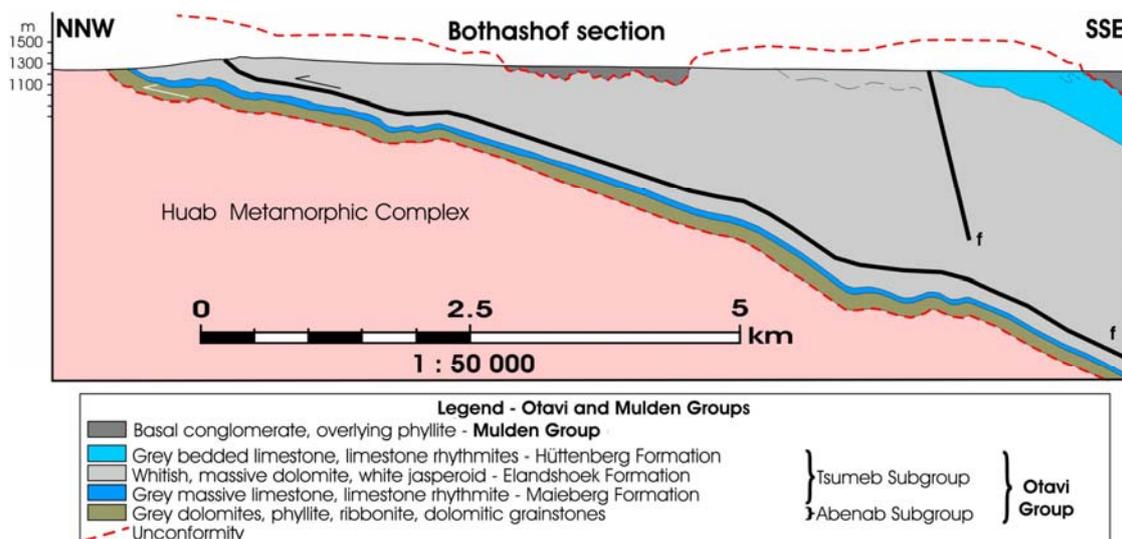
Locality 19 (UTM 33k0540262, 7765286): Elongate Kalahari-filled doline in very light grey to whitish weathering Elandshoek Fm; fill is red-brown, highly silicified Kalahari siltstone with some quartz grit and small fragments of Elandshoek dolomite and chert, fragments most abundant along edges of doline.

Locality 20 (UTM 33k0540419, 7765211): Hüttenberg Fm limestone; northern part of Farm Tsumamas 74. Thin- to medium-bedded Hüttenberg Fm (Fig. 2.9) weathers medium grey, slightly lighter grey on fresh surface. Base of Hüttenberg Fm about 40 m below this locality.

Locality 21 (UTM 33k0540410, 7764945): Hüttenberg Fm limestone; rhythmites with laminae of limestone turbidite and a few very thin light grey pelagic dolomite laminae, bedding dip 28/128; tight minor folds overturned to the north, fold axial plane dip 47/140, strike of fold hinges 54° - 43°, i.e. south to north compression and overturning. Zones of silicified laminae, some bands of light to dark grey, brown-weathering chert (latter typical for Hüttenberg) parallel to bedding.



**Figure 2.9.** Typical thin to medium bedding of grey Hüttenberg Formation limestone, often with internal rhythmite laminations. Brown silicified beds. Farm Tsumamas 74.



**Figure 2.10.** Section along the northern part of Traverse 2N.

### Traverse 2S; Swakop Group; farm Landeck 77

#### Stratigraphy

This traverse is a continuation of Traverse 2N. It starts in the poorly exposed Mulden Group and continues in the Swakop Group rocks on Hankow 78 and Landeck 77 and thence to the poorly exposed Kuiseb schists towards the southern border of Landeck 77 (Fig. 2.11). For the Swakop Group rocks, reference is made to Clifford (2008). Clifford's Saturn Formation corresponds to Miller's (2008) Ugab Subgroup, his Landeck Formation corresponds to the combined Chuos, Okonguarri and Ghaub Formations (the latter two were unknown at the time he was mapping in the 1960s and are not mapped out separately), Clifford's Bergfriede

Formation corresponds to the Karibib Formation and his Okaua Formation corresponds to the Kuiseb Formation. Clifford considered the Okaua Formation in the south and the Mulden Group north of the Khorixas-Gaseneirob Thrust to be one and the same unit. Localities recorded for Traverse 2S and the section line for Figure 2.28 are shown in Figure 2.11. The detailed map of Clifford (2008) has been used as a lithological guide but the sedimentology, the Chuos, Okonguarri and Ghaub Formations and internal structure of layers need remapping throughout the area that he mapped.

#### Sedimentology

The entire Swakop Group succession was deposited in deep water south of the huge fault scarp that formed the northern boundary of the deep Nosib-age rift which encompassed the Northern Zone and the northern Central Zone.

Bedding and sedimentary structures are generally poorly developed in the Saturn

Formation although Clifford (2008) does record the presence of algal structures.

Carbonate layers and some siliciclastic layers in the Chuos Formation are mass flows or thinly bedded turbiditic grainstone rhythmites. Some contain abundant stromatolite fragments and others transported silicified oolites. Although

locally well-exposed, the formation is poorly exposed for the most part. The presence of the iron formation, again poorly exposed, is indicated by float.

Three facies of the Karibib Formation are present. One occurs between the roof and sole thrusts shown in Figures 2.11 and 2.28 and contains some mass flows and graded beds (Clifford, 2008). The other two, apparently more distal than the first, consist of a lower and upper facies separated from each other by a phyllitic schist marker and located south of the roof thrust (Figs. 2.11, 2.28). The lower facies starts with 2 m of tan dolostone of the Keilberg Member, the cap carbonate to the glaciogenic Ghaub Formation, followed by grey limestone. Bedding and some graded bedding (Fig. 2.19) can be distinguished in places but generally an intense bedding-parallel foliation obscures much of the original sedimentary detail. The third facies, the upper Karibib Formation, is comprised of numerous, readily distinguishable mass-flow layers of varying thickness and with varying clast sizes. Many of these have a strong

## Structure

Clifford (2008) recognised a late-sedimentary - pre-tectonic slump, the Saturn Slide, of Ugab, Chuos and Karibib stratigraphy onto the same stratigraphic units further down slope.

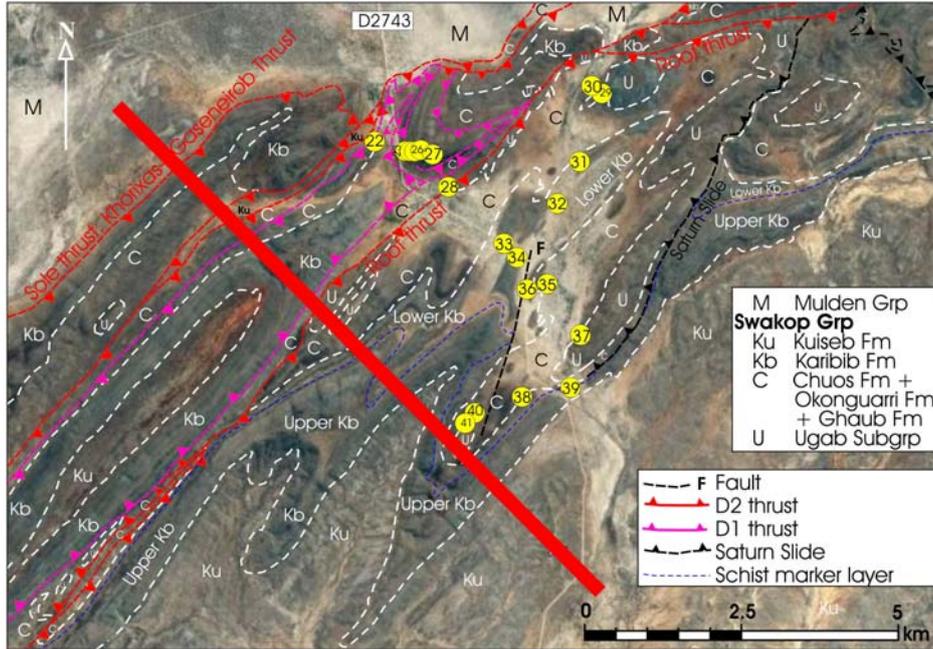
Clifford (2008) recognised a D1 phase of thrusting (Figs. 2.11, 2.28) but an  $s_1$  axial planar foliation, which would be best displayed in D2 fold closures, was not discernable. Further to the west, Miller (1980) recognised large, open E-W folds but  $s_1$  is a bedding-parallel micaceous fabric in the Kuiseb schists (Lehmann *et al.*, 2015). Clifford (2008) recognised D2 thrusts east of Traverse 2S but most of his large faults along this traverse are reinterpreted here as thrusts. D2 deformation took place during

bedding-parallel foliation and intensely flattened limestone clasts. Dolomite clasts do not deform as readily. Thin interbeds of thinly bedded turbiditic grainstone rhythmites are common (Figs. 2.20 - 2.23). It should be possible to follow out individual mass-flow layers laterally until they pinch out. Several beds of grey limestone nodules set in a pale grey dolomite grainstone matrix occur near the top of the formation. The uppermost mass-flow layer contains the largest and least deformed clasts, some highly oolitic. This layer is considered to be the same layer that occurs at the top of the Hüttenberg Formation in Traverse 2N.

On this traverse, the Kuiseb Formation is not exposed but near the Summas Mountains to the SW it consists of turbiditic greywackes.

The Mulden Group is a syn- to post-D1, intramontane deposit consisting predominantly of grey chlorite-muscovite phyllites with a strong, steep to vertical, ENE-WSW foliation that formed during regional D2 compression.

intense D2 N-S to NW-SE compression and folding. The succession was tightly compressed against and then over the massive buttress of the fault scarp that formed the northern boundary of the Northern Zone rift (Fig. 2.28). The Khorixas-Gaseneirob Thrust is the floor thrust to the stacked succession of duplex-like thrusts of which there may be more than indicated, particularly along contacts between rocks of contrasting ductility. Much of the bedding is vertical or near vertical with an intense  $s_2$ , bedding-parallel foliation. The orientation of the fault scarp probably controlled the orientation of the D2 structures. The intense compression steepened up structures during and after D2 thrusting.



**Figure 2.11.** Google image of the region covered by Traverse 2S, mainly farm Landeck 77. The red line is the section line in Figure 2.28. Stratigraphy and structure are modified from Clifford (2008).

Locality 2.22 (UTM 33k0544006, 7756727): Karibib Formation; farm Hankow 78. Highly complex structure in this area immediately adjacent to the Khorixas-Gaseneirob Thrust. There are more thrust dislocations than shown, particularly along

schist layers. Bedding vertical to N-vergent; N-vergent isoclinal folds, axial plane dip 66/225, plunge of axis 34° in direction 280° (Fig. 2.12). Siliceous iron formation float in areas of Chuos Fm outcrop and subcrop.



**Figure 2.12.** Steeply N-vergent isoclinal folds in Karibib Formation limestone adjacent to the Khorixas-Gaseneirob Thrust on farm Hankow 78.

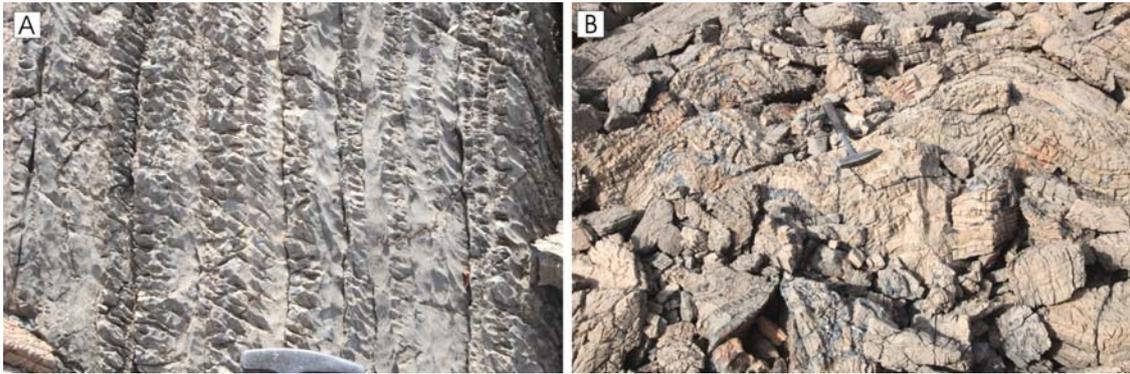
Locality 2.23 (UTM 33k0544530, 7756473): Chuos Formation; farm Landeck 77. Hill with interbedded zones of dolomite,

limestone and siliciclastic units. At this locality, thickly bedded, very dark grey dolomite, tight minor folds, two 20-30 cm

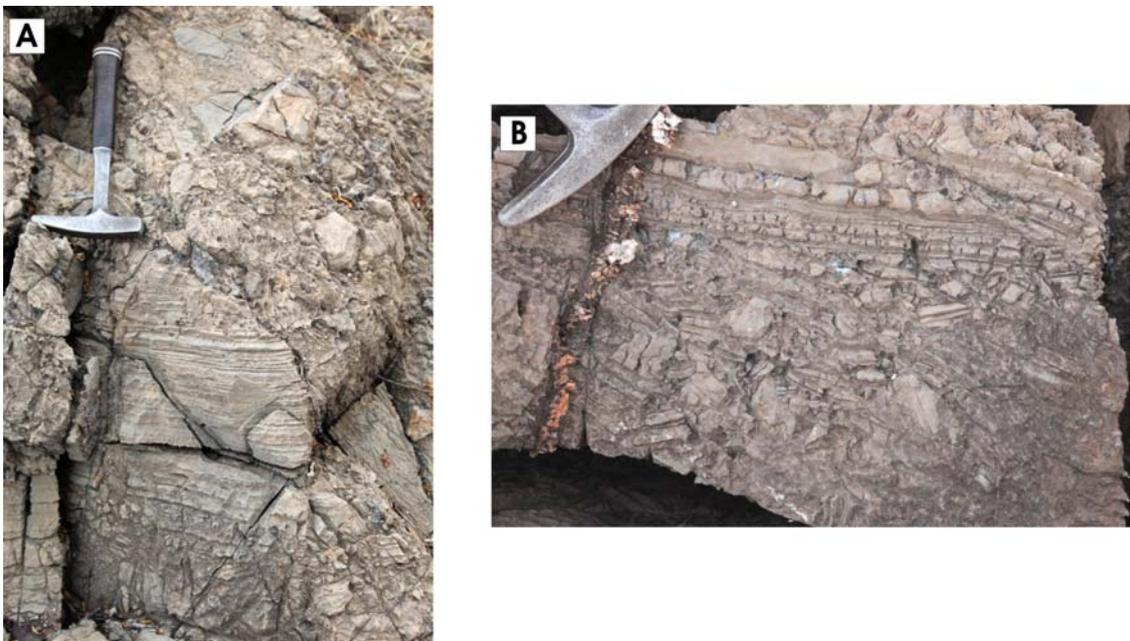
thick slump breccias made up of fragments of this same dolomite. May be near the stratigraphic top of the Chuos Fm.

Locality 2.24 (UTM 33k0544593, 7756465): Same hill, Chuos Formation, next carbonate layer stratigraphically lower down. The whole of this light grey unit is comprised of stacked, graded, turbiditic dolomite grainstones, individual layers between <1 cm and 12 cm thick (Fig.

2.13A). The lower part of unit consists mostly of slump folds (Fig. 2.13B) and slump breccias with clasts of light grey, thinly to very thinly bedded dolomite (Figs. 2.14A, B). Younger solution collapse breccias in this slump breccia cemented by white to black sparry calcite (Fig. 2.15). This dolomite is underlain by blue-grey limestone.



**Figure 2.13.** (A) Dolomite zone within the Chuos Formation made up entirely of stacked, graded dolomite turbidite layers between <1 cm and 12 cm thick. Top to right, fine-grained tops form the smoother layers; (B) Layer of small-scale slump folds in the dolomite grainstone turbidite sequence of 'A', cavity fillings of white sparry calcite. Farm Landeck 77.



**Figure 2.14.** (A) Mass flow or slump breccia layer of very thinly bedded light grey dolomite; (B) Mass-flow layer within the succession of thin, stacked, dolomite turbidite grainstones shown in Fig. 2.13A. Fragments are all derived from these thin turbidite layers.



**Figure 2.15.** Post-deformation solution collapse breccia in syn-sedimentary slump breccia, cement of white to black sparry calcite.

Locality 2.25 (UTM 33k0544712, 7756508): Same hill, Chuos Formation. Zone of highly foliated phyllite with thin siltstone beds. Clifford marks a D1, bedding-parallel thrust at this level that was folded by F2. Phyllite underlain by a dolomite layer which is a mass flow containing many small dolomite fragments and very finely laminated fragments of small stromatolites. The southern edge of this layer (i.e. top) is made up of small *in situ* stromatolites 5-10 cm in diameter and 20 cm in height all perpendicular to bedding.

Locality 2.26 (UTM 33k0544772, 7756560): Same hill, Chuos Formation. Next dolomite layer down in the stratigraphy – also a mass flow.

Locality 2.28 (UTM 33k0544920, 7756527): Same hill, Chuos Formation. Next dolomite layer down in the stratigraphy - also a mass flow. Platy dolomite fragments, some fragments of small stromatolites and many lumps of silicified material.

Locality 2.28 (UTM 33k0545191, 7756006): Saturn Fm, farm Landeck 77. Core of NE-trending anticline that is cut off

on its NW flank by the long NE-trending roof thrust shown on Fig. 2.28. The core of this structure is a brown-weathering dolomite that is very light grey when fresh. This is cut by numerous calcite and quartz-rich veins with rather abundant limonite dodecahedra after pyrite. The marginal layer is a breccia (mass flow?) with blocks of brown-weathering dolomite and limestone set in a sparse, sparry calcite cement.

Locality 2.29 (UTM 33k0547535, 7757541): Chuos Formation, farm Landeck 77, near NE corner. An anticline cored by massive, light coloured Saturn Fm dolomite. This locality is on the first carbonate layer within the basal siliciclastics of the overlying Chuos Fm. The carbonate layer is a mass flow composed almost entirely of small fragments up to 10 cm across of stromatolites (reef debris). There are also some scattered fragments of grey, fine-grained dolomite from 1 cm to 50 cm in size (Fig. 2.16). There is a siliceous Fe formation layer lower down in the Chuos (i.e. stratigraphically below this mass flow) but above the Saturn dolomite. Bedding vertical, strike NE.



**Figure 2.16.** Lowest carbonate layer in Chuos Formation at locality 2.29. This is a mass flow composed almost entirely of light grey stromatolitic reef debris and a few large angular fragments of grey dolomite, NE Landeck 77.

Locality 2.30 (UTM 33k0547472, 7757614): Chuos Formation, farm Landeck 77, near NE corner. Next carbonate layer up in the Chuos Fm. Also a mass flow. Immediately overlain by a brown, slightly feldspathic sandstone containing layers and scattered grit-size grains of white silicified oolites and a few fragments of brown dolomite up to 3 cm across, i.e a mass-flow sandstone (Fig. 2.17). Interbedded with the sandstone is a black, very fine-grained

graphitic metapelite that is foliated in places and massive in others - weathered surface light grey. There is also an associated, highly feldspathic layer speckled by tiny red Fe-stained spots. This is a recrystallised acid volcanic containing numerous tiny acicular and euhedral crystals of zircon. The same graphitic phyllite and speckled feldspathic volcanic rock occur at the copper prospect at locality 2.40.



**Figure 2.17.** Gritty, feldspathic mass-flow sandstone in the Chuos Fm containing well-sorted, grit-sized grains of white silicified oolites and a few small clasts of brown dolomite up to 3 cm across (one at hammer head). Farm Landeck 77.

Locality 2.31 (UTM 33k0547247, 7756215): Lower Karibib Formation, farm Landeck 77. Intense bedding-parallel foliation of grey Karibib Fm limestone containing some white streaks and calc-

silicate layers. The outcrop consists of vertical, small-scale antiforms, most of which are defined by calc-silicate layers, separated from each other by narrow zones of shearing (Fig. 2.18).



**Figure 2.18.** Vertical, small-scale anticlinal folds in Karibib Formation limestone. Synclines sheared out. Farm Landeck 77.

Locality 2.32 (UTM 33k0546668, 7755804): Base Karibib Formation, farm Landeck 77. Tan-coloured Keilberg Member dolostone 2 m thick at the base of the Karibib Formation. There is abundant very coarsely crystalline brown calcite at the contact between the Keilberg Member and the underlying Chuos Fm.

Locality 2.33 (UTM 33k0546235, 7754887): Karibib Formation, farm Landeck 77. Traverse from base to middle of Karibib Fm limestone - an intense bedding-parallel foliation throughout.

Locality 2.34 (UTM 33k0546264, 7754854): Karibib Formation, farm Landeck 77. Graded limestone beds 3-10 cm thick near base of Karibib Formation (Fig. 2.19).



**Figure 2.19.** Graded limestone beds 3-10 cm thick near the base of the Karibib Formation.

Locality 2.35 (UTM 33k0546508, 7754350): Base Karibib Formation, farm Landeck 77. Undulating but gently dipping brown dolomite of the Keilberg Member at the base of the Karibib Fm. Beds dip 10-22/280.

Locality 2.36 (UTM 33k0546446, 7754356): Karibib Formation, farm Landeck 77. Karibib Fm about 50 m above the Keilberg Member. Beds dip 54/270 but dip undulates considerably.

Locality 2.37 (UTM 33k0547309, 7753595): Saturn Fm, farm Landeck 77. Massive, structureless, featureless, light brown weathering dolomite.

Locality 2.38 (UTM 33k0546338, 7757373): Karibib Formation limestone, farm Landeck 77. Lower part of Karibib Fm below negatively weathering and valley-forming marker phyllitic schist layer. Intense bedding-parallel foliation in limestone except in closures of minor folds where foliation is scarcely developed. No mass-flow layers seen in this traverse across the lower Karibib Fm.

Locality 2.39 (UTM 33k0547132, 7752753): Upper Karibib Formation, farm Landeck 77. North to south traverse across the outcrop from near the top of the marker layer of phyllitic schist to the top of the Karibib Formation.

Top of phyllitic schist: A limestone layer near the top of the schist is a clast-bearing mass-flow unit.

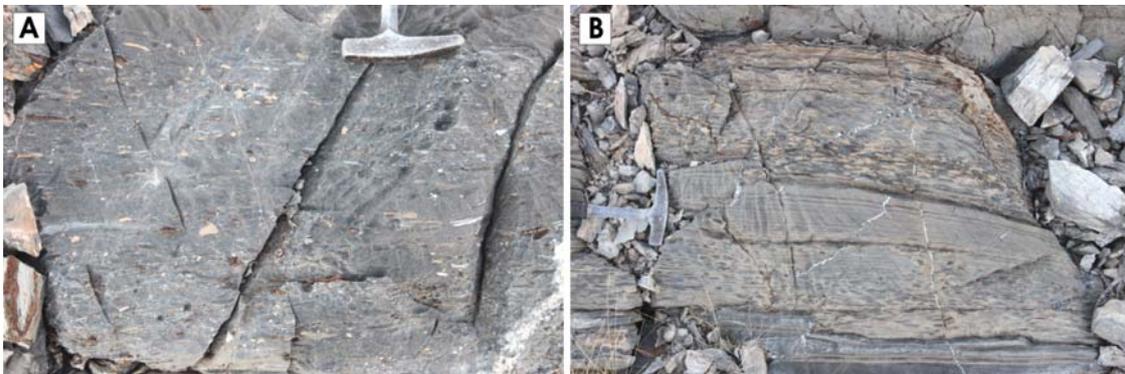
The upper Karibib limestone unit above the phyllitic schist marker: This consists of numerous mass flows layers interbedded with varying thicknesses of laminated rhythmite and grainstone flows of varying grain sizes. The laminated rhythmite is comprised of grey limestone turbidite laminae, some of which are capped by thinner, light grey pelagic dolomite layers. The rhythmite lamination becomes very

indistinct in places. The mass flows vary from centimetres to several metres in width. Most clasts in the mass flows are flattened and drawn out fragments of grey or, less commonly, white limestone. Dolomite clasts are light grey, distinctly less numerous and less deformed than the limestone clasts. Some flows contain only clasts smaller than about 5 cm in size. The largest clasts in other flows are generally not much larger than about 25 cm. In some flows, the clast size fines upwards. Figure 2-20 is from a 10 m-thick, medium grey, limestone mass-flow layer with white, drawn-out limestone clasts and less deformed, brown-grey dolomite clasts. Layer thickness, clast size and proportions of grey limestone and light grey dolomite clasts vary from layer to layer (Figs. 2.21A, B).

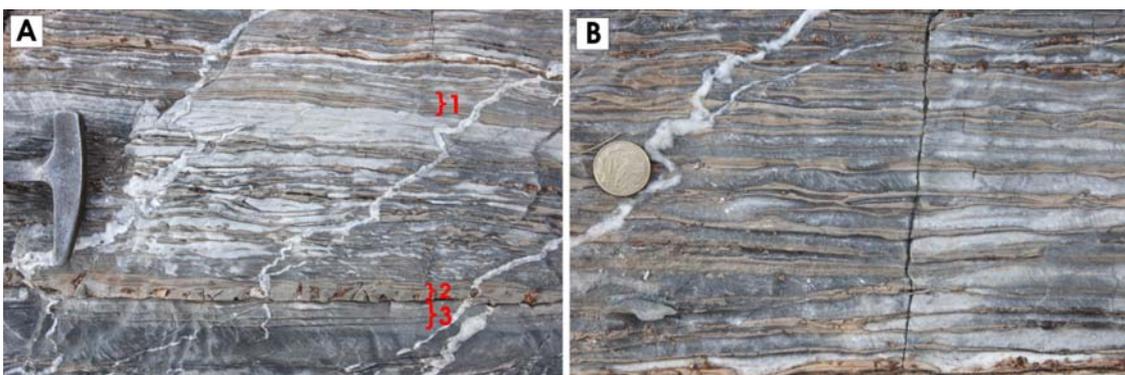
Towards the top of the unit is a zone of very thin mass-flow layers, individually 6-7 cm thick but also up to 15 cm thick, many of which have platy grey limestone clasts set in a light grey-brown dolomite grainstone matrix. Some of these contain some light grey dolomite clasts or consist almost entirely of light grey dolomite clasts in a grey limestone grainstone matrix (Figs. 2.22A, B, 2.23A, B). Closely associated with these thinly bedded flows are a few layers of small, grey limestone nodules set in a light grey dolomite matrix (Fig. 2.24). The penultimate layer at the top of the formation is a 7 m-thick mass-flow unit containing dark grey and grey limestones clasts with very few, very light grey dolomite clasts. The matrix of the lower 4 m is grey limestone and that of the upper 3 m is light grey dolomite (Fig. 2.25). The uppermost few metres of the Karibib Fm consist of limestone with an intense bedding-parallel foliation. The Kuiseb Fm schists occur above this but are not exposed.



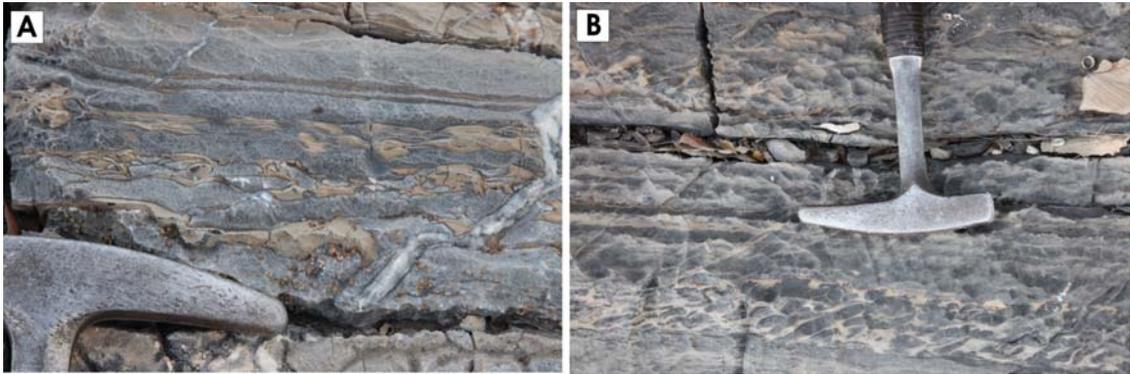
**Figure 2.20.** 10 m thick limestone mass-flow layer in the middle of the upper Karibib Fm containing white, drawn-out limestone clasts and less deformed brown-grey dolomite clasts. Note the intense foliation which is almost bedding-parallel. Southern part of Landeck 77.



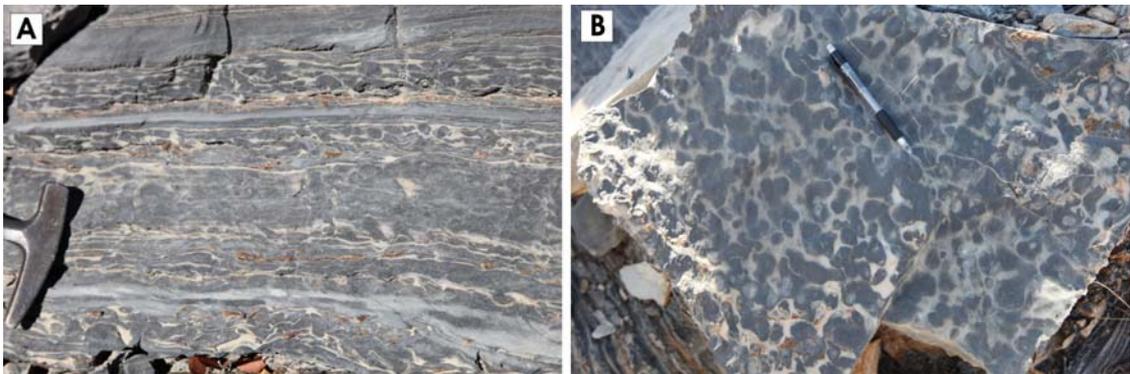
**Figure 2.21.** Mass-flow layers in the Karibib Fm stratigraphically above the layer of Figure 2.20. **(A)** Large platy, deformed clasts of grey limestone and small clasts of less deformed, white and brown dolomite; **(B)** Two mass-flow layers with grey limestone clasts in a very light grey dolomite grainstone matrix. These two layers are underlain and separated by laminated rhythmite, i.e. thin, deep-water turbidites.



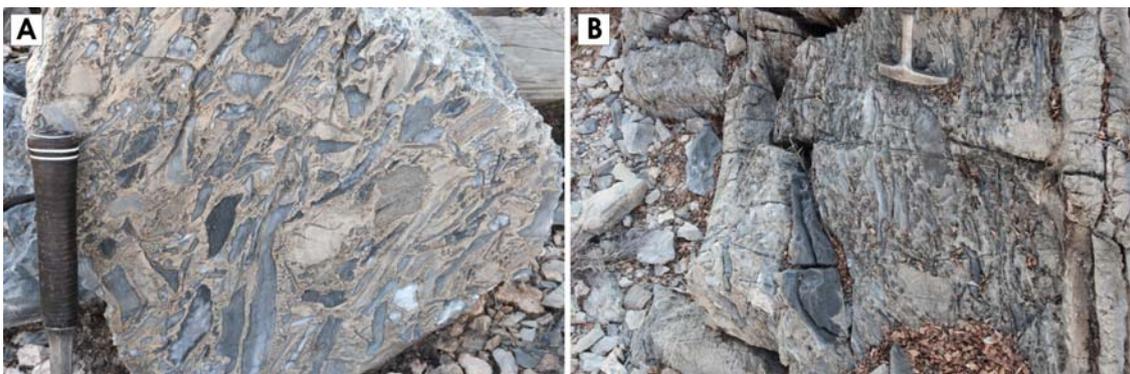
**Figure 2.22.** Mass-flow layers: **(A)** Platy clasts of grey to whitish limestone orientated parallel to bedding and set in a very light grey dolomite grainstone matrix. Mass flows are separated by laminated layers of limestone or dolomite: 1 - Graded limestone turbidite with a very thin capping of positively weathering pelagic dolomite; 2 - Turbiditic and pelagic dolomite; 3 - as for 1. **(B)** Close up view of a mass-flow layer with platy clasts of grey to whitish limestone orientated parallel to bedding and set in a very light grey-brown, positively weathering dolomite grainstone matrix.



**Figure 2.23.** Mass-flow layers: **(A)** Close up view of a thin mass-flow layer in which individual larger and smaller, bedding-parallel platy limestone clasts are readily distinguishable in the very light grey dolomite grainstone matrix. **(B)** Two mass-flow layers with an imbrication-like orientation of the limestone clasts. Both orientations may be primary depositional features; the tectonic foliation is not apparent in the rock.



**Figure 2.24.** Layers with limestone nodules: **(A)** Thin layers of grey limestone nodules set in a light grey dolomite matrix; **(B)** As for A but plan view of a bedding plane surface displaying the shape of the limestone nodules.



**Figure 2.25.** Uppermost, 7 m-thick mass flow just below the top 3m of the Karibib Fm. Blocky and platy angular clasts of grey limestone are set in a grainstone matrix of very light grey dolomite. A few almost white dolomite clasts. **(A)** View onto a surface subparallel to bedding give the impression of being undeformed; **(B)** View of the bedding of the same layer shows that there is a rather strong bedding-parallel orientation of clasts and foliation in the matrix.

Locality 2.40 (UTM 33k0545592, 7752345): Chuos Formation, farm Landeck 77. Copper prospect on western Landeck. In Chuos Fm, same graphitic phyllite and speckled volcanic rock as at locality 2.30. Bedding tightly undulating about horizontal,

ferruginous gossan composed mainly of ramifying veins of limonite after pyrite with some malachite, chrysocolla and rare azurite (Fig. 2.26). Gossan appears to be largely horizontal.



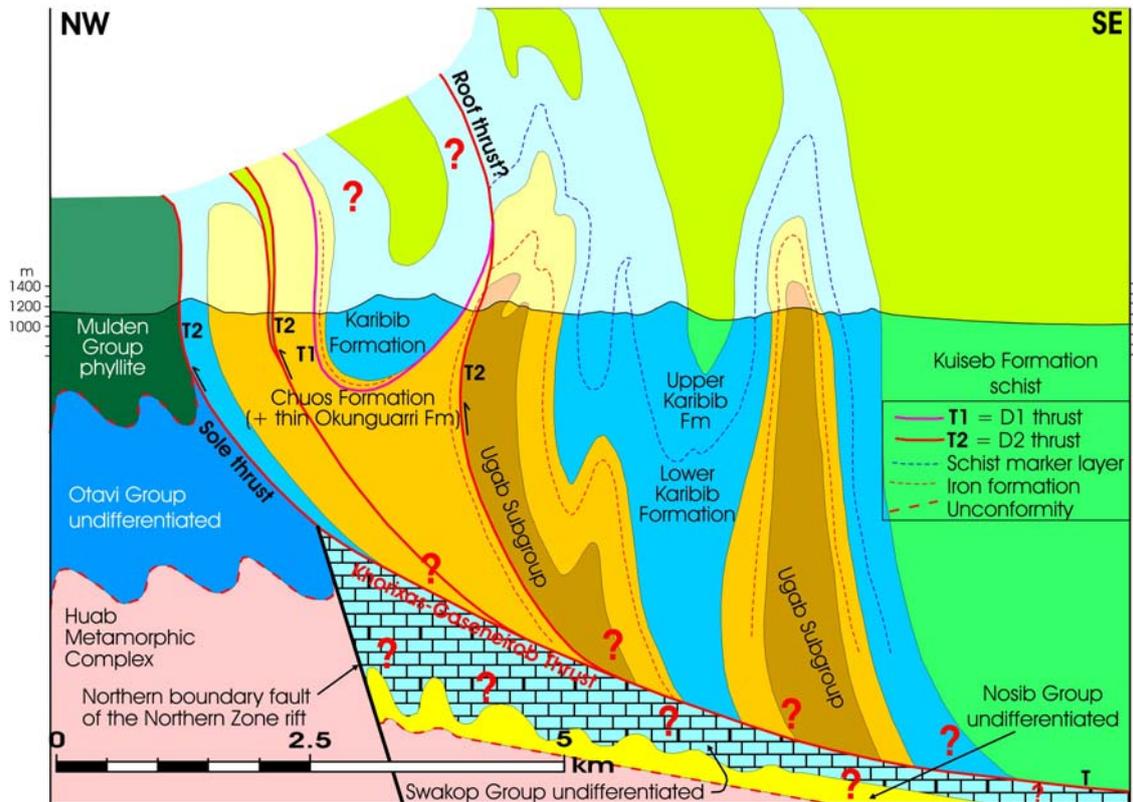
**Figure 2.26.** Malachite and chrysocolla associated with veins of limonite after pyrite in the Chuos Formation on the western part of Landeck 77.

Locality 2.41 (UTM 33k0545487, 7752143): Top of Saturn Fm. Thin to very thin layers of brown dolomite interbedded with layers of schist of similar thickness

(Fig. 2.27). Very similar to the top of the Ugab Subgroup on the eastern edge of the Summas Mountains near the spring at the northern edge of the farm Löwenfontein.



**Figure 2.27.** Thin interbedded layers of brown dolomitic grainstone and schist at the top of the Saturn Fm.



**Figure 2.28.** Section along the southern part of Traverse 2S incorporating modified stratigraphic and structural data from Clifford (2008).

**Traverse 3N; farms Hillendale 238, Gelukspoort, 349, Mooilaagte 322**

**Stratigraphy**

The base of the Otavi Group occurs on the southern edge of the farm Hillendale 238. Most of the guest farm Gelukspoort 358 is underlain by rocks of the Otavi Group. The top of the Otavi Group occurs just south of the southern border of Gelukspoort on the farm Mooilaagte 322. Here the Otavi Group is overlain unconformably by the post-D1 - pre-D2 molasse of the Mulden Group.

The basal part of the Fransfontein Ridge is composed of rocks of the Berg Aukas Formation, the cap carbonate to the Chuos Formation. Along strike from this locality are minor occurrences of the Chuos

Formation (Miller & Grote, 1988; Miller, 2008). The Ghaub Formation also occurs along strike to the east and west but is absent at the traverse locality (erroneously marked as Chuos by Miller & Grote, 1988). Above the Ghaub, the three formations of the Tsumeb Subgroup are present.

The Mulden Group lies unconformably on, and has cut into, the top of the Hüttenberg Formation.

There is a ridge of silicified breccia of uncertain age as well as red, breccia- and sand-filled and silicified dolines of Kalahari age.

## Sedimentology

The Berg Aukas Formation consists of laminated grey dolomite with thin slump breccias near the base.

The Maieberg Formation consists of very light grey to off-white, massive to thickly bedded limestone. The thick Elandshoek Formation consists mainly of very light grey to off-white, massive dolomite in which bedding or laminae are rarely present. A few mass-flow and oolite layers are present. Near the base of the formation are a few stromatolites but these become much more abundant in the upper quarter of the formation. Oolites and stromatolites indicate shallow-water depos-

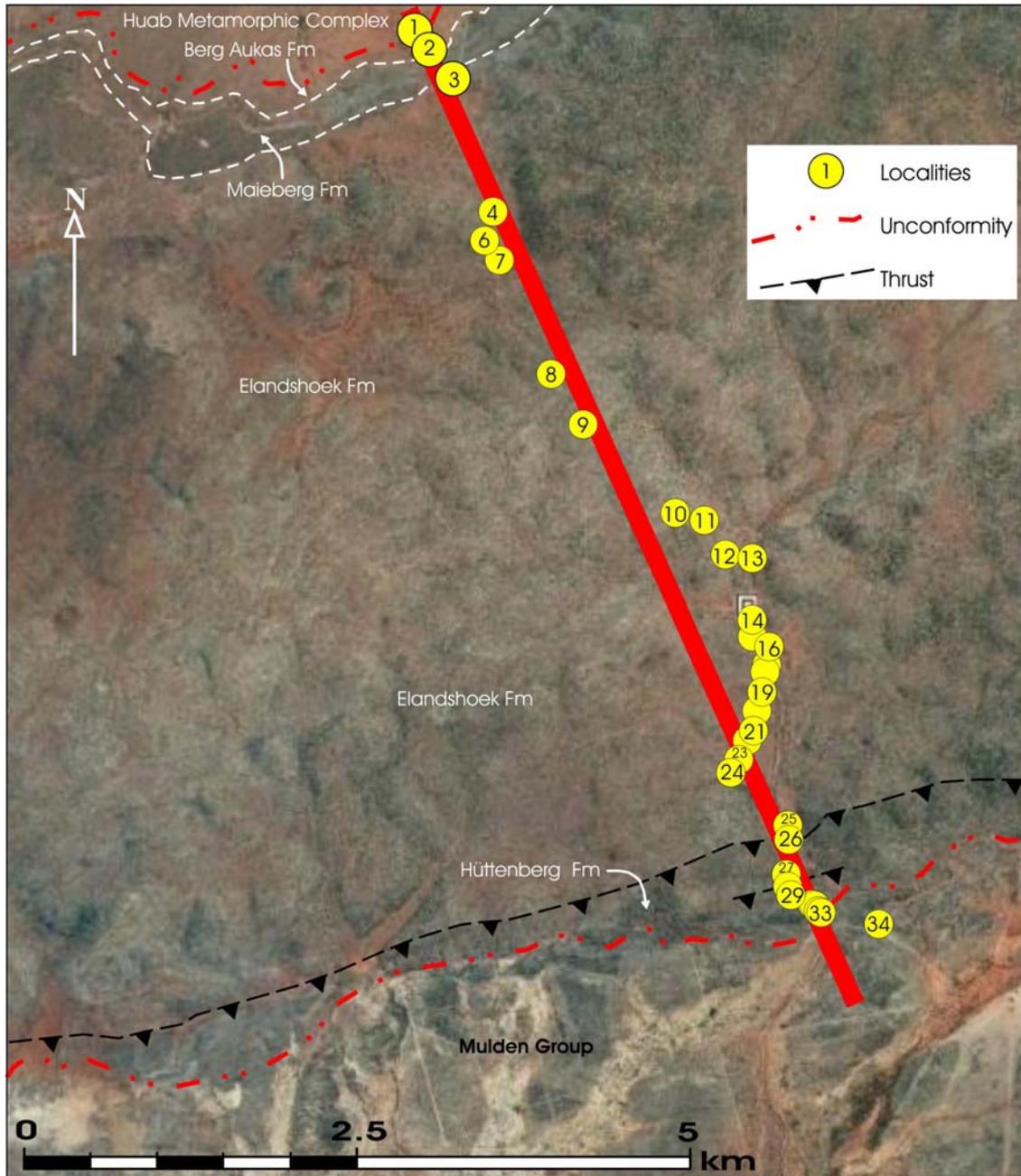
ition. Some stromatolites and oolite layers are foetid. White jaspilite silicification with some of pink to red colour in places, occurs throughout the formation but is most common in the lower half. This silicification seems to be early diagenetic since jaspilite fragments occur in some of the upper mass-flow layers. The Hüttenberg Formations starts with rhythmites suggesting a marked change in water depth. Slumping is evident in the formation. The top of the Hüttenberg is a mass flow with large fragments of dark grey limestone.

The Mulden Group consists of phyllites.

## Structure

In contrast to Travers 2N, the whole Fransfontein Ridge succession in this traverse is steeply inclined to the south. The contact between the Elandshoek and Hüttenberg Formations is 3 m above a D2 thrust. For several metres below the thrust the stromatolite domes are flattened parallel to bedding. All are orientated updip suggesting northward transport of the thrust in the direction 340° (magnetic). Above the

thrust, axes of minor F2 folds are orientated down dip. The I2 stretching lineation parallels these axes, both suggestive of sheath folding associated with the thrust in the direction 360° (magnetic). A second thrust fault occurs half way up in the Hüttenberg Formation. Some bedding-parallel chert layers are boudinaged. The overlying Mulden phyllites have a vertical foliation.



**Figure 3.1.** Google map of the localities on Traverse 3N. Location of section line of Figure 3.11 also shown (thick red line).

Locality 1 (UTM 33k0570476, 7775853): The basal 2.5 km of the succession is vertical to very steeply southerly dipping. Berg Aukas Formation: about 500 m thick, consists of laminated grey dolomite of the cap dolostone to the Chuos Formation. This forms the base of the

sequence. Thin layers of slump breccia occur near the base of the formation. The other Abenab Subgroup formations are missing.

Locality 2 (UTM 33k0570366, 7775753): Maieberg Formation: Very light grey to almost white, massive to thickly

bedded limestone. Basal tan-coloured Keilberg Member is missing. The Maieberg Formation is about 1 km thick.

Locality 3 (UTM 33k0570241, 7775592): The Maieberg is overlain by the very light grey to whitish dolomites of the Elandshoek Formation.

Locality 4 (UTM 33k0570084, 7774496): Northern border of Gelukspoor 358. Massive, almost unbedded very light grey to whitish dolomite of the Elandshoek Fm with a few scattered stromatolites in places. Abundant, very coarse filigree-like

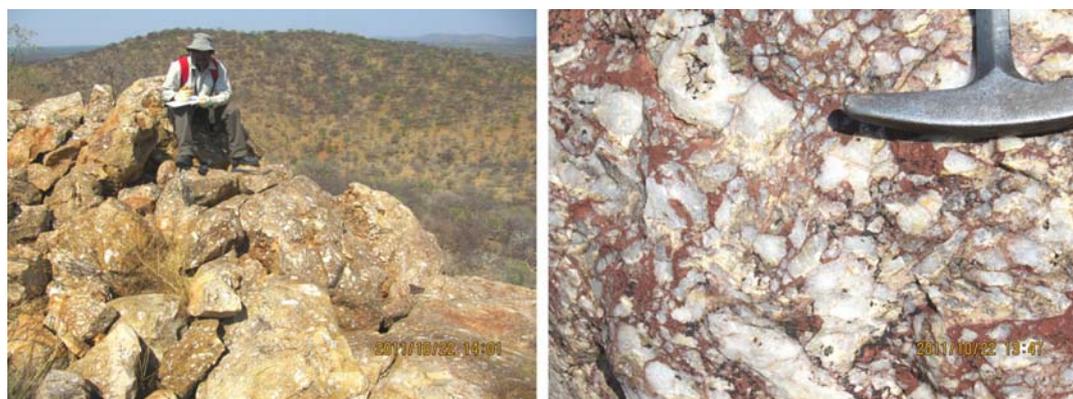
white jaspilite silicification that is typical of the Elandshoek Fm (Fig. 3.2A) (Jaspilite - a term used by TCL for silica that is too coarse grained to be called chert and too fine grained to be called quartz). Faint lamination in places, dip 88/65, i.e. beds slightly overturned. Many silicification stringers are parallel or subparallel to the lamination (Fig. 9.2B). Some of the ramifying jaspilite veins appear to enclose fragments of a hydraulic breccia (i.e. no disorientation of fragments) but they may also simply be filling ramifying fractures.



**Figure 3.2.** Silicification in the Elandshoek Formation. (A) Irregular bodies of massive silicification, some with a very coarse filigree-like texture. (B) Silicification stringers parallel to steeply dipping bedding lamination. Note the stromatolite beneath the hammer handle.

Locality 5 (UTM 33k0569944, 7774314): Northern Gelukspoor 358. Large elongate, hard, weather-resistant, ridge-forming body of brecciated white jaspilite

cemented by red, yellow, pink and white jaspilite (Fig. 3.3). Samples of red and yellow parts for analysis. Breccia is about 600 m long and subparallel to bedding.



**Figure 3.3.** Photographs of ridge-forming body of brecciated white jaspilite fragments cemented by red and yellow jaspilite.

Locality 6 (UTM 33k0570026, 7774269): Northern Gelukspoor 358. Bedding-parallel breccia with abundant highly ferruginous calcite.

Locality 7 (UTM 33k0570157, 7774141): Northern Gelukspoor 358. Doline 5 x 10 m in diameter in Elandshoek dolomite. Filled with red, highly silicified Kalahari sand with patches of red jasper. Patches of manganese wad or pyrolusite (?) around the edges of the doline. Veins of the red silicified Kalahari sand radiate into the dolomite away from the doline.

Locality 8 (UTM 33k0570534, 7773278): Northern Gelukspoor 358.

Vertical lamination, strike 58°. White jaspilite still present but less abundant than lower down in the stratigraphy.

Locality 9 (UTM 33k05707065, 7772900): Northern Gelukspoor 358. Elandshoek Fm, several bedding-parallel jaspilite bands, bedding 58-85/160, i.e. undulating southerly dip.

Locality 10 (UTM 33k0571489, 7772203): Northern Gelukspoor 358. Narrow, intermittent, bedding-parallel zone of red jasper veining in the Elandshoek Fm, possibly breccia cementing (Fig. 3.4).



**Figure 3.4.** Bedding-parallel zone of red jasper veining in the Elandshoek Formation.

Locality 11 (UTM 33k0571657, 7772153): Northern Gelukspoor 358. The Rooikop. 100 m-diameter area of intense veining of the Elandshoek dolomite by red jasper, layered in places by variably intense silicification. Probably of Kalahari age.

Locality 12 (UTM 33k0571818, 7771888): Gelukspoor 358. Same dolomite and red jasper veining.

Locality 13 (UTM 33k0572034, 7771885): Gelukspoor 358. Red jasper veining of dolomite in hillsides to east and west of this locality.

Locality 14 (UTM 33k0572066, 7771348): Gelukspoor 358. Bedding in

Elandshoek dolomite 65/136. A few broad domal stromatolites in this area.

Locality 15 (UTM 33k0572012, 7771200): Gelukspoor 358. Elandshoek Fm. A 1 metre thick grainstone made up of carbonate oolites and pisolites, each individually enclosed in a thin coating of silica.

Locality 16 (UTM 33k0572122, 7770995): Gelukspoor 358. Elandshoek. Some slightly foetid stromatolites.

Locality 17 (UTM 33k0572106, 7770968): Gelukspoor 358. Elandshoek but with less white jaspilite than usual, bedding 80/180. Layer of silicified oolites (Fig. 3.5); also foetid.



**Figure 3.5.** Layer of foetid silicified oolites near the top of the Elandshoek Fm, carbonate oolites weathered out of a silica cement that has replaced the original matrix to the oolites.

Locality 18 (UTM 33k0572089, 7770856): Gelukspoor 358. 60 cm-thick mass flow in Elandshoek Fm, fragments mostly Elandshoek dolomite but also some fragments of white jaspilite, i.e. jaspilite silicification was syndepositional to early diagenesis and took place during continued Elandshoek deposition. Several zones or patchy occurrences of variously silicified oolites between this and the last locality.

Locality 19 (UTM 33k0572038, 7770601): Gelukspoor 358. Massive Elandshoek dolomite is medium grey on weathered surfaces but is still very light grey

to whitish on fresh surfaces, not foetid. Some white jaspilite still present. Clear bedding planes rare.

Locality 20 (UTM 33k0571736, 77710401): Gelukspoor 358. E-W elongate doline in very light grey Elandshoek dolomite, 40 x 70 m in diameter and filled with red, highly silicified Kalahari sandstone and siltstone. Bedding dip in the dolomite 70/174. Some stromatolites in the dolomite.

Locality 21 (UTM 33k0571734, 77710344): Southern Gelukspoor 358. Stacked stromatolites in Elandshoek dolomite (Fig. 3.6). Dolomite foetid.



**Figure 3.6.** Stromatolite near the top of the Elandshoek Fm, near southern border of farm Gelukspoor 358.

Locality 22 (UTM 33k0571848, 7770248): Southern Gelukspoor 358. Stromatolites fairly numerous between this and Locality 26. Occasional layer of grey to dark grey dolomite that is very light grey when fresh.

Locality 23 (UTM 33k0572271, 7769835): Southern Gelukspoor 358. Elandshoek Fm. Layers of silicified oolites; some very slightly foetid stromatolites. Brown silicification of some layers. Bedding 43/184.

Locality 24 (UTM 33k0572293, 7769727): Southern Gelukspoor 358. Elandshoek Fm, very light grey to whitish on fresh surfaces but light grey on

weathered surfaces. Some white jaspilite. Silicification often in thin laminae and often defining the laminae in numerous stromatolites. 15 m-wide zone of strongly transposed stromatolites. These initially formed upright, parallel columns but at this locality are all bent parallel to bedding which dips 70/160 (Fig. 3.7). Transport direction seems to be approximately up dip. Oolites occur between the stromatolite columns; slightly foetid. Above this 15 m-wide zone there are fewer stromatolites but they are all deformed in the same way. Between the layers containing stromatolites there are some lensoid layers with sugary silicification but no obvious oolites.



**Figure 3.7.** Part of a 15 m-wide zone of strongly transposed silicified stromatolites so that they are all orientated parallel to bedding which dips 70/160.

Locality 25 (UTM 33k0572325, 7769523): Southern Gelukspoor 358. Approaching the top of the Elandshoek Fm, very light grey to whitish on fresh surfaces but light grey on weathered surfaces. Abundant unsilicified oolitic grainstones, bedding 54/175. Veins of white jaspilite.

Locality 26 (UTM 33k0572326, 7769472): Southern Gelukspoor 358. Top of Elandshoek Fm and base of Hüttenberg Fm. 4 m-wide shear zone which may be a thrust (Figs. 3.8, 3.11). Overlain by 3m of very light grey Elandshoek dolomite with some cross-cutting veins of white jaspilite. The base of the Hüttenberg Fm consists of

15 m of limestone rhythmite. The rhythmite consists of graded laminae of turbiditic limestone and thinner, finer-grained laminae of pelagic dolomite. This is the first zone of continuous well-developed bedding encountered since starting at the base of the Elandshoek Fm and appears to mark a sharp change from shallow-water upper Elandshoek Fm deposition to deep-water Hüttenberg deposition. Bedding 40/164. There are two rhythmite zones separated and overlain by massive, light grey dolomite which is white with faint pink patches on the fresh surface.



**Figure 3.8.** Strong foliation in a 4 m-wide shear zone within 3 m of the top of the Elandshoek Fm.

Locality 27 (UTM 33k0572313, 7769343): A 40 m-thick mass flow with angular fragments of very fine-grained dark grey dolomite set in a rather abundant matrix cement of white sparry calcite (Fig. 3.9). This mass flow may be the result of

very passive, short-distance slumping because there are parts in it with scarcely any disruption but these also contain a few patches of the sparry calcite. This scarcely broken zone is interlayered with more broken zones with much sparry calcite.



**Figure 3.9.** Mass flow or slumped layer consisting of angular fragments of dark grey dolomite cemented by sparry calcite cement.

Locality 28 (UTM 33k0572349, 7769321): Shear zone with lozenge-shaped fragments of dark grey dolomite with chert veins and various internal textures (Fig.

3.10A). Black to dark grey, bedding-parallel chert layers in the grey dolomite above the shear zone, typical of the Hüttenberg Fm (Fig.3.10B). Bedding 51/175.



**Figure 3.10.** Hüttenberg Formation: **(A)** Shear zone with lozenge-shaped fragments of dark grey dolomite with various internal textures and chert veins. **(B)** Grey, bedded Hüttenberg dolomite with boudinaged, bedding-parallel lenses of dark grey to black chert.

Locality 29 (UTM 33k0572457, 7769257): Hüttenberg Formation. Minor folds in Hüttenberg. Bedding 52/165, axial plane of minor fold 75/156, stretching lineation parallel to minor fold axis - plunge 53° in direction 180°.

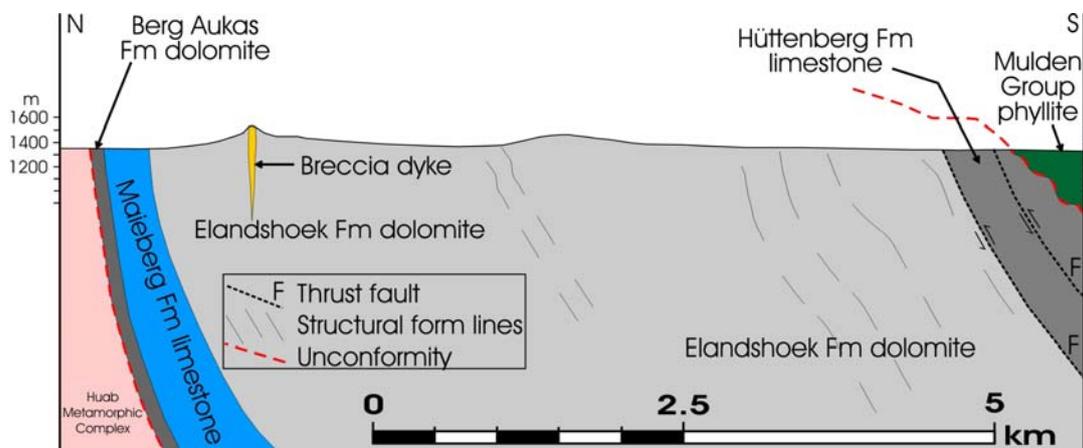
Locality 30 (UTM 33k0572475, 7769252): Hüttenberg Formation. Eight stacked, thinly to very thinly bedded limestone turbidites, very light grey on the weathered surface but dark grey on fresh surfaces. Rest of the outcrop massive or with rare bedding planes or laminations.

Locality 31 (UTM 33k0572509, 7769197): Hüttenberg Formation. Top 10 m of the Hüttenberg Fm is a mass flow containing fragments of dark grey limestone.

Locality 32 (UTM 33k0572536, 7769179): Hüttenberg Formation. End of Hüttenberg outcrop. Base of Mulden Group on Hüttenberg. Mulden covered and not exposed. Farm Mooilaagte 322.

Locality 33 (UTM 33k0572974, 7769103): Mulden Group, farm Mooilaagte 322. Weathered Mulden phyllite, some layers tan coloured, others silvery grey, some dark grey to black. Phyllite - vertical, strike 82°.

Locality 34 (UTM 33k0538026, 7767981): Mulden Group. At farm house on Mooilaagte 322. Very dark grey Mulden phyllite, carbonaceous?



**Figure 3.11.** Section along Traverse 3N.

**Traverse 3SW; farms Mooilaagte 322, Tsuwandas 107**  
**Traverse 3SE; farms Mooilaagte 322, Tsuwandas 107, Zuwitsaub 108 and Steineck 109**

### **Stratigraphy**

The Khorixas-Gaseneiob Thrust is the boundary between contrasting stratigraphies, Otavi, Mulden and Swakop Groups on the northern side and only Swakop Group on the southern side. At the northern end of both traverses Mulden Group phyllites unconformably overlie the top unit of the Tsumeb Subgroup, the Hüttenberg Formation, of the Fransfontein Ridge. But the Mulden Group is also overlain by a thrust sheet, the Mooilaagte Nappe consisting of the full, 3-formation Tsumeb Subgroup succession. This nappe is tectonically overlain by the Wolffsgrund Nappe consisting of the Chuos and Karibib Formations of the Swakop Group.

### **Sedimentology**

The reader is referred to Traverse 3N for an indication of the sedimentology of the Otavi Group rocks in the Mooilaagte Nappe but this is a deeper water facies of that on the Fransfontein Ridge and the sedimentology needs to be mapped in detail. Limestones and dolomites of the Maieberg Formation are overlain by dolomites of the Elandshoek Formation, the latter being overlain by limestone and dolomite of the Hüttenberg Formation.

Iron formation float indicates the presence of this ferruginous layer in the Chuos Formation around the base of the Snake Head Mountain. Best exposures of the Chuos are in the Snake Head Mountain where it is massive but zones of different

### **Structure**

Two stages of nappe development took place. First the intensely deformed Wolffsgrund Nappe was thrust northwards onto the deep-water facies of the Tsumeb Subgroup, either during D1 or early D2. Then the deep-water Tsumeb Subgroup

The Swakop Group south of the Khorixas-Gaseneiob Thrust consists of the Chuos, Karibib and Kuiseb Formations. The Chuos Formation is poorly exposed on Tsuwandas and the Kuiseb Formation is not exposed at all. Drilling and float in the calcrete indicate that the Karibib Formation is not as extensive as shown on Clifford's (2008) map and the cores of the southern anticlines have more Chuos than he shows (F. Bockmühl, farm owner of Tsuwandas, pers. comm., 2011). For clarification of the structure and the sections, the traverse is divided into southwestern (3SW - Fig. 3.15) and southeastern parts (3SE - Fig. 3.16).

sized clasts of granite and gneiss suggest a crude layering.

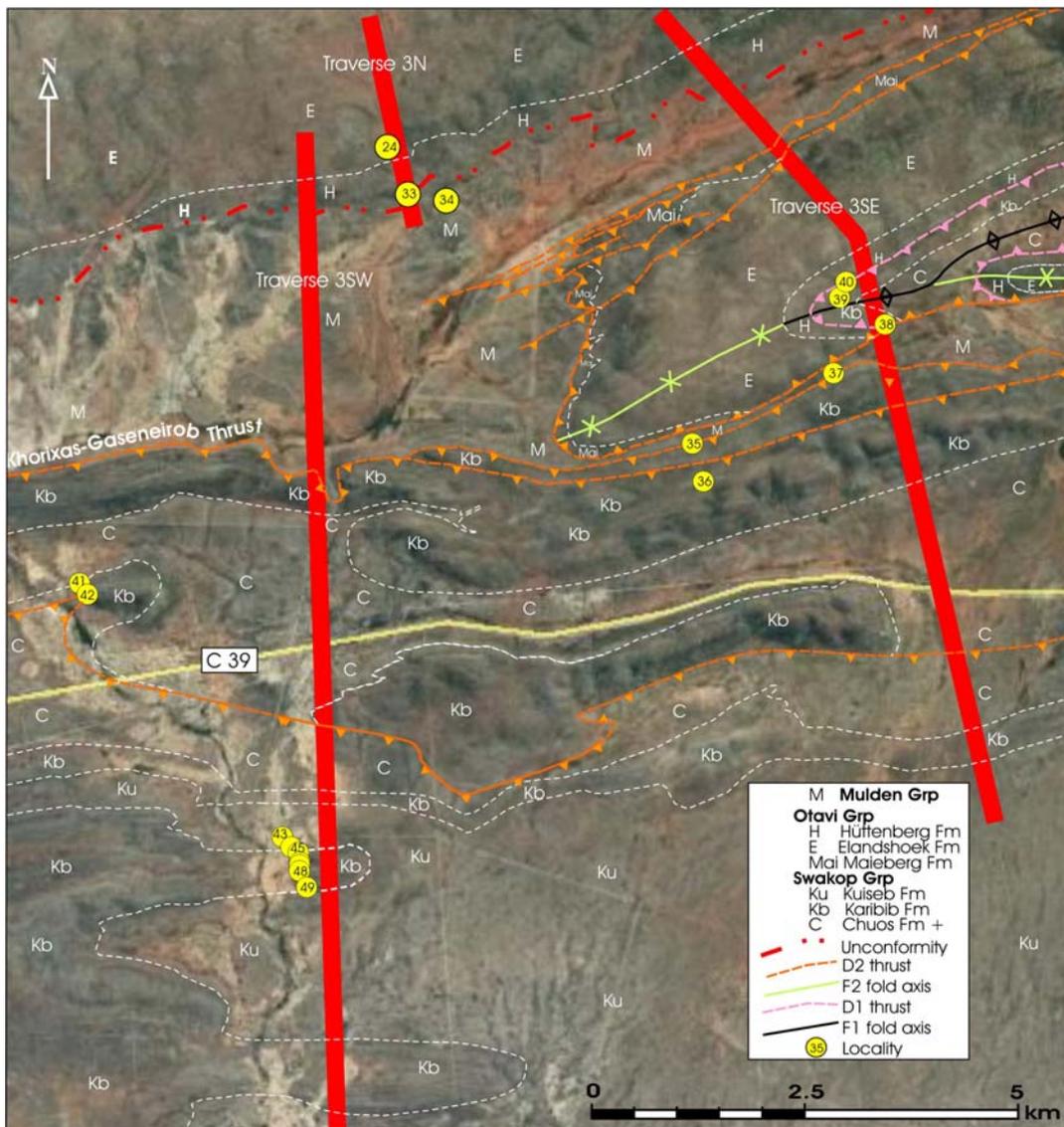
Two facies of the Karibib Formation occur as in the Landeck area of Traverse 2S. The facies north of the roof thrust (Fig. 3.15) is thickly bedded to massive and lacks sedimentary features except for thin ribbonites at the top and bottom of the formation in the Snake Head Mountain. The southern facies is thinly to thickly bedded with zones of ribbonite and many mass-flow layers. As with the Landeck area, the sedimentology of the Karibib Formation needs to be mapped in detail. It may be possible to map out the lateral extent of individual mass-flow lobes.

facies with its piggy-back of the Wolffsgrund Nappe was thrust during late D2 onto the Mulden Group phyllites during northward thrusting along the Khorixas-Gaseneiob Thrust. The Otavi Group rocks in the D2 Mooilaagte Nappe are far less

deformed than those of the overlying Swakop Group rocks in the Wolffsgrund Nappe. Nevertheless, their structures need mapping, particularly the segmented northern edge of the Mooilaagte Nappe which may be a series of sheath folds that could reveal the transport direction of the nappe.

The Swakop Group rocks are intensely deformed in the D2 structures further south. Except in tight D2 fold

closures, there is an intense vertical bedding-parallel foliation in the Karibib marbles which tends to obscure detail in thinly bedded ribbonites and stretches out clasts in the mass-flow layers. Close to the Khorixas-Gaseneiob Thrust, the stretching lineation plunges down the dip direction of the foliation, i.e.  $150^\circ$ , which suggests a thrust transport direction of  $330^\circ$ . The area requires detailed structural mapping.



**Figure 3.12.** Google image of the region covered by Traverses 3SW and 3SE, farms Killarney 369, Tsuwandas 107, Mooilaagte 322, Zuwitsaub 108 and Steineck 109. The lines of the sections in Figures 3.15 and 3.16 are also shown (red lines). Stratigraphy and structure modified from Clifford (2008).

Locality 35 (UTM 33k0575878, 7766209): Karibib Fm, farm Mooilaagte 322. Intensely foliated, medium grey Karibib limestone, foliation dip 65/170. This locality just above the Khorixas-Gaseneirob Thrust which dips parallel to the foliation. The Karibib limestone is intensely foliated for the entire distance between this and the next locality.

Locality 36 (UTM 33k0575997, 7765770): Karibib Fm, farm Mooilaagte 322. Intensely foliated Karibib limestone, foliation dip 65/180, poorly developed stretching lineation plunge 57° in direction 150°. Rare very thin layers of parallel laminations that may be rhythmites.

Locality 37 (UTM 33k0577541, 7767037 (39) - Karibib Fm, farm Mooilaagte 322. Intensely foliated siliceous Karibib marble just above Khorixas-Gaseneirob Thrust where Karibib Fm thrust over Mulden phyllites. Foliation dip 80/146, plunge of stretching lineation on the foliation 75° in direction 150°, i.e. stretching lineation almost exactly down dip.

Locality 38 (UTM 33k0578131, 7767647): Karibib Fm, farm Mooilaagte 322. Intensely foliated Karibib Fm limestone. Foliation dip 83/160.

Locality 39 (UTM 33k0577605, 7767990): Karibib Fm, farm Mooilaagte 322. Intensely foliated Karibib Fm limestone. Foliation vertical, strike 90°. The Chuos Fm with tillite containing granite clasts occurs below the Karibib marble between localities 38 and 40. The Chuos and the Karibib marble between localities 38 and 40 form a D1 anticline that was tightened during D2 overthrusting. A very narrow strip of Karibib Fm(?) phyllites separates this locality from locality 40.

Locality 40 (UTM 33k0577660, 7768125): Hüttenberg Fm, farm Mooilaagte 322. Topmost layer of Hüttenberg. Chaotic mass flow with clasts of grey limestone, grey chert and silicified oolite and pisolite. Not strongly foliated. This layer forms the top of the Hüttenberg Fm and is the same mass flow layer that occurs at the top of the Hüttenberg Fm on the Fransfontein Ridge

and at the equivalent stratigraphic level at the top of the Karibib Fm on the southern part of Landeck 77 (Fig. 2.25).

A D1 thrust separates localities 39 and 40; i.e. the Karibib/Chuos succession has been thrust over the underlying Otavi rocks forming the Wolffsgrund Nappe. D2 then thrust the Otavi rocks of the Mooilaagte Nappe with its Wolffsgrund Nappe piggy-back northwards onto the Mulden phyllites. Further D2 compression folded the D1 thrust, tightened the Karibib/Chuos D1 anticline and formed the Otavi syncline underneath.

Locality 41 (UTM 33k0568699, 7764525): Karibib and Chuos formations, farm Tsuwandas 107, Snake Head Mountain. Chuos Fm tillite with numerous pebbles and boulders of granite and gneiss. 5 m of rhythmite form the basal 5 m of the Karibib Fm. Above this the formation is thickly bedded to massive with no sedimentary structures.

Locality 42 (UTM 33k0568784, 7764437): Top of Snake Head Mountain. There may be thin ribbonites in the Karibib Fm at this locality

Farm Tsuwandas 107 south of the main tar road. Only Chuos, Karibib and Kuiseb formations present, extensive parts of the Karibib Fm are covered by calcrete. The Chuos and Kuiseb formations are covered by calcrete or soil, but iron formation float and occasional thin bands of carbonate that stick up through the calcrete help to delineate the Chuos Fm. Water boreholes indicate that the Chuos Fm is more extensive than shown by Clifford (2008) on the southern part of the farm where it is largely covered by calcrete.

Locality 43 (UTM 33k0571206, 7761392): Karibib Fm, farm Tsuwandas 107. Thinly to thickly bedded Karibib Fm dolomite, extensive karsting along joints. No sedimentary structures. Bedding dip 28/275.

Locality 44 (UTM 33k0571247, 7761346): Karibib Fm, farm Tsuwandas 107. Rapid change in dip to 86/184. Strongly developed bedding-parallel foliation.

Locality 45 (UTM 33k0571268, 7761298): Karibib Fm, farm Tsuwandas 107. Thinly bedded Karibib Fm limestone with very thin mass-flow layers 0.5 to 4 cm thick consisting of tabular, dark grey limestone clasts set in a light grey matrix of dolomite grainstone. (Identical to the very thin mass flow layers seen on the southern

part of Landeck). There is a strong bedding-parallel cleavage and clasts in mass-flow layers are drawn out in the foliation. Bedding dip vertical, strike 90°. A few metres further up in the succession are more mass-flow layers up to 3 m thick containing a variety of clasts, all of which are strongly drawn out in the foliation (Fig. 3.13).



**Figure 3.13.** Mass flow near the top of the Karibib Formation on the southern part of farm Tsuwandas 107. Note intense flattening of clasts in the bedding-parallel foliation.

Locality 46 (UTM 33k0571277, 7761125): Karibib Fm, farm Tsuwandas 107. 3 m-thick mass flow. Bedding vertical, strike 90°.

Locality 47 (UTM 33k0571287, 7761159): Karibib Fm, farm Tsuwandas 107. Vertical isoclinal folds near the top of

the Karibib Formation limestone (Fig. 3.14). Fold axes strike 90°.

Locality 48 (UTM 33k0571276, 7761100): Karibib Fm, farm Tsuwandas 107. Layers of single oolites in thinly bedded Karibib limestone; oolites probably emplaced by mass flow. Bedding vertical, strike 90°.



**Figure 3.14.** Vertical isoclinal folds near the top of the Karibib Formation limestone. Southern part of farm Tsuwandas 107.

Locality 49 (UTM 33k0571354, 7760958): Karibib Fm, farm Tsuwandas 107. Top of Karibib Fm and end of outcrop. Karibib is here overlain by the Kuiseb Fm

but this is covered by calcrete. A few thin bands of carbonate up to 40 cm wide poke up through the calcrete.

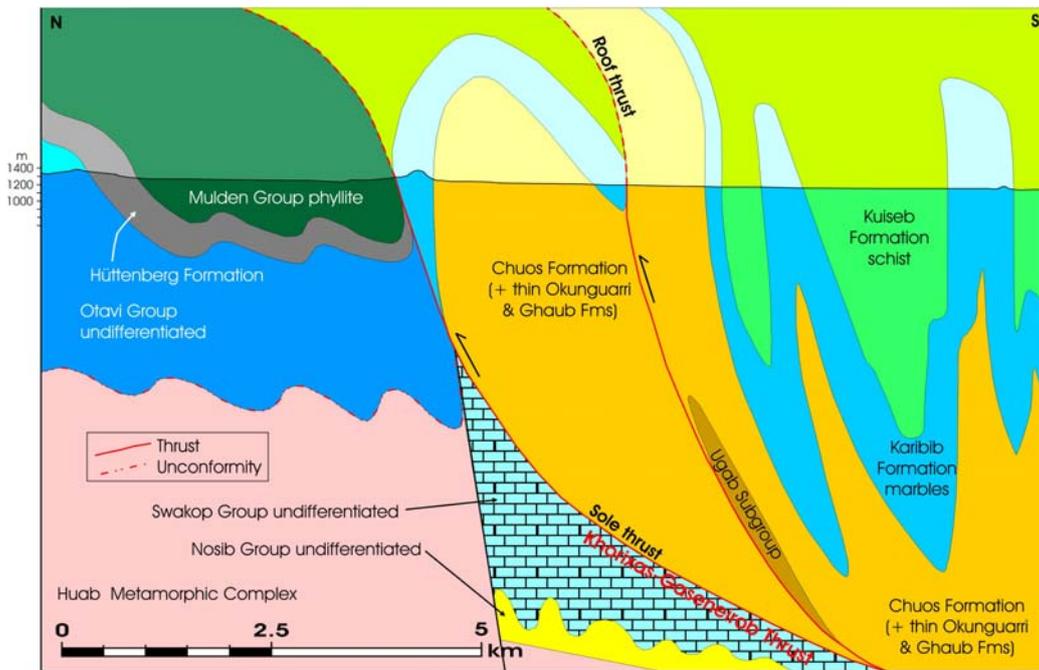


Figure 3.15. Geological section for Traverse 3SW showing D2 structures.

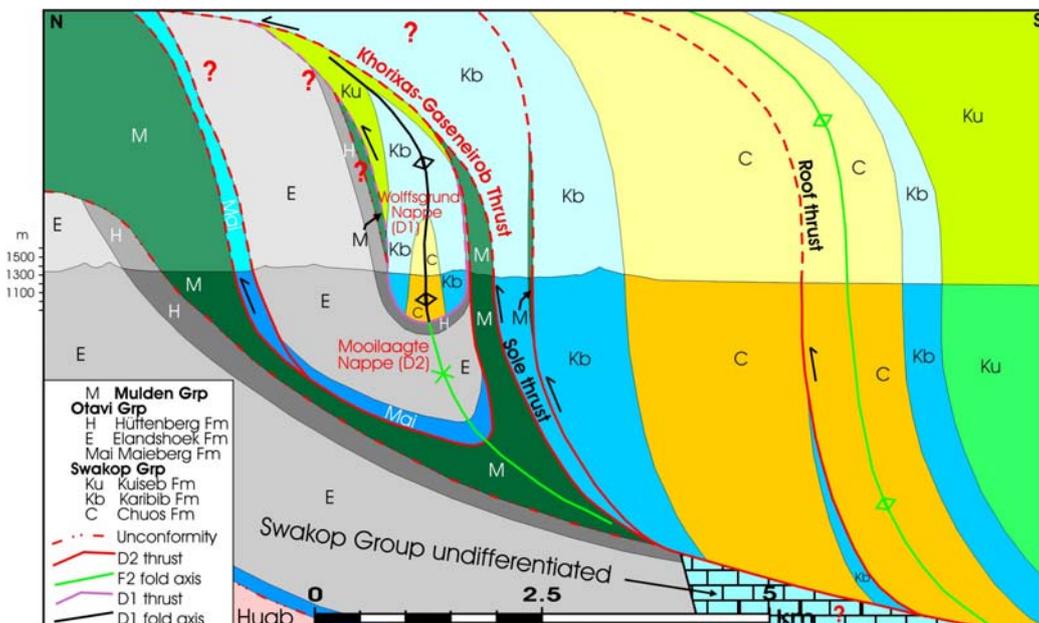


Figure 3.16. Geological section for Traverse 3SE showing D1 and D2 structures.

#### **Traverse 4; farms Bergveld 239, Belina 132 and Straussenheim 134.**

This traverse starts at the base of the Otavi Group succession in the eastern Fransfontein Ridge, continues up through the Otavi rocks and crosses the calcrete and soil-covered valley underlain by the Mulden Group. South of the Mulden the traverse crosses the Khorixas-Gaseneiob Thrust into rocks of the Swakop Group. The rocks of the Fransfontein Ridge were mapped by Tsumeb Corporation geologists and their subdivision of the stratigraphy has been used for the 1:500 000 Geological Map of the

Damara Orogen (Miller & Grote, 1988). Of the Abenab Subgroup rocks in this traverse, only the Gauss Formation is represented. There is no Berg Aukas Formation and no Auros Formation. The Swakop Group rocks have been thrust over the Mulden Group along the Khorixas-Gaseneiob Thrust and occur to the south of this thrust. Exposures are generally poor on Staussenheim 134 south of the northernmost ridge of Karibib Formation marble. The location of the traverse is shown in Figure 4.1.

#### **Stratigraphy**

On the Fransfontein Ridge, the Gauss Formation of the Abenab Subgroup is overlain by the Ghaub Formation of the Tsumeb Subgroup followed by the Maieberg, Elandshoek and Hüttenberg

formations. Unconformably above the latter are the phyllites of the Mulden Group.

South of the Khorixas-Gaseneiob Thrust the stratigraphy consists of the Saturn, Chuos and Karibib formations of the Swakop Subgroup.

#### **Sedimentology**

##### ***Otavi Group in the Fransfontein Ridge***

The lower part of the Gauss Formation is massive to faintly laminated, very light grey dolomite but the bulk of the formation consists of a slump breccia in which fragments are enclosed in rims of fibrous isopachous cement. The texture is identical to that of the Gauss Formation in the Otavi Mountainland.

The glaciogenic Ghaub Formation contains mainly carbonate clasts with some chert and some stromatolite clasts. The Maieberg Formation consists of limestone rhythmites. Above it, the Elandshoek Formation is made up of very light grey to whitish, massive dolomite with some white

jaspilite veining near the base and zones of laminated bedding and a mass-flow layer cemented by white jaspilite in the upper 300 m. The dolomite is foetid in places. The base of the Hüttenberg Formation consists of medium-grey, laminated to massive dolomite with white jaspilite veins and nodules and grey and black chert lenses. Several dolomite grainstone mass-flow layers with clasts of limestone, reef debris and white silicified oolites occur higher up. The upper 100 m of the Hüttenberg Formation consists of laminated rhythmites. Mulden phyllites lie unconformably on the Hüttenberg Formation.

##### ***Swakop Group south of Khorixas-Gaseneiob Thrust front***

The Saturn Formation consists of strongly foliated, pale grey dolomite. Above it, the only exposures of the Chuos Formation are thinly bedded to intensely foliated layers of grey dolomite, one of

which contains tremolite needles. An intense foliation in the Karibib Formation generally obscures sedimentary structures but locally thinly bedded rhythmites and grainstones are evident.

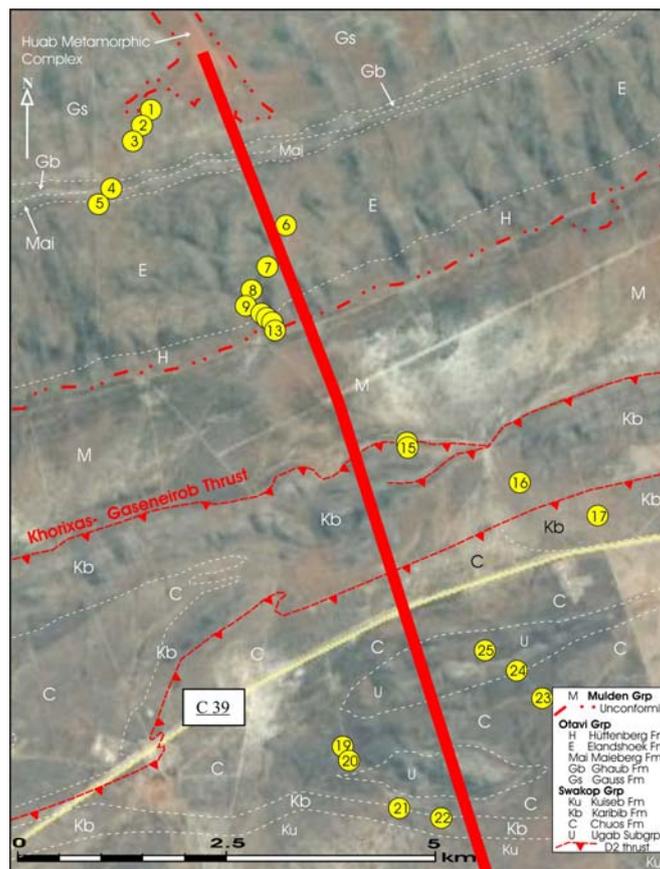
## Structure

The Fransfontein ridge has an undulating southerly dip of between 30° and 79°. There is a bedding-parallel shear zone at the top of the Ghaub Formation suggestive of a thrust. Small-scale, N-vergent isoclinal folds occur at the top of the Elandshoek Formation.

Up against the Khorixas-Gaseneirob Thrust, the Karibib Formation has an intense foliation that dips steeply south. East and west of the traverse line and eastwards almost to the C68, the main road to Etosha, Clifford (2008) records a layer of what he calls 'rib rock' (Figs. 4.6, 4.7) all along the Khorixas-Gaseneirob Thrust with short, parallel extensions in the Karibib marbles in places. The 'ribs' are ling, thin, rib-like

cleavage and fold mullions of chert layers that have been rotated into the transport direction by sheath folds that characterise the thrust. The orientation of the mullions indicates a 320° (magnetic) transport direction. The lateral extensions of the 'rib rock' into the marbles mark the locations of parallel thrusts. The Khorixas-Gaseneirob Thrust is the frontal or floor thrust of a stacked sequence of duplex thrusts, many of which may be along lithological contacts and have not been recognised (Fig. 4.8).

South of the thrust, the Saturn dolomites, much of the Karibib marble and dolomite layers in the Chuos Formation, are vertical and intensely foliated.



**Figure 4.1.** Google image of the region covered by Traverse 4, mainly farms Bergveld 239, Belina 132 and Straussenheim 134. The line of the section in Figure 4.8 is also shown (red line). Stratigraphy and structure modified slightly from Clifford (2008).

### ***Abenab Subgroup, Gauss Formation***

Locality 1 (UTM 33k0600297, 7776913): Basal Otavi Group, farm Bergveld 239. Near base of Otavi (base not exposed). Massive to faintly laminated, very light grey dolomite that weathers to medium or light grey. Difficult to determine bedding. Rare stromatolites.

Locality 2 (UTM 33k0600201, 7776663): Very light grey dolomite, bedding dip 54/196.

Locality 3 (UTM 33k0600091, 7776525): Very light grey dolomite, jointing that may be bedding or shearing, dip 79/170. Colloform texture, i.e. early diagenetic, sub sea floor, fibrous isopachous cement enclosed fragments of a slump breccia which constitutes the bulk of the formation. This is the typical texture of the Gauss Formation in the Otavi Mountainland. Dip of bedding just below the Ghaub Formation is 48/185.

### ***Tsumeb Subgroup, Ghaub Formation***

Locality 4 (UTM 33k0599827, 7775973): Ghaub Formation containing mainly carbonate clasts with some chert and some stromatolite clasts. Largest clast is 40 cm across but most are much smaller than this. The matrix of the top 10 m of the formation is sheared suggesting a possible thrust, foliation dip 47/185. The top half of

this shear zone has a pink matrix and contains mainly small clasts. The intensity of the foliation decreases downwards and the centre of the formation is unfoliated. True thickness of the formation is about 75 m. Overlain by Maieberg Fm, Keilberg Member missing.

### ***Tsumeb Subgroup, Maieberg Formation***

Locality 5 (UTM 33k0599691, 7775788): Maieberg Fm limestone rhythmites, medium grey on weathered surfaces, light grey when fresh, bedding dip

30/180. Nearby is a Kalahari doline filled with red, highly silicified Kalahari siltstones.

### ***Tsumeb Subgroup, Elandshoek Formation***

Locality 6 (UTM 33k0601941, 7775531): Elandshoek Fm, northwestern part of Belina 132. Very light grey to whitish, massive Elandshoek dolomite with some white jaspilite veining but not as abundant as on Traverse 3N. Dolomite slightly foetid in places.

Locality 7 (UTM 33k0601704, 7775007): Elandshoek Fm. Open fold in Elandshoek, bedding dip 20/240.

Locality 8 (UTM 33k0601520, 7774630): Elandshoek Fm. Bedding dip in Elandshoek 62/170.

Locality 9 (UTM 33k0601529, 7774522): Elandshoek Fm. 20 m thick mass flow of Elandshoek fragments in a white jaspilite cement - poor exposure.

Locality 10 (UTM 33k0601665, 7774481): Elandshoek Fm. Some laminations. Minor, tight, N-vergent isoclinal folds; bedding dip variable, average 72/145.

### ***Tsumeb Subgroup, Hüttenberg Formation***

Locality 11 (UTM 33k0601689, 7774431): Base Hüttenberg Fm. Medium

grey laminated to massive dolomite that weathers dark grey, white jaspilite veins and

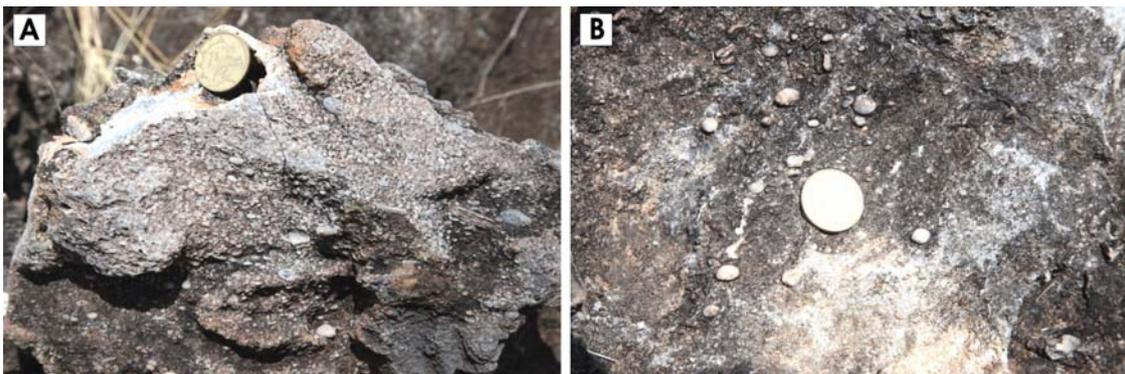
nodules. Local intense silicification of the laminations. Grey and black chert lenses. Two mass-flow layers a little higher in the stratigraphy.

Locality 12 (UTM 33k0601718, 7774321): Hüttenberg Fm. 4 m-thick mass flow with abundant stromatolitic reef debris, some silicified (Fig. 4.2). Also fragments of

layers of silicified oolites (Fig. 4.3 A) and loose oolites and pisolites in the matrix (Fig. 4.3B). The upper  $\frac{3}{4}$  of the Hüttenberg Fm apart from the uppermost 100 m, is intensely silicified, the remainder consists of numerous grainstones containing abundant oolites (Fig. 4.4). Bedding dip 55/165.



**Figure 4.2.** Mass flow in the Hüttenberg Formation containing abundant fragments of silicified and unsilicified reef debris and silicified oolites and pisolites; curved laminae of silicified stromatolite fragment at top left of photograph; farm Belina 132.



**Figure 4.3.** (A) Fragment of a layer of silicified oolites in the mass flow of Figure 4.2. (B) Abundant silicified oolites and some pisolites scattered through the dolomite grainstone matrix of the mass flow of Figure 4.2.



**Figure 4.4.** Dolomite grainstone with abundant detrital silicified oolites in upper Hüttenberg Formation, farm Belina 132.



**Figure 4.5.** Flaser bedding in the top 100 m of the Hüttenberg Formation on Belina 132. The light layers are composed of detrital silicified oolites. The dark layers consist of dolomite grainstone containing scattered detrital oolites.

Locality 13 (UTM 33k0601718, 7774321): Hüttenberg Fm. The uppermost 100 m of the Hüttenberg Fm consists of finely laminated flaser beds and rhythmites

(Fig. 4.5). A 10 m-thick, small-fragment mass flow occurs about 30 m from the top. Farm Belina 132.

### ***Mulden Group***

Between Localities 13 and 14. Not exposed, calcrete and soil covered. Farm

Belina 132. Clifford (2008) indicates phyllite in places.

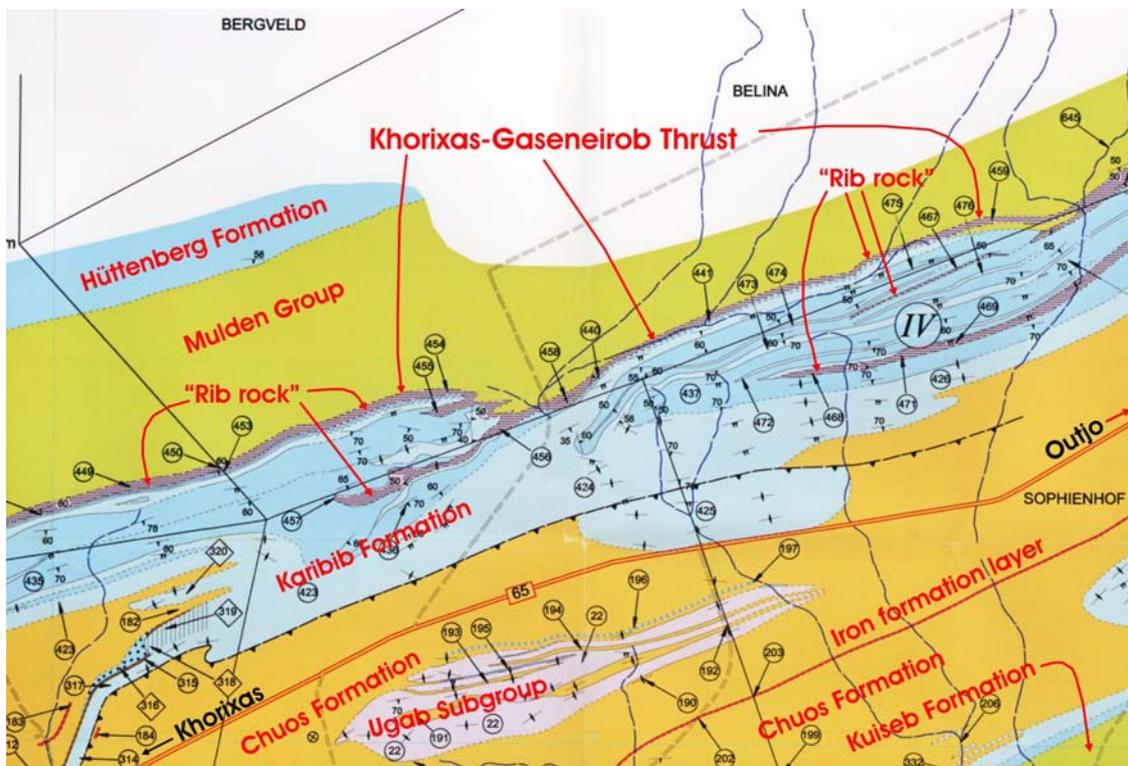
### ***Swakop Group, Karibib Formation***

Locality 14 (UTM 33k0603364, 7772891): Karibib Fm, southern border of farm Belina 132. Locality situated in

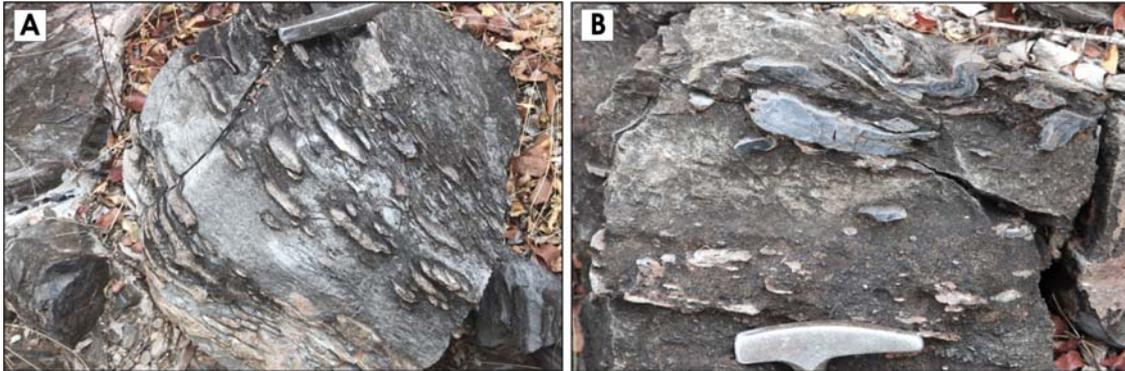
intensely foliated Karibib marble immediately against the Khorixas-Gaseneirob Thrust. Foliation dip 72/184.

Locality 15 (UTM 33k0603364, 7772891): Karibib Fm, southern border of farm Belina 132. “Rib rock” of Clifford (2008) (Figs. 4.6, 4.7). This “rib rock” formed when the silicified layers in the Karibib Formation were disrupted during deformation into fold or cleavage mullions. As deformation progressed, these mullions were rotated into the transport direction of the deformation and became extended in that direction. All these siliceous mullions have been so stretched out that they are like sword blades or “ribs”, i.e. flat, 2-3 cm wide and long. They are all parallel and plunge down and define the stretching lineation

(Fig. 4.7A). The axes of minor fold mullions are also parallel to the stretching lineation (Fig. 4.7B). Such intense deformation and rotation of mullions is typical of sheath folding associated with major overthrusting. Thus, the Karibib Fm all along the northern limit of its outcrop where Clifford has mapped “rib rock” has been deformed into sheath folds. From Clifford’s map it would appear that the whole northern half of this ridge of Karibib Fm marbles, if not the entire width of the ridge, is deformed into sheath folds. Plunge of stretching lineation  $50^\circ$  in direction  $140^\circ$  which is indicative of a  $320^\circ$  (magnetic) transport direction.



**Figure 4.6.** Copy of geological map by Clifford (2008) of the ridge of Karibib Formation marble along the boundary between the farms Belina 132 and Straussenheim 134/Sophienhof 133. Note the locations of his strike-parallel “rib rock” at the northern margin of the Karibib marble and at places within the marble where it is also strike parallel. Published with permission of the Geological Society of South Africa.



**Figure 4.7.** So-called “rib rock” of Clifford (2008). **(A)** Flattened cleavage-mullions of disrupted chert layers in the Karibib Formation immediately adjacent to the Khorixas-Gaseneirob Thrust front. Each flattened mullion is stretched out like a sword blade. All are parallel and define the stretching lineation indicating that this part of the Karibib Formation, and possibly the whole ridge of Karibib marbles, consists of sheath folds. Near the southern border of farm Belina 132. **(B)** Fold mullion of chert, the axis of which extends down the mullion and is orientated parallel to the stretching lineation. Same locality as Figure 4.7A.

Locality 16 (UTM 33k0604701, 7772395): Karibib Fm, northern part of farm Straussenheim 134. Bedding vertical, strike  $140^\circ$ .

Locality 17 (UTM 33k0605641, 7771985): Karibib Fm, northern part of farm Straussenheim 134. Layers of thin limestone turbidites, 4 mm to 12 cm thick. Bedding vertical, strike  $85^\circ$ .

#### ***Swakop Group, Chuos Formation***

Locality 18 (UTM 33k0602635, 7769090): Chuos Formation, farm Straussenheim 134 south of the main road. Near the base of the Chuos Formation: A few thin layers of thinly to thickly bedded, dark grey or brown dolomite separated from each other by several metres of calcrete. No other features in the dolomites. Bedding dip  $55/340$ , i.e. nose of fold structure.

Locality 19 (UTM 33k0602599, 7769214): Chuos Formation, farm Straussenheim 134. Dolomite layer protruding through calcrete, bedding dip  $71/135$ .

Locality 20 (UTM 33k0602583, 7769187): Chuos Formation, farm Straussenheim 134. Tremolite needles in poorly exposed dolomite layer.

#### ***Swakop Group, Karibib Formation***

Locality 21 (UTM 33k0603275, 7768452): Karibib Formation, farm Straussenheim 134, at farm house. Thinly bedded grainstones, Bedding vertical, strike  $130^\circ$ .

Locality 22 (UTM 33k0603767, 7768340): Karibib Formation, farm Straussenheim 134. Bedding obscured by intense foliation, foliation dip  $85/185$ .

#### ***Swakop Group, Chuos and Saturn formations***

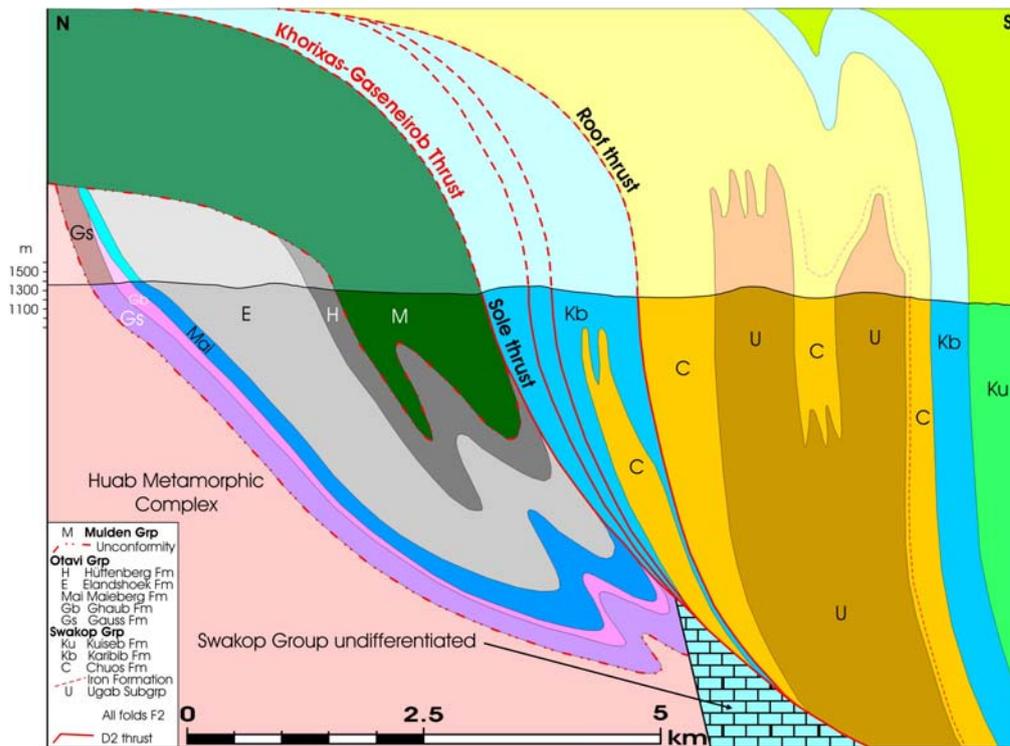
Locality 23 (UTM 33k0604957, 7769792): Chuos Fm, eastern part of farm Straussenheim 134. Very dark grey dolomite

(fresh and weathered), partly massive, partly finely laminated, steep southerly dip. Some loose blocks appear to have stretching

lineations so the laminations may be a tectonic foliation.

Locality 24 (UTM 33k0604664, 7770111): Saturn Fm, eastern part of farm Straussenheim 134. Very strongly foliated light grey Saturn Fm dolomite, foliation dip 80/160.

Locality 25 (UTM 33k0604284, 7770365): Saturn Fm, eastern part of farm Straussenheim 134. Featureless, light grey Saturn Fm dolomite that weathers both light and dark grey. Intense foliation that oscillates about vertical and strikes 90°. Whole ridge like this.



**Figure 4.8.** Section along traverse 4, includes stratigraphic and structural data from geological maps of Clifford (2008) for the Swakop Group rocks.

## Conclusions

The unit above the Ghaub Formation in the Fransfontein Ridge is not well mapped and has been referred to as the Maieberg Formation (i.e. Otavi Group) in Figure 13.76 of Hoffman & Halverson (2008) and Karibib Formation (i.e. Swakop Group) in their Figure 13.77. This unit consists of the three formations of the Tsumeb Subgroup of the Otavi Group. Furthermore, it has been affected by the large-scale thrusting just to the south. All along the Fransfontein Ridge this unit needs careful stratigraphic, sedimentological and structural mapping.

The northern boundary fault of the Northern Zone Rift had a throw of at least 6.6 km (Miller, 1980, 2008). It must also have been the location of a huge growth fault during deposition of the Swakop Group which was approximately 16 km thick in the Okonguarri area (Ugab Subgroup + Chuos + Okonguarri + Karibib + Kuseib formations). This separated the Otavi facies on the top of the fault scarp from Swakop Group facies below the scarp. Although deformation has now tightly compressed the Swakop Group succession and thrust it northwards, detailed facies analyses may reveal the present

location of that part of the Swakop Group succession that was closest to the growth

fault.

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