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TECTONIC SUBDIVISION, LITHOSTRATIGRAPHY AND STRUCTURAL GEOLOGY OF THE UPPER BLACK NOSSOB RIVER AREA

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ABSTRACT

Three major tectono-stratigraphic units are distinguished in the upper Black Nossob River area, east of Okahandja. The Ekuja-Otjihangwe Nappe Complex, which is the lowermost unit, is made up mainly of pre-Damara basement with a relatively thin cover of lower Damara Sequence metasedimentary and metavolcanic rocks. Most of the cover rocks are correlated with the Vaalgras Subgroup of the Southern Margin Thrust Belt, but in addition one outcrop of metasediments belonging to the Kudis Subgroup was also found. Furthermore, a unique succession of syntectonic metaconglomerate, marble, and minor schist, which has been named the Hochberg Formation, occurs just below the Hochberg Thrust, which separates the Ekuja-Otjihangwe Nappe Complex from the overlying Khomas Zone.

The Khomas Zone is subdivided into two tectono-stratigraphic units, of which the Onjona-Vrolikheid Fold Complex is the lower unit and the Onyati Mountains Schist Belt is the upper unit. The Onjona-Vrolikheid Fold Complex is essentially composed of coarse-grained quartzites and marbles as well as some schists, all belonging to the lower Damara Sequence, but a few outcrops of basement gneiss were also found in the south. In addition ultramafic rocks fringe the Ekuja-Otjinhangwe Nappe Complex in the east, but tectonically they appear to occur at the base of the Khomas Zone. The Onyati Mountains Schist Belt consists of the Kuiseb Formation of the upper Damara Sequence, which is a very thick succession of pelitic, semi-pelitic and psammitic schists with some amphibolites, calc-silicates, and minor marble. Syntectonic granite-pegmatites have intruded the Kuiseb schists in the north.

Intense deformation has resulted in repeated folding and at least two penetrative foliations in all three tectonostratigraphic units. However, despite some structural similarities there are also important differences. Apart from an early pre-Damara foliation in the basement of the Ekuja-Otjihangwe Nappe Complex, the earliest Damaran structures of this unit are probably younger than the D_1 and D_2 structures of the Khomas Zone.

Isoclinal F_1 and F_2 folds and the penetrative s_1 and s_2 foliations of the Khomas Zone have been folded by tight and isoclinal F_3 folds. In the Onyati Mountains Schist Belt progressive deformation during D_2 resulted in the rotation of the F_2 folds into the direction of shearing, which is parallel to a prominent west-north-westward plunging l_2 mineral lineation. A distinct northward plunging stretching lineation is associated with the Hochberg Thrust, while the F_2 and possibly the F_3 folds in the Onjona-Vrolikheid Fold Complex have been rotated into the direction of overthrusting, indicating that at least the first two phases of deformation of the Khomas Zone predate the Hochberg Thrust. The west to west-north-westward plunging and southward vergent F_3 folds together with the stretching lineations of the Hochberg Thrust indicate that thrusting of the Khomas Zone over the Ekuja-Otjihangwe Nappe Complex was from north to south.

The Ekuja-Otjihangwe Nappe Complex is characterised by large-scale thrusts, which are associated with isoclinal folds and two penetrative foliations. These early structures have been refolded locally by upright, northward plunging F_3 folds, which are probably related to lateral ramps in blind thrusts below the present erosion surface. Thrust related ramps at depth may also explain the basement domes in the area. As the F_3 folds in the Ekuja-Otjihangwe Nappe Complex have folded the Hochberg Thrust, they must be younger than the F_3 folds in the Khomas Zone, which are probably related to the Hochberg Thrust.

The D_1 and D_2 structures of the Khomas Zone are interpreted in terms of a model of north-westward subduction below an active continental margin, while southward thrusting in the Ekuja-Otjihangwe Nappe Complex and the F_3 folds of the Khomas Zone are related to continental collision of the Congo and Kalahari Cratons. The Hochberg Thrust is a major tectonic boundary separating the Khomas Zone from the Ekuja-Otjihangwe Nappe Complex of the Southern Margin Thrust Belt.

1. INTRODUCTION

The upper Black Nossob River area is situated approximately 70-80 km to the east of Okahandja (Fig. 1). Most of the area was mapped fairly recently by Hegenberger (1977), but no detailed work has as yet been done on its structural geology and metamorphic petrology. The purpose of the present investigation is to unravel the structural and metamorphic evolution of

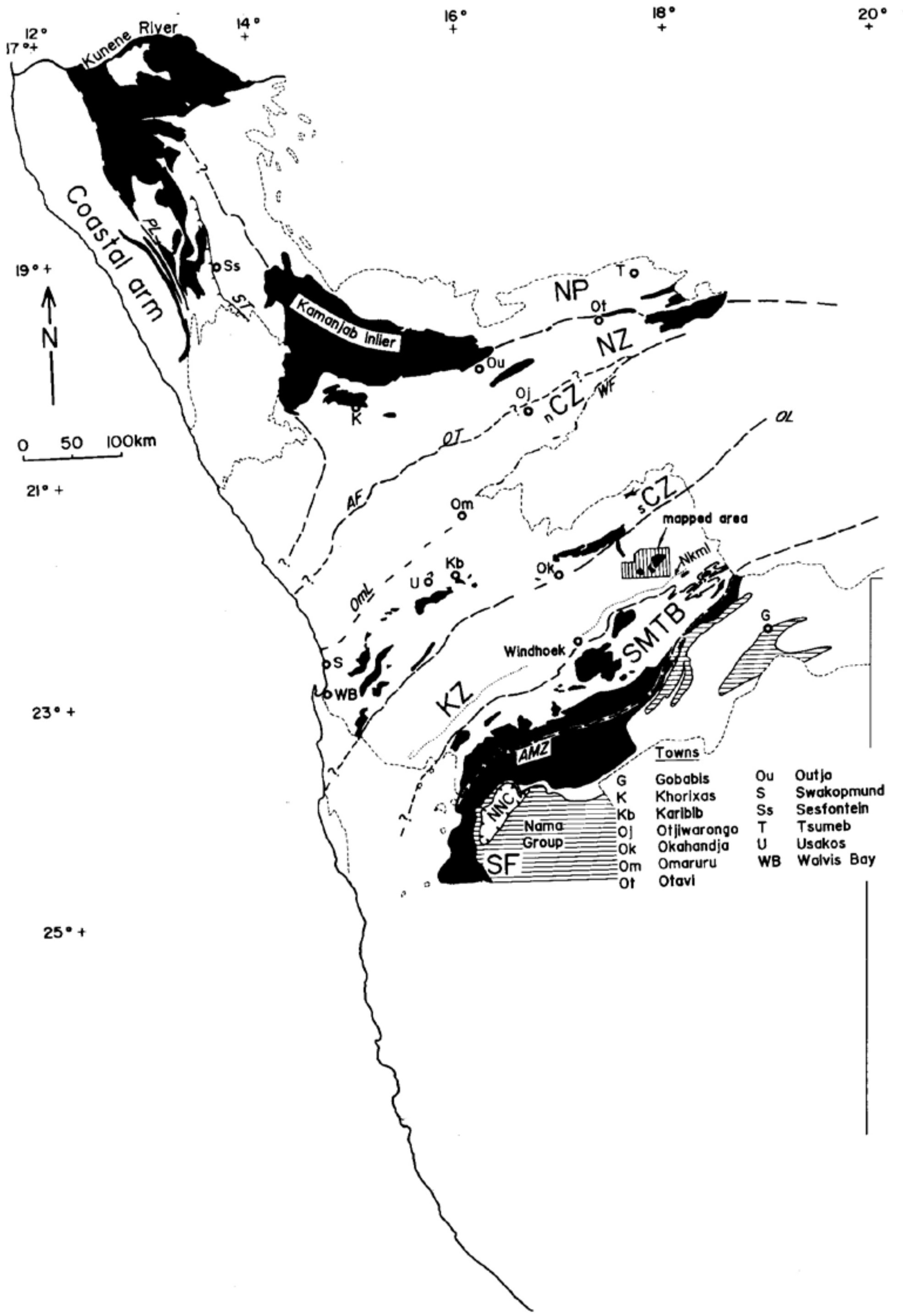

Fig. 1: Tectonic zones of the intracontinental branch of the Damara Orogen (modified after Miller, 1983 and Hoffmann, 1983). The zones are: NP = Northern Platform, NZ = Northern Zone, CZ = Central Zone, KZ = Khomas Zone, SMTB = Southern Margin Thrust Belt, SF = Southern Foreland. Major lineaments are: PL = Purros Lineament, ST = Sesfontein Thrust, AF = Autseib Fault, OT = Otjihorongo Thrust, OmL = Omaruru Lineament, WF = Waterberg Fault, OL = Okahandja Lineament, AMZ = Areb Mylonite Zone. Also shown are the Naukluft Nappe Complex (NNC), the Matchless Amphibolite (Nkml), and the locality of the mapped area.

the area and to explore the possible existence of major tectonic boundaries. However, for the better understanding of the structure of an area a good knowledge of its lithostratigraphy is essential. In the present report the lithostratigraphy of the upper Black Nossob River area and aspects of its structural geology are discussed. A detailed investigation of the metamorphic petrology and tectonothermal evolution is in progress and the results will be presented elsewhere (Kasch, in prep.).

Unfortunately most of the area is poorly exposed making mapping extremely difficult, and much is based on the interpretation of aerial photographs. Nevertheless, structural form lines are well defined on the aerial photographs, and together with isolated outcrops it is possible to trace most major structures fairly accurately. The western portion of the area, which is close to the Swakop River valley, is very well exposed. Field work is presently in progress in this part of the area.

2. REGIONAL TECTONIC SETTING

Several attempts have been made in recent years to subdivide the Damara Orogen into tectonic zones characterised by distinct stratigraphic, structural, and metamorphic criteria (Hartnady, 1978, 1979; Barnes and Sawyer, 1980; Hoffmann, 1983; Miller, 1983). Except for the southern boundary of the Southern Margin Thrust Belt of Hoffmann (1983), the zone boundaries of all these subdivisions are generally the same and only the names of the various zones differ. A subdivision closely resembling that of Miller (1983) is illustrated in Fig. 1, but the Southern Zone (Khomas Zone of Hoffmann, 1983) and the Okahandja Lineament Zone have been combined in the Khomas Zone.

Basically the upper Black Nossob River area is situated in the north-eastern Khomas Zone. However, as will be shown later, a portion of this area, the Ekuja-Otjihangwe Nappe Complex (Fig. 2), has many lithological and structural criteria in common with the Southern Margin Thrust Belt.

In the Southern Margin Thrust Belt the metamorphic grade increases through a typical Barrovian progression from the lower greenschist facies in the south-east to the middle amphibolite facies in the north-west (Hoffer, 1978, 1983; Kasch, 1983a, b). Relatively high pressures of up to 10 kbar were obtained for the boundary between the Southern Margin Thrust Belt and the Khomas Zone (Kasch, *op. cit.*). The temperature was more or less constant across the whole width of the Khomas Zone, while the pressure decreased by at least 5 kbar towards the north-west. The rocks in the BNR area have been subjected to middle amphibolite facies conditions, and the assemblage kyanite + staurolite + garnet + biotite + muscovite + plagioclase + quartz is found almost everywhere. However, in the north-western portions of the area (north-western Otjisauna North 157, Zwerveling 91, Baviaanskop 153, Vreemdeling 90, and central Engadin 74) sillimanite gradually replaces kyanite increasing in a northerly direction (Kasch, in prep.)

3. TECTONOSTRATIGRAPHIC UNITS

Both structural and lithostratigraphic considerations allow the distinction of three major tectonostratigraphic units in the upper Black Nossob River area (Fig. 2). The Ekuja-Otjihangwe Nappe Complex is the lowermost unit and it covers the southern, central, and eastern portions of the area. The middle unit is the Onjona-Vrolikheid Fold Complex, which occurs in the central, northern and north-eastern parts, while the upper unit is the Onyati Mountains Schist Belt which is restricted almost entirely to the west. The last two tectonostratigraphic units are both part of the Khomas Zone, which is separated from the Ekuja-Otjihangwe Nappe Complex by the Hochberg Thrust. Although intense deformation in all three tectonostratigraphic units has resulted in several phases of folding and at least two penetrative foliations, not all the structures can be correlated across the Hochberg Thrust.

The Ekuja-Otjihangwe Nappe Complex is characterised by major thrusts which have resulted in the repetition of pre-Damara basement and Damara Sequence metasedimentary and metavolcanic rocks. Lithologically these rocks closely resemble the pre-Damara basement and parts of the Damara Sequence of the Southern Margin Thrust Belt.

The lithostratigraphy of the Khomas Zone is distinctly different. Repeatedly folded, coarse-grained quartzites and marbles as well as some schists, all belonging to the lower Damara Sequence, make up the Onjona-Vrolikheid Fold Complex. Although only a few small outcrops of basement have been found in the south, more basement is present to the north-west of the area, where mapping is presently in progress. Finally, the Onyati Mountains Schist Belt consists of a thick succession of well foliated schists belonging to the Kuiseb Formation of the upper Damara Sequence. No major thrusts have as yet been identified in the Khomas Zone, but several phases of isoclinal folding suggest that intense shearing has affected these rocks.

The Khomas Zone between Windhoek and Okahandja can also be subdivided into distinct tectono-stratigraphic units (Fig. 2). Appropriate names for these units would be Eros Mountains Schist Belt and Ovitoto Mountains Schist Belt, which are the equivalent of the Southern Zone and the Okahandja Lineament Zone respectively of Miller (1983). The schists of the Eros Mountains Schist Belt have apparently been less intensely deformed than the schists of the Onyati Mountains Schist Belt (Miller, pers. comm., 1985), while deformation in the Ovitoto Mountains Schist Belt was even less intense (Hälbich, 1977). The western boundary of the Onyati Mountains Schist Belt has not yet been located, and it is also not known whether the schists to the south of the mapped area are part of the Onyati Mountains Schist Belt or the Eros Mountains Schist Belt.

4. LITHOSTRATIGRAPHY

4.1 The pre-Damara Basement

In the area mapped so far the pre-Damara basement is restricted almost entirely to the Ekuja-Otjihangwe Nappe Complex. However, some basement is also found at the base of the Khomas Zone on the farm Klipdrif 339 in the south (Fig. 3). The most common lithotypes are medium-grained grey paragneiss and grey to pale pink banded migmatitic gneiss. The latter consists of alternating bands and lenses of coarse-grained leucosome and fine-grained, somewhat darker gneiss with a fair amount of biotite. Thin bands of feldspathic quartz-biotite schist are locally developed and probably represent the restite of more extensive partial melting. In addition medium- to coarse-grained granitic augen-gneiss and deformed pegmatites are common throughout the sequence, and near the top well foliated amphibolite is frequently found.

4.2 The Damara Sequence

The Damara Sequence is not completely represented in the upper Black Nossob River area. In the Ekuja-Otjihangwe Nappe Complex most of the cover rocks are correlated with the Vaalgras Subgroup, and only one outcrop of Kudis Subgroup metasediments was found. The quartzites and marbles of the lower Damara Sequence in the north-east and the Kuiseb Formation schists of the Khomas Subgroup in the west are restricted to the Onjona-Vrolikheid Fold Complex and the Onyati Mountains Schist Belt respectively.

4.2.1 The Kudis Subgroup

Only one small outcrop of thinly bedded platy quartzite and graphitic schist belonging to the Kudis Subgroup was found near the north-eastern corner of Petersfarm 169 (Fig. 3). Although more graphitic schists may be present under the sand cover, the Kudis Subgroup is certainly not very thick in the upper Black Nossob River area.

4.2.2 The Vaalgras Subgroup

A succession of metasedimentary and metavolcanic rocks closely resembling parts of the Vaalgras Sub-

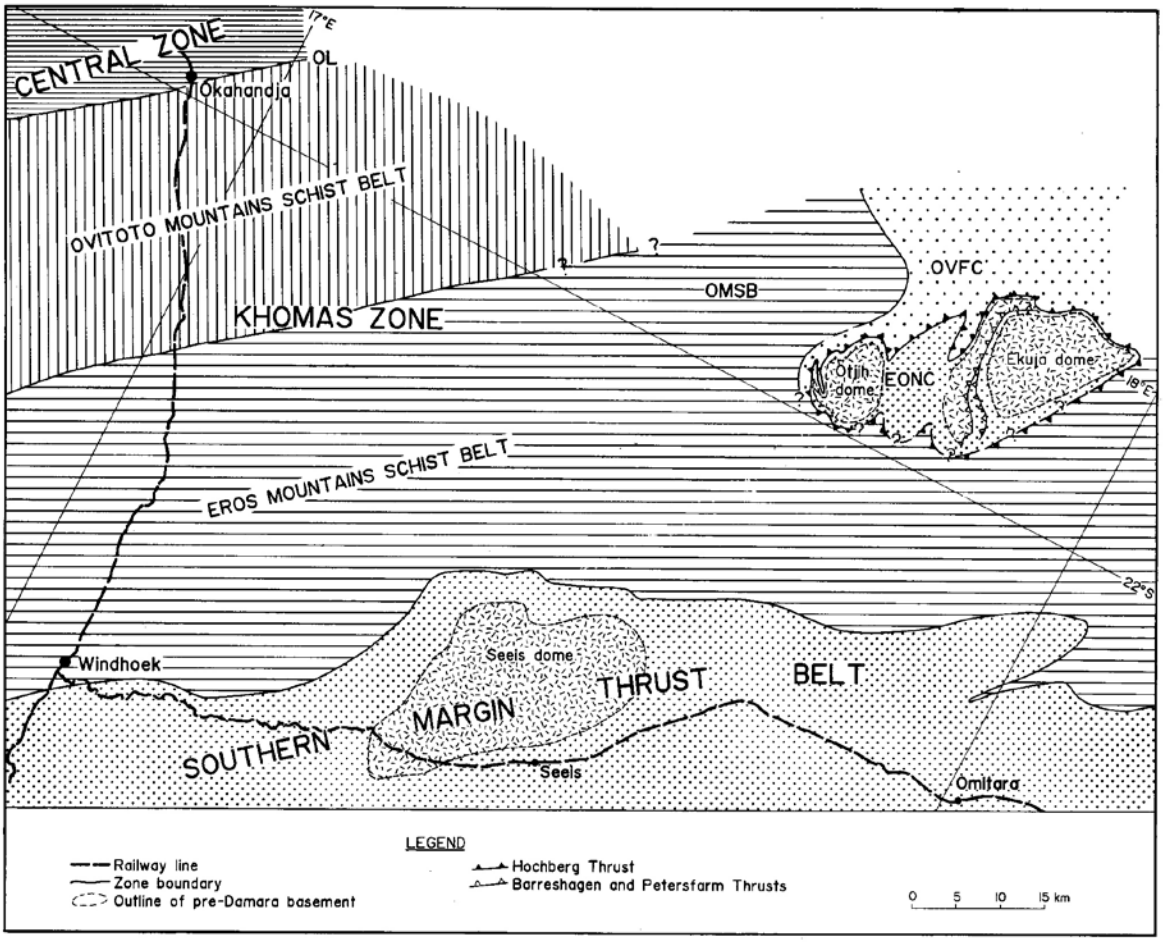

Fig. 2: Tectonostratigraphic subdivision of the south-eastern Damara Orogen with particular reference to the tectonostratigraphic units of the upper Black Nossob River area: OMSB = Onyati Mountains Schist Belt, OVFC = Onjona-Vrolikheid Fold Complex, EONC = Ekuja-Otjihangwe Nappe Complex.

group of Hoffmann (1983) is fairly well exposed along the Black Nossob River (Fig. 3). It is made up mainly of biotite-muscovite schist, garnet- and kyanite-bearing schist, hornblende- and garnet-bearing schist, quartzite, and amphibolite with minor marble and calc-silicate rock. The complete Vaalgras Subgroup as defined by Hoffmann (1983) is not represented in this area, and at least the Chuos Formation with its often described pebbly schist is absent. The thickness of the Vaalgras Subgroup is extremely variable in the upper Black Nossob River area, but this may be due to large-scale thrusting.

The Vaalgras Subgroup succession is most complete along the Black Nossob River on the farms Aurora 159, Otjite-Nord 160, and Otongovi 170. There the basal unit is made up of garnet-kyanite-mica schist, garnet-biotite schist and some amphibolite, and it is correlated with the Melrose Formation of Hoffmann (1983). This is overlain by a fine- to medium-grained pink quartzofeldspathic rock and some amphibole schist. The former appears to be an acid metavolcanic rock, which could be the equivalent of the “Red Band” of De Waal (1966) and Hälbich (1970). Together with the amphibole schist this unit of only a few metres thickness is correlated with the Gomab River Formation of Hoffmann (1983). Overlying this unit is a succession of mica schists with a fair amount of hornblende-garnet-mica schist, quartzite, amphibolite, and calc-silicate rock, which is correlated with the Kleine Kuppe Formation of Hoffmann (1983) and the Omitara Formation of Kasch (1983a). Although it is very difficult to estimate the thickness of the Vaalgras Subgroup along the Black Nossob River, it is at least 750 metres thick on southern Otjite 160.

On the south-eastern slopes of Hochberg hill (farm Hochberg 158) the basement gneiss is overlain by a succession of medium- to coarse-grained garnet-biotite schist, kyanite-garnet-biotite schist, quartz-kyanite-mica schist, and minor amphibole schist (Fig. 4). The

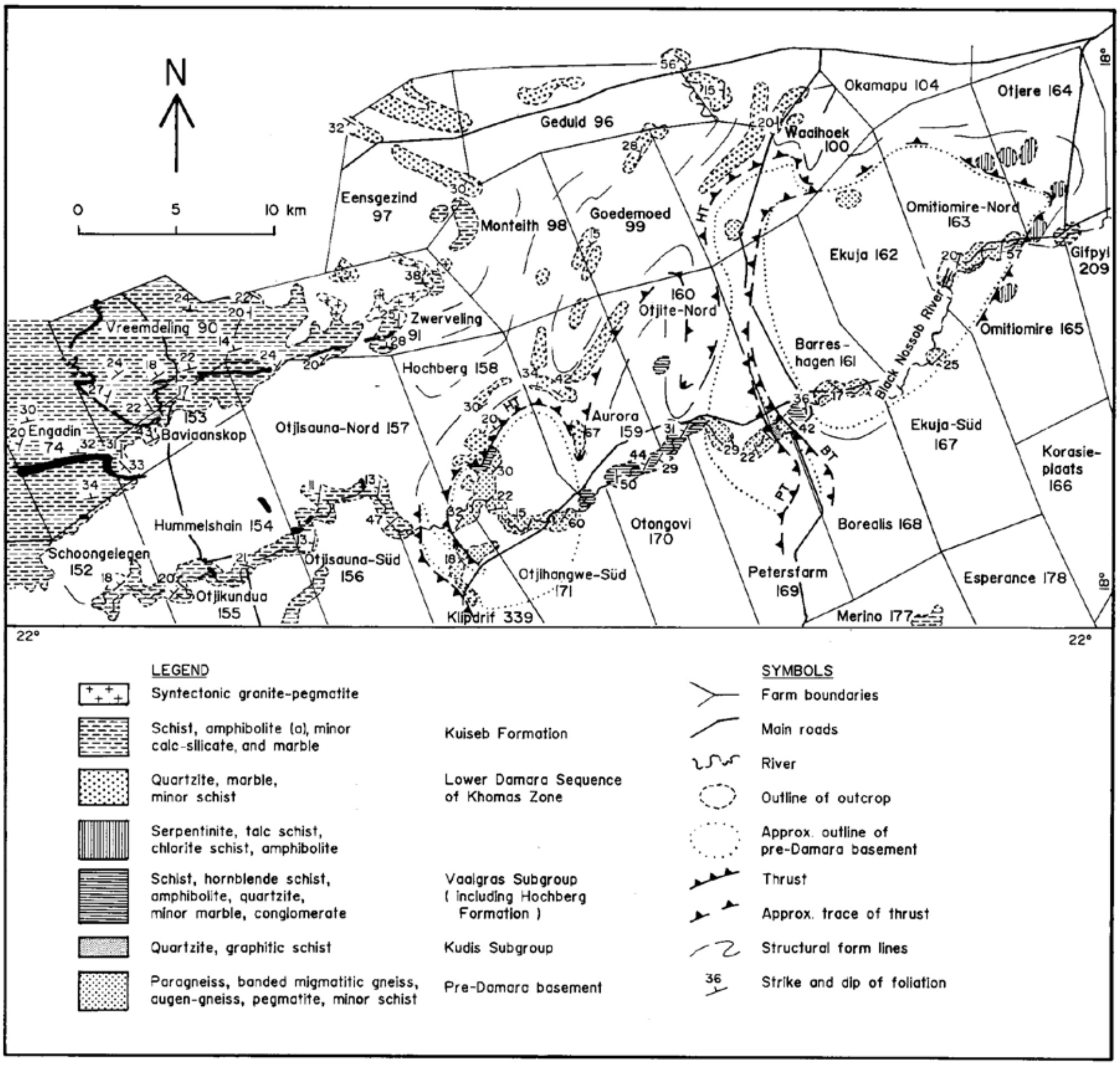

Fig. 3: Geological map of the upper Black Nossob River area. Otj Dome = Otjihangwe Dome, HT = Hochberg Thrust, PT = Petersfarm Thrust, BT = Barreshagen Thrust.

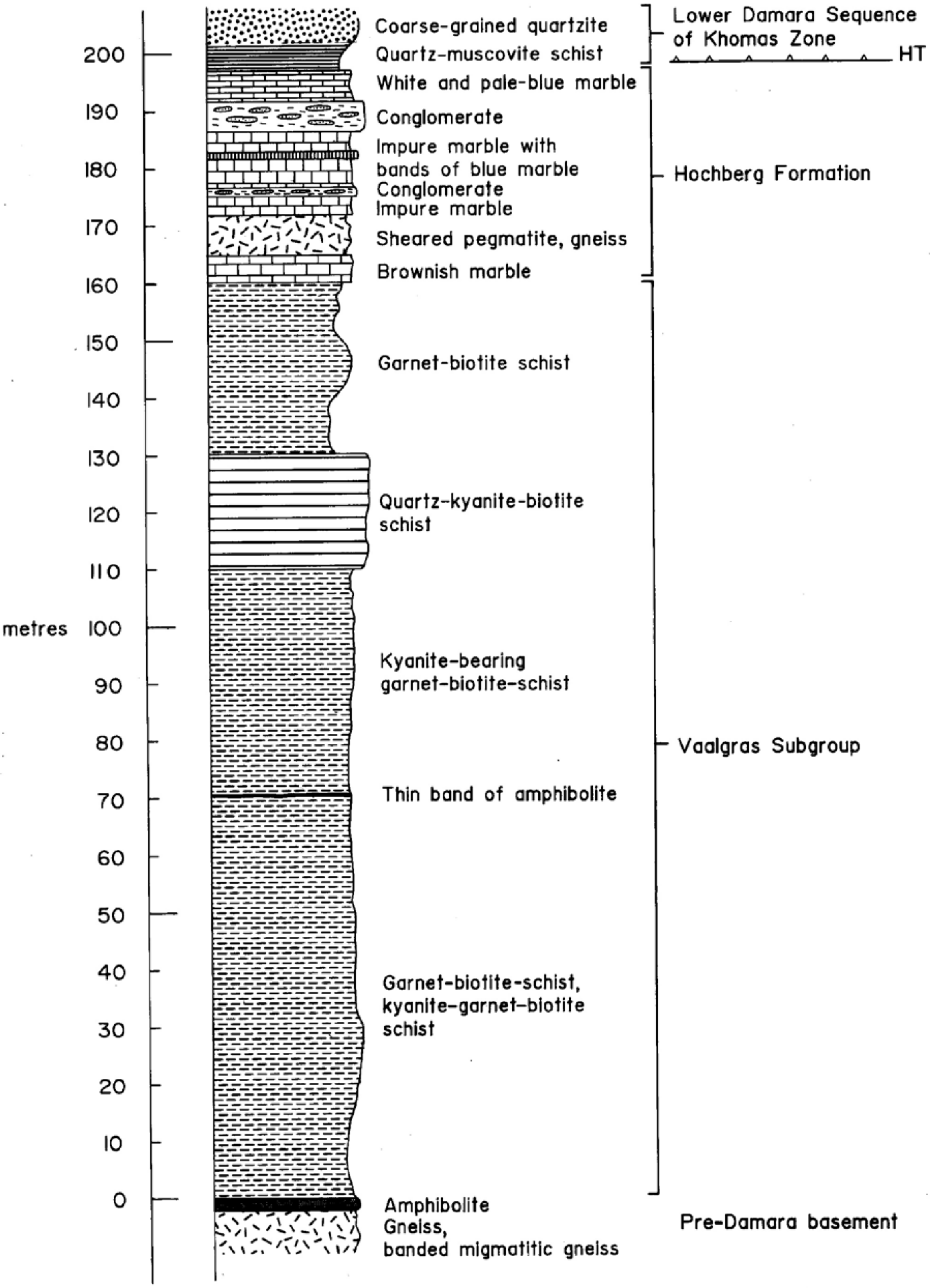

Fig. 4: Lithostratigraphic profile of the Damara Sequence on the south-eastern slopes of Hochberg hill. HT = Hochberg Thrust.

quartz-kyanite-mica schist is bluish-grey, very coarse-grained and is composed mainly of quartz, muscovite and kyanite with a fair amount of biotite and minor garnet and plagioclase. This succession is approximately 150 to 160 metres thick and it is tentatively correlated with the Melrose Formation of the Southern Margin Thrust Belt, but it may also be part of the pre-Damara basement. The higher stratigraphic units of the Vaalgras Subgroup (*cf.* Hoffmann, 1983) are certainly not present in the Hochberg profile (Fig. 4).

4.2.3 The Hochberg Formation

The uppermost succession of the Hochberg profile is unique to this area and, therefore, the name Hochberg Formation is proposed. It is made up of intercalated impure pale pink to brownish marble, some white to pale blue sugary marble, and two pebble-supported conglomerates (Fig. 4). Near the base of this succession there is a thin gneissic rock, which could be a basement wedge or a highly deformed pegmatite. The Hochberg Formation is approximately 40 metres thick and it is only exposed on Hochberg hill.

The quartzite pebbles and boulders in the conglomerates are intensely stretched and extremely variable in size. They resemble the coarse-grained quartzite of the lower Damara Sequence of the Onjona-Vrolikheid Fold Complex, which is sometimes pale green due to the presence of fuchsite. At least two isolated pebbles of fuchsitic quartzite were found in the upper conglomerate of the Hochberg Formation. It is concluded, therefore, that the quartzite pebbles in the conglomerates were derived from a quartzite similar to the one which is presently found directly above the Hochberg Thrust (Fig. 4). Erosion of this quartzite must have occurred at the leading edge of the Khomas Zone during the initial stages of thrusting and at a time when the quartzite presently found on top of Hochberg hill was still tens of kilometres further to the north and covered by several thousand metres of Kuiseb schists.

It is suggested that the marbles and conglomerates of the Hochberg Formation are the result of syntectonic sedimentation in a fore-deep basin in front of the advancing Khomas Zone during closure of the Damara ocean. However, a correlation of the Hochberg Formation with the Chuos Formation, for which a similar origin has been proposed by Hartnady (1979) and Martin *et al.* (1983), is not implied. Indeed, the lithological appearance of the Chuos Formation pebbly schists is different from that of the conglomerates of the Hochberg Formation, and Hoffmann (1983) has challenged the interpretation of the former as an olistostrome or sedimentary melange. On the contrary, however, the Hochberg Formation may be a time equivalent of the Kleine Kuppe Formation, which Hoffmann (1983) has interpreted as a syntectonic sediment. If this is true the Hochberg Formation should be included in the Vaalgras Subgroup as a local formation of the upper Black Nossob River area.

4.2.4 The Lower Damara Sequence of the Khomas Zone

The lower Damara Sequence of the north-eastern Khomas Zone consists of coarse-grained, white quartzite, white to pale blue marble, and some grey quartz-muscovite schist. It is difficult to correlate this rock unit with other formations of the Damara Sequence in central SWA/Namibia, but it is also present to the north of the upper Black Nossob River area, and a similar succession is found much further north at Otjozondo (Hegenberger, pers. comm., 1984). It may well belong to the Ugab or the Kudis Subgroup, both of which contain a fair amount of marble (*cf.* SACS, 1980), but the presence of coarse-grained quartzite is characteristic of the lower Damara Sequence in the Onjona-Vrolikheid Fold Complex.

The quartzite is in places pale green due to the presence of fuchsite and a few small occurrences of disseminated manganese of no economic value were also found. The presence of manganese supports the correlation of the lower Damara Sequence in the north-central upper Black Nossob River area with a similar succession at Otjozondu. Due to isoclinal folding it is difficult to estimate the true thickness of this quartzite-marble-schist succession, but it is at least several hundred if not close to a thousand metres thick.

4.2.5 The Kuiseb Formation of the Khomas Subgroup

The Kuiseb Formation is a very thick succession of monotonous pelitic, semi-pelitic, and quartz-rich psammitic schists with several amphibolites, feldspathic psammitic schists and calc-silicate rocks. A few layers of coarse-grained, white marble are present near the base of this formation. In the metapelites staurolite and kyanite are commonly found together with garnet, biotite, muscovite, and quartz, and in addition sillimanite is present in the north-west.

The Kuiseb Formation of the upper Black Nossob River area is very similar to the Kuiseb Formation elsewhere in the Khomas Zone (see Sawyer, 1981; Hoffmann, 1983; Miller, 1983; Miller *et al.*, 1983). It is a flysch sequence and has an average chemical composition between that of an average greywacke and a shale (Miller *et al.*, 1983).

4.2.6 The Ultramafic Rocks

Several outcrops of talc schist, silicified serpentinite, and minor chlorite schist, talc-tremolite schist, and amphibolite are found along the eastern edge of the Ekuja basement dome (Fig. 3). The geochemistry of several other ultramafic rocks of the Damara Orogen together with metamorphic considerations suggest that these are tectonic intrusions (Barnes, 1982, 1983), and, therefore, it is impossible to include them in the conventional lithostratigraphy of the Damara Sequence. However, tectonically the ultramafic rocks of the upper Black Nossob River area appear to be at the contact between the Ekuja-Otjihangwe Nappe Complex and the Khomas Zone, provided that the schists along the Black Nossob River on southern Otjere 164 are Kuiseb schists and not part of the Vaalgras Subgroup.

4.2.7 The Zwerveling Granite-pegmatite

Several syntectonic granite-pegmatites have intruded the Kuiseb Formation on central and north-eastern Zwerveling 91 (Fig. 3). They are very coarse-grained, grey to pale pink, and frequently contain elongate megacrysts of alkali feldspar up to 50 cm long in a fairly well foliated matrix of quartz, alkali feldspar, plagioclase, some muscovite and minor biotite. Large garnets up to 3 cm in diameter, enclosed by alkali feldspar megacrysts, were found in one outcrop. Several well foliated pegmatite veins are folded by F_3 folds which have also affected the surrounding schists. These veins as well as the contacts of the larger granite-pegmatites cut across the main foliation of the schists (composite $S_{1.2}$), suggesting that they have intruded sometime between the second and third phase of deformation. Lithologically these granite-pegmatites are very similar to the pegmatites of the Donkerhuk Granite east of Okahandja. However, this does not necessarily imply that they are time equivalents of the Donkerhuk Granite.

5. STRUCTURE

Although all three tectonostratigraphic units of the upper Black Nossob River area have experienced polyphase deformation resulting in repeated folding, there are some distinct differences in the structures observed at well as the trends of folds and stretching lineations. Furthermore, reorientation of the folds in the Onjona-Vrolikheid Fold Complex relates to overthrust movements along the Hochberg Thrust and, therefore, this is a transition zone between the Onyati Mountains Schist Belt and the Ekuja-Otjihangwe Nappe Complex. Hence there are three structural domains in the upper Black Nossob River area.

5.1 The Onyati Mountains Schist Belt

At least three generations of isoclinal or near-isoclinal, southward vergent folds are observed in the schists of the Khomas Zone. Evidence for F_1 fold and the s_1 foliation is restricted to the quartz-rich schists and calc-silicate rocks, whereas s_1 is usually completely transposed into a composite $S_{1.2}$ foliation in the mica-rich schists. In the quartz-rich and psammitic schists s_2 is usually a penetrative s_2 crenulation foliation, and several examples of F_2 folds refolding F_1 folds were found. The F_2 folds and the l_2 mineral lineations are in turn folded by F_3 folds (Fig. 5b). In addition to the structures described above, open F_4 folds and crenulations are occasionally found.

The F_2 folds usually plunge at a low to moderate angle to the west-north-west to north-west, while the F_3 folds plunge to the west to west-north-west (Fig. 5a). A distinct mineral lineation (l_2) which is marked by the preferred orientation of kyanite, sillimanite, staurolite, and hornblende parallel to the B_2 fold axes, is present everywhere in the Onyati Mountains Schist Belt. Several localities were found where the F_2 folds are rotated within their own axial planes and their fold axes plot on a great circle, but the l_2 minerallineation defines a constant trend (Fig. 5c). This indicates that l_2 is a stretching lineation and that the F_2 fold were rotated into the direction of shearing due to progressive deformation during D_2 (*cf.* Escher and Watterson, 1974). This in turn suggests the presence of sheath folds which are associated with intense shearing or thrusting (Quinquis *et al.*, 1978; Cobbold and Quinquis, 1980). Similar observations were made in the Kuiseb schists to the north of Windhoek, where F_2 folds are rotated on a large scale and also plot on a great circle (Hälbich, 1977; Miller, 1983). However, it is not yet known whether the F_2 folds to the north of Windhoek are the equivalent of the F_2 folds in the Onyati Mountains Schist Belt, because the Eros Mountains Schist Belt has apparently been subjected to less intense deformation (Miller, pers. comm., 1985).

5.2 The Hochberg Thrust and the Onjona-Vrolikheid Fold Complex

The Hochberg Thrust is a major tectonic boundary which separates the Khomas Zone from the Ekuja-Otjihangwe Nappe Complex. This thrust has resulted in intense shearing near the top of the Hochberg profile (Fig. 4), where quartzite pebbles in the conglomerates of the syntectonic Hochberg Formation just below the thrust have been highly stretched, defining a prominent northward plunging lineation (Fig. 5d). This stretching lineation together with the southward vergent folds above and below the thrust indicate over-thrusting from north to south. Due to the poor exposures in this part of the upper Black Nossob River area it is impossible to follow the Hochberg Thrust over long distances in the field, but on aerial photographs it can be traced fairly accurately from the Otjihangwe dome to the northern edge of the Ekuja dome (Figs 2 and 3). The eastward extension of the Hochberg Thrust around the Ekuja dome is uncertain, and due to the thick sand cover it is impossible to trace the Hochberg Thrust to the south of the Black Nossob River, where it separates the Ekuja-Otjihangwe Nappe Complex from the southern Khomas Zone (Fig. 2).

It is impossible at this stage to estimate the amount of displacement along the Hochberg Thrust, but a minimum displacement of several tens of kilometres is proposed for the following reason. The Hochberg Formation is interpreted as a syntectonic sedimentary succession which was deposited in a fore-deep basin in front of the advancing Khomas Zone. Syntectonic garnets in the matrix of the conglomerates of the Hochberg Formation have been partly pseudomorphed by post-tectonic kyanite and biotite.

Garnet-biotite temperatures for this post-tectonic breakdown of garnet to kyanite and biotite are of the order of 600°C (Kasch, in prep.), and the presence of kyanite suggests a minimum pressure of 5 kbar using the kyanite-sillimanite inversion of Holdaway (1971). Hence the Khomas Zone above the Hochberg Thrust was at least 18 km thick after thrusting had stopped. If a single ramp is assumed climbing southward at 45° from the present Hochberg hill to the top of the original Khomas Zone, a minimum displacement of 25 km is obtained. However, it is unlikely that there was only one large ramp without any flats in between, and that this ramp was as steep as 45°. Therefore, the actual displacement was probably far in excess of 25 km.

The F_2 and F_3 folds in the quartzites and marbles of the Onjona-Vrolikheid Fold Complex generally plunge towards the north (Figs. 3 and 5d). These folds tend to be subparallel to a prominent northward plunging rodding in the quartzite just above the Hochberg Thrust and the stretching lineation in the Hochberg Formation just below the thrust (Fig. 5d). It is evident, therefore, that southward thrusting along the Hochberg Thrust was responsible for the rotation of the F_2 and F_3 folds near the base of the Khomas Zone into a north-south direction, which is almost at right angles to the F_2 folds and mineral lineations as well as the F_3 folds in the Kuiseb schists higher up in the sequence.

It is impossible that shearing along a single major thrust was responsible for both the l_2 mineral lineations in the Onyati Mountains Schist Belt and the stretching lineations associated with the Hochberg Thrust. West-north-west plunging F_2 folds and mineral lineations in the Kuiseb Formation are, therefore, the result of intense shearing before thrusting of the Khomas Zone over the Ekuja-Otjihangwe Nappe Complex. Hence the Hochberg Thrust and the earliest Damaran structures in the Ekuja-Otjihangwe Nappe Complex must be younger than the D_1 and D_2 structures of the Khomas Zone.

Although the Onjona-Vrolikheid Fold Complex is not very well exposed, structural form lines clearly define a pattern of elongate basin and dome structures, with the long axes oriented more or less north-south. These basin and dome structures must be related to the prominent domes of the Ekuja-Otjihangwe Nappe Complex below the Onjona-Vrolikheid Fold Complex.

5.3 The Ekuja-Othihangwe Nappe Complex

The Ekuja-Otjihangwe Nappe Complex consists of large thrust sheets with an internal structure characterised by intense and repeated folding, and at least two penetrative foliations. Its structure is, therefore, very similar to that of the Southern Margin Thrust Belt.

Evidence for thrusting was found along the Black Nossob River on south-western Barreshagen 161 and north-eastern Petersfarm 169, where pre-Damara basement overlies metasediments of the lower Damara Sequence (Fig. 3). Both basement and Damara Sequence dip at low to moderate angles towards west-south-west. Just like the Hochberg Thrust it is not possible to follow these thrusts along strike in the field, but on aerial photographs they can be traced fairly accurately for several kilometres. From the interpretation of aerial photographs it is apparent that the Petersfarm and Barreshagen Thrusts splay from a single thrust approximately 4 km north of the Black Nossob River, and that the Petersfarm Thrust climbs a frontal ramp to the south of the Black Nossob River (Fig. 3). This would indicate that overthrusting along these two thrusts was also from north to south. The length of the Otjihase basement sheet, which stretches from Waaihoek 100 in the north to central Petersfarm 169 in the south, suggests that the displacement along the Petersfarm Thrust was approximately 17 km.

The earliest foliation in the pre-Damara basement is always parallel to the banding in the migmatites. As the metamorphic grade at the present erosion level was not high enough for extensive partial melting during the Damaran orogeny (Kasch, in prep.), both the migmatites and the earliest foliation must be the product of a pre-Damara tectonothermal event. This foliation has been folded by isoclinal folds which are often associated with a crenulation foliation. These folds generally trend north-south, but in places they vary considerably and their fold axes define a great circle within the s_2 axial plane (Fig. 6). This together with the fact that they are both eastward and westward vergent suggests that they have been rotated towards the extension direction (cf. Escher and Watterson, 1974), implying that they are sheath folds which are related to southward thrusting (*cf.* Quinquis *et al.*, 1978; Cobbold and Quinquis, 1980).

The main penetrative foliation (s_2 in the mica-rich schists of the lower Damara Sequence has refoliated an earlier bedding-parallel foliation (s_1), and in the quartz-rich schists and the calc-silicate rocks isoclinal F_2 folds have folded the s_1 foliation. It is evident that these structures were produced by the same deformation event that was responsible for the isoclinal folds in the pre-Damara basement. Northward plunging upright F_3 folds have folded all the structures in the pre-Damara basement and the Damara Sequence described above, and in addition they have also folded the Hochberg Thrust as well as the lower Damara Sequence of the Onjona-Vrolikheid Fold Complex. These folds are fairly tight and they are restricted to a north-south trending zone in the central portions of the upper Black Nossob River area.

Butler (1982) has shown that horse accretion by lat-

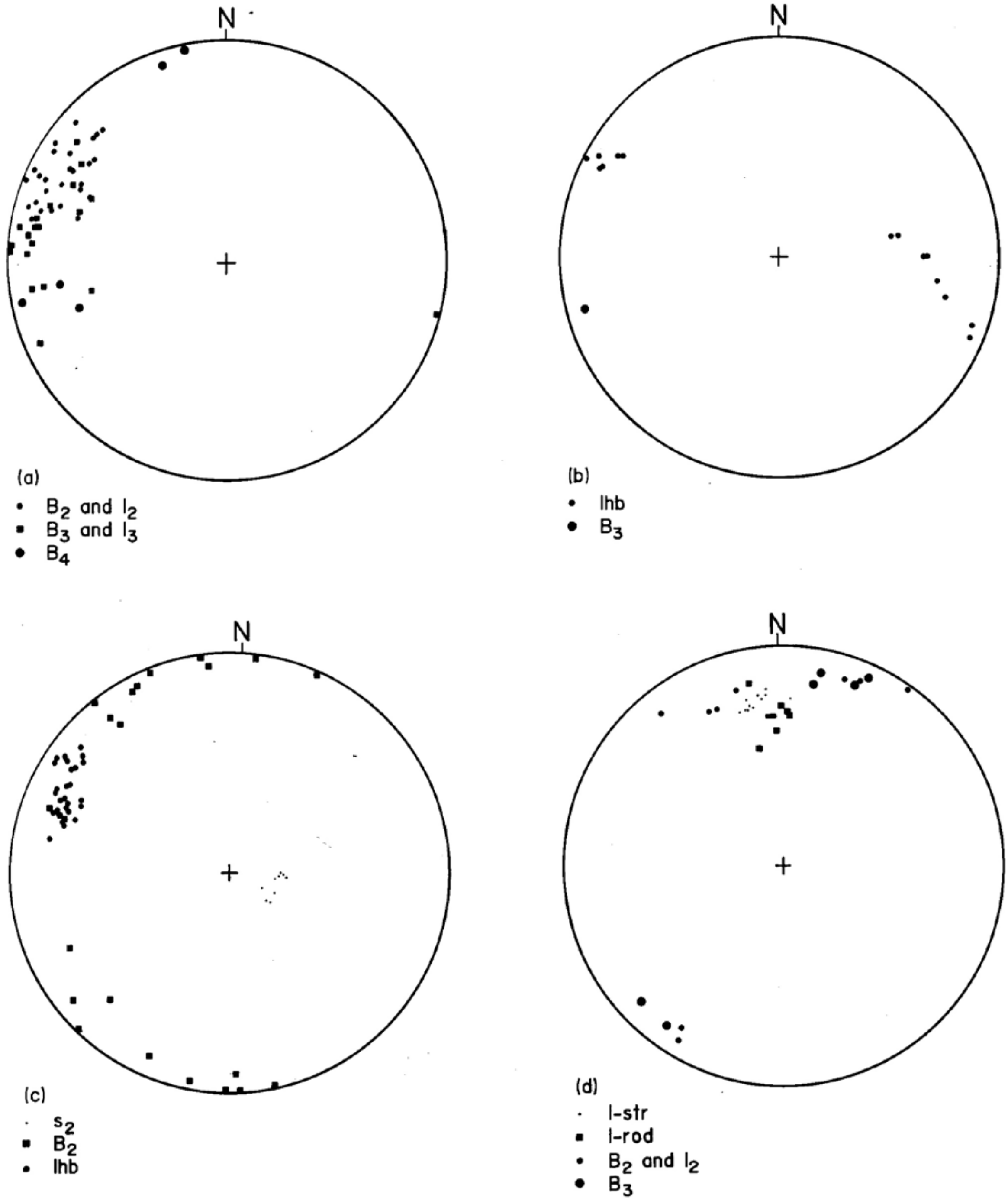

Fig. 5: Structural data shown on the lower hemisphere of a Schmidt equal-area net.

(a) Regional trends of B_2, l_2, B_3, l_3, and B_4 in the Onyati Mountains Schist Belt.

(b) Example of hornblende lineation (lhb) folded by a F_3 fold on south-eastern Engadin 74.

(c) Example of B_2 fold axes plotting on a partial great circle normal to the poles to s_2. Note the constant trend of the hornblende lineation (lhb). Locality; Baviaanskop 153.

(d) Stretching lineations associated with the Hochberg Thrust (Hochberg 158) and structural data of B_2, l_2, and B_3 from the Onjona-Vrolikheid Fold Complex. l-str = stretched quartzite pebbles in conglomerate, l-rod = rodding in quartzite above the thrust.

eral ramps will initially result in extensional strains normal to the movement direction. However, continuous accretion of horses will result in compressional strains and folding above the hanging wall. It is suggested that horse accretion associated with several north-south trending lateral ramps below the present erosion surface was responsible for the northward plunging F_3 folds between the Otjihangwe dome and the Otjihase basement sheet. Furthermore, the combination of several frontal, lateral and oblique ramps related to blind thrusts is probably responsible for the dome structures in the Ekuja-Otjihangwe Nappe Complex and the overlying Onjona-Vrolikheid Fold Complex (*cf.* Butler, 1982; Parish, 1984).

It would be tempting to correlate the two penetrative foliations in the lower Damara Sequence of the Ekuja-Otjihangwe Nappe Complex with those in the Kuiseb schists of the Khomas Zone. However, the penetrative foliations and the F_2 folds in the lower Damara Sequence as well as the isoclinal folds in the pre-Damara basement of the Ekuja-Otjihangwe Nappe Complex are clearly related to thrusting. On the contrary the F_2 folds in the Kuiseb schists are older than the Hochberg Thrust and only the F_3 folds appear to be related to southward thrusting of the Khomas Zone over the Ekuja-Otjihangwe Nappe Complex. Therefore, the isoclinal F_2 folds in the Kuiseb schists of the Khomas Zone must be older than the earliest Damaran structures in the Ekuja-Otjihangwe Nappe Complex.

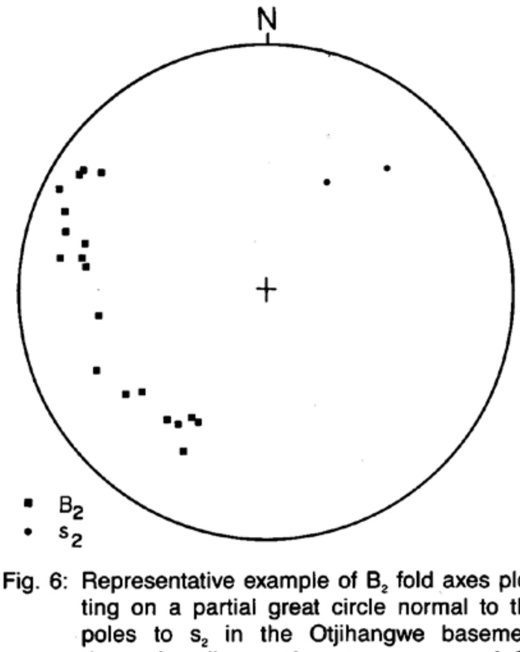

Fig. 6: Representative example of B_2 fold axes plotting on a partial great circle normal to the poles to s_2 in the Otjihangwe basement dome. Locality south-eastern corner of Otjisauna Nord 157.

6. DISCUSSION AND CONCLUSIONS

Hoffmann (1983) suggested that syntectonic sedimentation in a fore-deep environment was responsible for extensive interfingering between the upper Vaalgras Subgroup and the lower Kuiseb Formation along the northern edge of the Southern Margin Thrust Belt near Windhoek. If this interpretation is correct, then the earliest structures in the Khomas Zone must, by implication, be older than the early folds and thrusts in the Southern Margin Thrust Belt.

During the present investigation it was found that the F_1 and F_2 folds in the Khomas Zone of the upper Black Nossob River area are older than the isoclinal folds and thrusts in the Ekuja-Otjihangwe Nappe Complex. Furthermore there is strong evidence suggesting that the marbles and conglomerates of the Hochberg Formation are syntectonic sediments, which were deposited in a fore-deep basin. As both lithostratigraphic and structural evidence suggest that the Ekuja-Otjihangwe Nappe Complex is part of the Southern Margin Thrust Belt, the present results support the interpretation of Hoffmann (1983) as well as the structural implications thereof.

In the upper Black Nossob River area the Hochberg Thrust separates the Khomas Zone from the Ekuja-Otjihangwe Nappe Complex of the Southern Margin Thrust Belt. Evidence for extensive tectonic overprinting and large scale thrusting is also found along the northern edge of the Southern Margin Thrust Belt near Windhoek (Hoffmann, 1983), while regional P-T variations across the southern Damara Orogen (Kasch, 1983a, b) suggest that there is a major tectonic boundary between the Khomas Zone and the Southern Margin Thrust Belt. Evidently the whole of the Khomas Zone was initially to the north of the Ekuja-Otjihangwe Nappe Complex. The distance between the northern edge of the Ekuja-Otjihangwe Nappe Complex and the southern edge of the Khomas Zone between Omitara and Seeis is 40 km, which must be the minimum distance of overthrusting of the Khomas Zone. This is also regarded as a minimum displacement estimate for the Hochberg Thrust.

It is concluded that deformation in the southern Damara Orogen was diachronous, and that the Khomas Zone experienced intense deformation while sedimentation was still in progress along the northern edge of the Kalahari Craton (later Southern Margin Thrust Belt). This relationship is interpreted in terms of a plate tectonic model with an active margin to the north-west and a passive margin to the south-east. It supports the fore-arc basin model for the deposition of a portion of the Kuiseb Formation in the Khomas Zone (Blaine, 1977; Miller, 1983; Miller *et al.*, 1983). Continental collision of the Congo and Kalahari Cratons resulted in abduction of the Khomas Zone onto the northern edge of the Kalahari Craton and large scale thrusting in the Southern Margin Thrust Belt (Barnes and Sawyer, 1980; Kasch, 1983a, c). The tectonic boundary between the Khomas Zone and the Southern Margin Thrust Belt is interpreted as the structure of continental collision.

7. ACKNOWLEDGEMENTS

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