Communs geol. Surv. S.W. Africa/Namibia, **4** (1988), 37-48

NEW ASPECTS OF THE SEDIMENTOLOGY AND STRUCTURE OF THE KUISEB FORMATION IN THE WESTERN KHOMAS TROUGH, DAMARA OROGEN, SWA/NAMIBIA

P.A. Kukla[1], C. Opitz[2], I.G. Stanistreet[1] and E.G. Charlesworth[1]
[1]Geology Department, University of the Witwatersrand, Johannesburg, 2050.
[2]Mineralogisches Institut der Universität Würzburg, Am Hubland, D 8700 Würzburg, FRG

ABSTRACT

The Late Proterozoic Kuiseb Formation within the western Khomas Trough of the southern Damara Orogen comprises a considerable thickness of intercalated metamorphic psammites (metagreywackes) and pelites. Prominent lithological markers of great lateral extent are represented by (1) a graphitic schist, up to 60 m thick, in the centre of the Khomas Trough and (2) the metabasic rocks within the Matchless Amphibolite Belt in the south. Minor lithologies are thin graphitic schists, quartzitic schists, calc-silicate-rich units, scapolite-bearing schists and minor amphibolite. A prominent linear zone of discordant scapolite replacement occurs in the northern part of the Khomas Trough. The regional structural pattern is characterized by four phases of deformation with corresponding tight to isoclinal and open folds. Zones of high and low strain express the distinct heterogeneity of the structural regime. The metamorphic grade increases from lower amphibolite facies conditions at the southern margin of the Khomas Trough to upper amphibolite facies in the north. Despite the deformation and metamorphism, original bedding and sedimentary structures such as graded bedding, cross-lamination, scour surfaces, load structures, flute casts and rip-up clasts are preserved. Palaeocurrents indicate sediment transport towards the south-west. The organization of major parts of the sedimentary sequence into cyclic successions and the depositional character of the Kuiseb schists imply deposition by turbidity currents within a submarine elongate fan system of considerable extent. A major sediment source is indicated towards the eastern end of the Khomas Trough.

1. INTRODUCTION

The Late Proterozoic Kuiseb Formation in the Southern Zone (or Khomas Trough, Fig. 1) of the inland branch of the Damara Orogen represents the uppermost stratigraphic unit of the Swakop Group and comprises a considerable thickness of intercalated metamorphic psammites and pelites as well as the narrow, 350 km long Matchless Amphibolite Belt. The southern margin of the Southern Zone is characterized by intensive thrusting (Hoffmann, 1983; Miller and Hoffmann, 1981). Towards the north, facies relationships with lithological units of the Central Zone are largely obscured by the intrusion of the late tectonic Donkerhoek Granite (Miller, 1983), but interfingering of the Kuiseb schists with the turbiditic carbonates of the Tinkas Formation (Porada, 1983) and the shelf carbonates of the Karibib Formation (Martin, 1983) has been recognized.

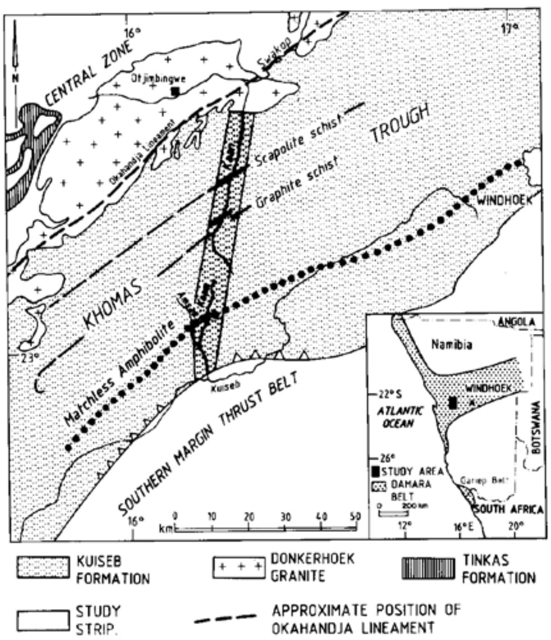


Fig. 1: Simplified geological map of the Central Khomas Trough (or Southern Zone) showing location of the study strip.

Pioneering work on the Kuiseb Formation in the Southern Zone was carried out by Gevers (1963) and Martin (1965). Structural studies were undertaken by Hälbich (1977), Blaine (1977), Sawyer (1981, 1983) and Miller (1979). A study of the lithostratigraphy of the Swakop Group in the Southern Margin Thrust Belt (Fig. 2) was undertaken by Hoffmann (1983). Blaine (1977) and Miller *et al.* (1983) have interpreted parts of the Kuiseb schists as possible fore-arc basin deposits. Metamorphic studies by Hoffer (1977, 1983) and Sawyer (1981) indicate that the metamorphic grade increases from upper greenschist facies conditions in the Southern Margin Thrust Belt to upper amphibolite facies conditions in the Southern Zone.

Detailed geological studies have been undertaken in order to characterize the tectonics and the sedimentation of the Kuiseb Formation in the Southern Zone. The investigated area is a north-south trending, 80 km long river section (Kaan, Koam and Amsas rivers) through the Khomas Hochland, about 120 km west of Windhoek (Fig. 1).

Preliminary results of these structural and sedimentological studies are presented here.

2. LITHOLOGY

The Kuiseb Formation comprises metasedimentary rocks, together with metavolcanic and metagabbroic rocks of the Matchless Amphibolite Belt. The predominant rock types encountered are metapsammites (with

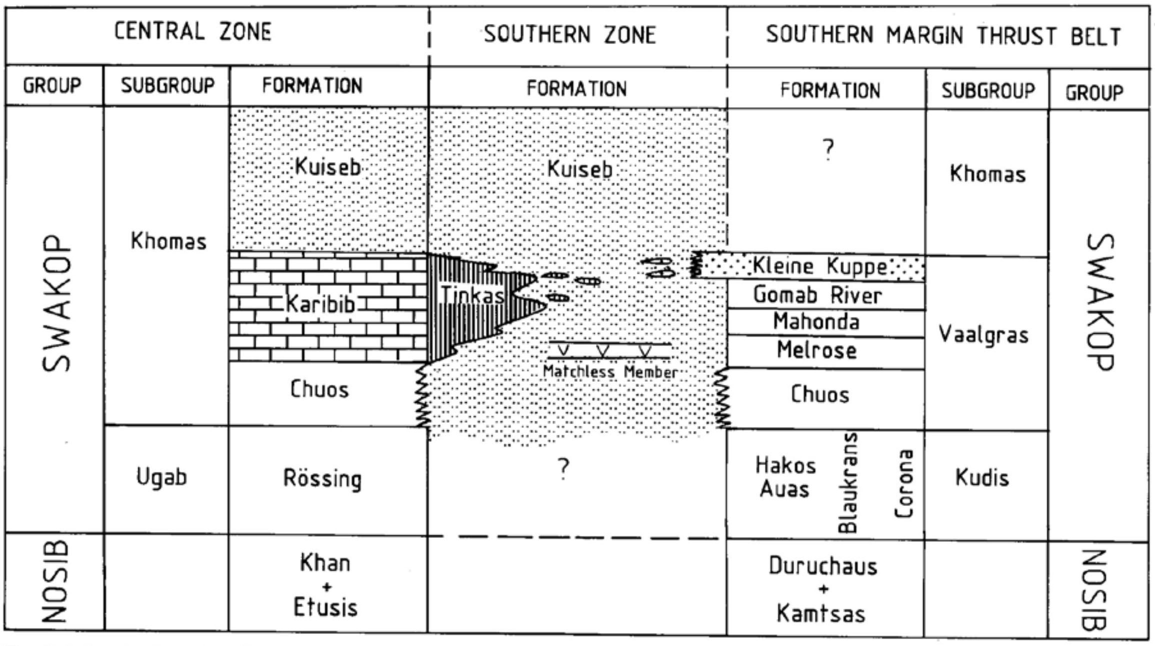


Fig. 2: Lithostratigraphy of the Southern Zone and the adjacent Southern Margin Thrust Belt (after Hoffmann, 1983) and Central Zone (after SACS, 1980).

intercalated layers and spindles of calc-silicates and quartzites in parts of the sequence), metasiltstones and metapelites (subsequently referred to as psammites, siltstones and pelites). Graphitic pelites and scapolite-bearing schists occur in various parts of the traverse (Fig. 3).

2.1 Psammite

The psammites range in thickness from a few centimetres to about 5 m and are light to grey, fine- to medium-grained, mineralogically uniform quartz-plagioclase-mica schists. They occur as either single massive layers with sharp base and top contacts or they grade upward from quartz-rich compositions at the base into mica-rich compositions at the top. Bedding and graded units are widespread and parts of the sequence even have cross-lamination and scour surfaces preserved.

2.2 Siltstone and pelite

Siltstones and pelitic schists range in bed thickness from 1 cm up to more than 10m. They show a variation in their mineralogical composition but are mainly mica-quartz-plagioclase schists. Garnet, staurolite, kyanite, andalusite, sillimanite and chlorite are present depending on composition and metamorphic grade.

2.3 Graphitic schist

Units of schist with a high graphite content and a thickness up to 60 m are developed within the traverse. The thickest of these graphitic pelites crops out on the farm Kaan 309; other units occur close to the contact

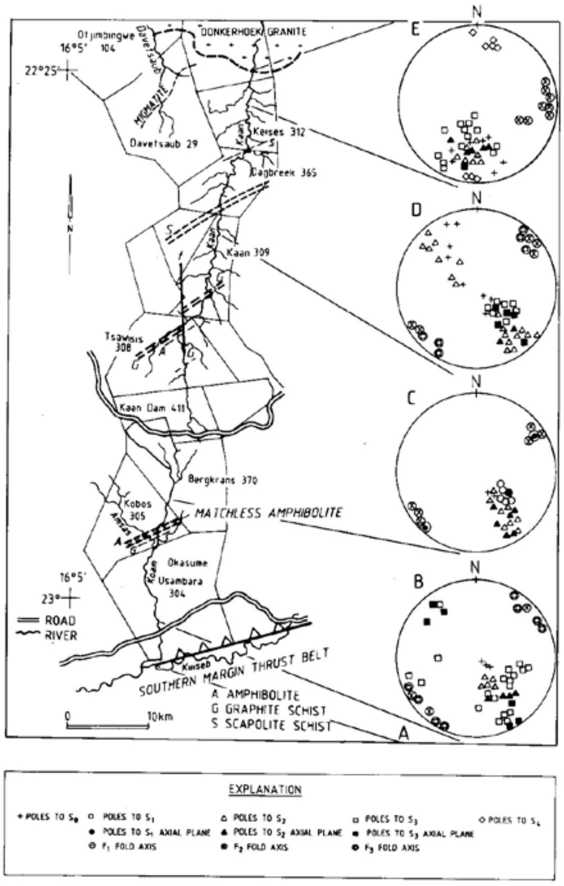


Fig. 3: Map of the study strip showing lithological marker units, structural domains A–E and associated structural fabric data. For details see text.

with the Matchless amphibolite on the farm Kobos 305 (Fig. 3).

2.4 Scapolite schist

Scapolite-bearing schists are a remarkable feature in the Khomas Trough. The scapolite is widespread in a variety of lithologies such as psammites, pelites, calc-silicates and amphibolites. However, the most striking scapolite schist crops out with a thickness of more than 200 m on the farm Dagbreek 365 (Fig. 3). Mapping showed discordant scapolitization of the predominantly pelitic schists. The scapolite occurs as aggregates on the centimetre scale and typically overgrows any structural fabric. Furthermore, extremely scapolite- and calc-silicate-rich pelitic schists are situated along the southern border of the farm Keises 312 (Fig.3).

2.5 Calc-silicate rocks, carbonate-rich and quartzitic rocks

Three different rock types occur as layers and spindles throughout the traverse and have been described by Porada (1973). In the first type 0,5 m thick calc-silicate rocks are composed of quartz, plagioclase, garnet, hornblende, diopside, ziosite, calcite, scapolite and epidote. A second type is carbonate-rich (greater than 20 % calcite) and also comprises quartz, plagioclase, biotite, muscovite and garnet whereas a third, quartzitic type is uniformly composed of quartz, plagioclase, large biotite grains and muscovite.

2.6 Metavolcanics and metagabbroic rocks

The Matchless Amphibolite Belt outcrops as amphi-

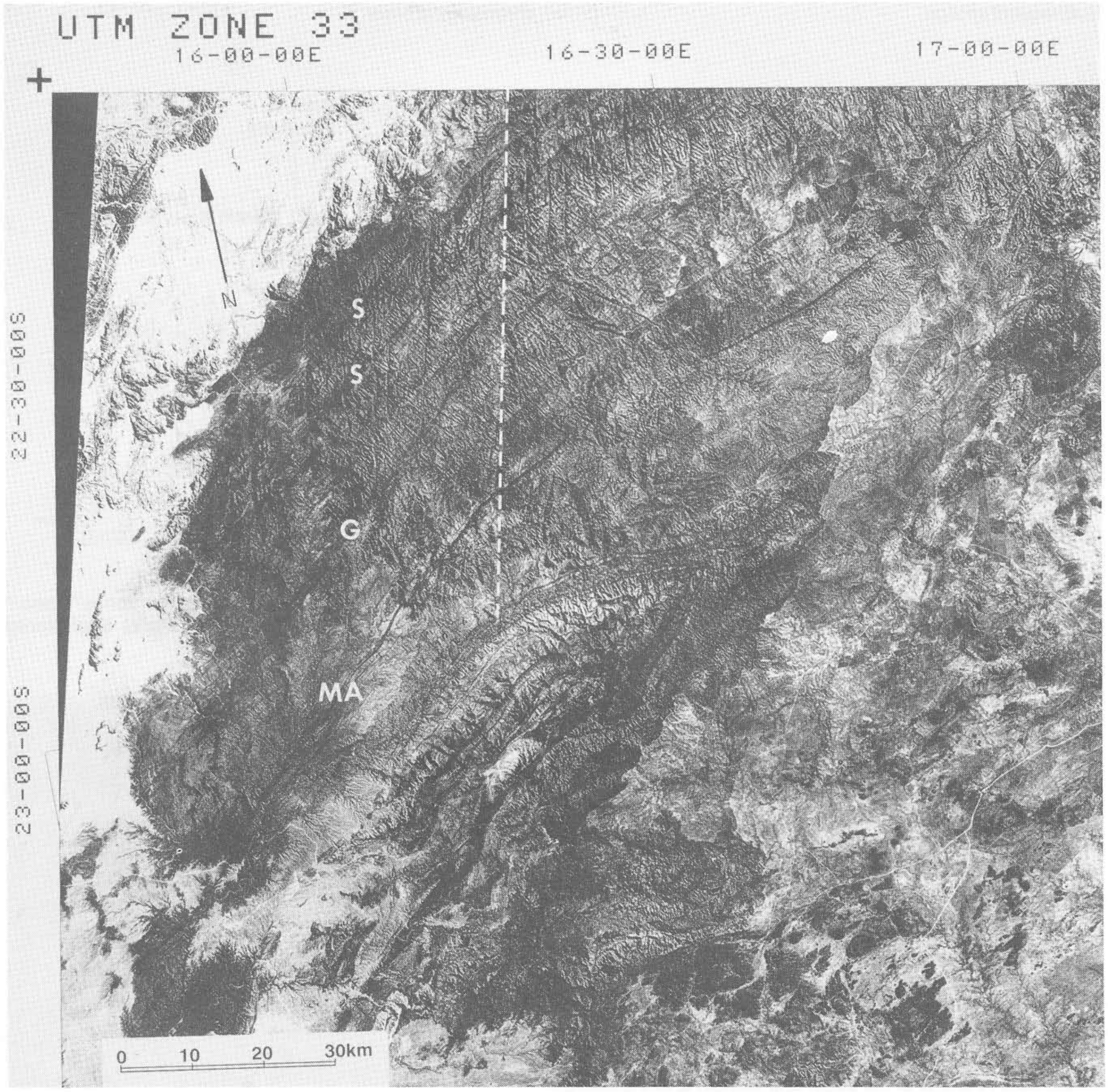


Fig. 4: Landsat image of the Central Khomas Trough showing marker units. Note lateral extent. Study strip is indicated by dashed line. MA = Matchless amphibolite, G = graphite schist, S = scapolite schists (reproduced with permission of the Satellite Applications Centre of the CSIR).

bolitic and metagabbroic rocks on the farm Kobos 305 (Fig. 3). Two types of amphibolite are distinguished; a banded, carbonate-rich type and a massive, dark-green, epidote-rich type. The latter contains pillow structures and is associated with volcanic breccias. The mineralogy of both types of amphibolite comprises plagioclase, hornblende, calcite, biotite, quartz, scapolite and epidote. The Matchless amphibolite in this area consists of two main units separated by approximately 20 m of schists. Graded bedding within these schists indicates that the amphibolite is not overturned as could be shown for other parts of the Khomas Trough (Killick, 1983; Preussinger, 1987; Klemd *et al.*, 1988). A second, tremolitic amphibolite is situated in the footwall of the 60 m thick graphite schist on the farm Kaan 309 (Fig. 3).

2.7 Marker lithologies

The Matchless amphibolite has long been recognized as an important stratigraphic marker in the Khomas Trough. Other markers which have been discerned during this study are the 60 m thick graphite schist on the farm Kaan 309 and the scapolite-rich successions on the farms Dagbreek 365 and Keises 312 (Fig. 1), both of which can be traced on the Landsat image over at least a hundred kilometres (Fig. 4).

3. STRUCTURAL DOMAINS AND DEFORMATION PHASES

3.1 Structural domains

With the exception of the southernmost part of the traverse, sedimentary layers, both graded and ungraded, are well preserved and therefore provide a good stratigraphic control in delineating fold structures. Major changes in fabric development, which sometimes coincide with a change in fold morphology, allow the recognition of five structural zones which are shown in Figs 3 and 5. These zones are referred to as 'domains' in this paper to avoid confusion with other terminology associated with the Damara Sequence. Each of these domains will be described in detail in the next section and phases of deformation will be interpreted in the subsequent section.

3.2 Description of structural domains

Domains C and 0 contain two penetrative cleavages which are overprinted by a third penetrative cleavage in domain 0 (Fig. 3). In both domains open asymmetric folds are apparent with a vergence to the south-east (Fig. 6). These folds are minor structures on the limbs of major synclinoria whose complementary anticlinoria have been structurally eliminated (Fig. 5). The southern part of domain C is characterized by the transition from open to isoclinal folding with associated downward facing folds and minor thrusting. The downward facing is recognized from the overturned aspect of graded units with respect to the axial planar cleavage of the isoclinal folds developed in this area. This is the first time that such downward facing structures have been identified in the Khomas Trough.

The fold style in domains C and 0 contrasts with fold styles in domains A and B to the south and domain E to the north. Domain A is dominated by an intense composite cleavage accompanied by only small scale intrafolial folds (Fig. 7) and a late phase crenulation cleavage. Domain B is characterized by tight to isoclinal folds and two penetrative cleavages which are also overprinted by a later crenulation cleavage. Domain E contains tight isoclinal folds with subvertical axial planes. Downward

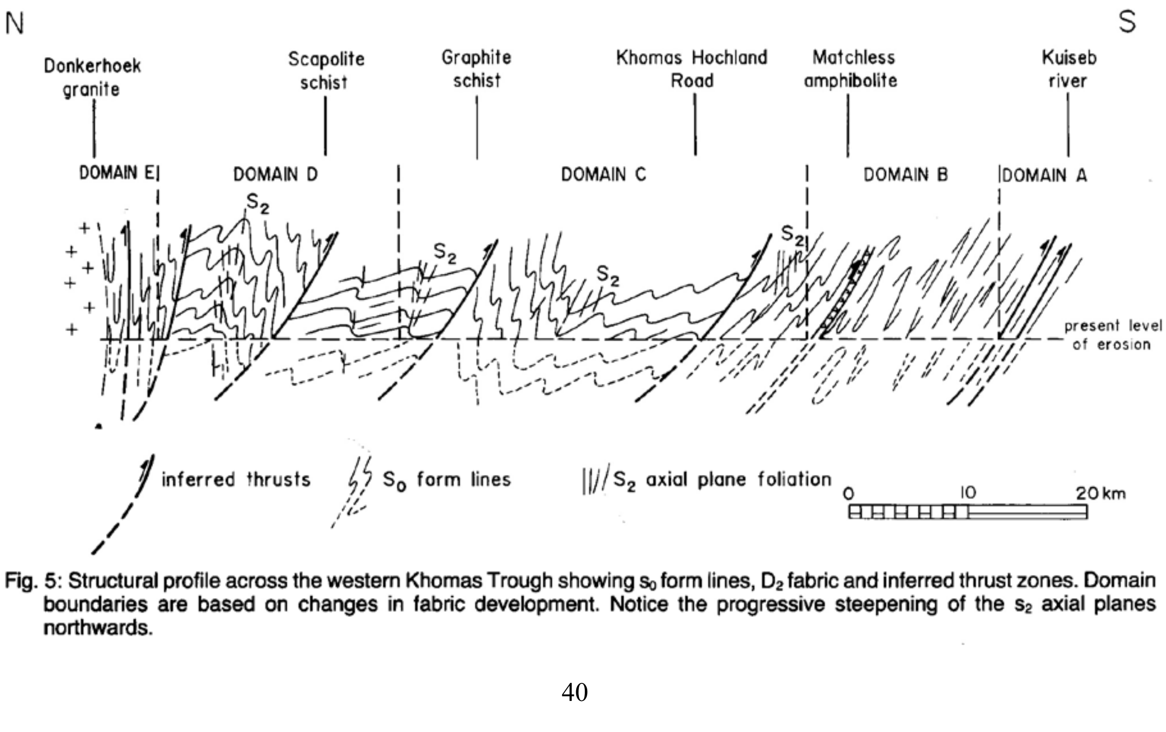


Fig. 5: Structural profile across the western Khomas Trough showing s_0 form lines, D_2 fabric and inferred thrust zones. Domain boundaries are based on changes in fabric development. Notice the progressive steepening of the s_2 axial planes northwards.

Fig. 6: Open asymmetric SE verging F_2 fold in psammitic schists in domain C. Bedding is demarcated by dashed lines. Height of scale is 1,7 m. Farm Kaan 309.

Fig. 8: S_2 metamorphic banding cleavage deformed by small-scale tight F_3 folds in psammitic schist. Note the deformed calc-silicate spindle in s_2 on the right hand side (indicated by arrow). Domain E, farm Keises 312.

facing structures have been identified. The two penetrative cleavages and the overprinting crenulation cleavage in this domain have an easterly strike which is in contrast to the north-easterly strike within the other domains (Fig. 3). In the northernmost part of domain E upright isoclinal folds occur with steeply inclined limbs and cleavages. These may be related to characteristic structures of the Okahandja Lineament Zone described by Miller (1979).

3.3 Deformation phases

Four phases of deformation have been identified within the study area. The second phase of deformation (D_2) is a structural event of regional importance. Fabrics associated with the D_2 event are developed throughout the Khomas Trough. In the investigated area it is characteristic that D_1, D_3 and D_4 fabrics are only recognizable in parts of the section. The deformation events will be described in their inferred chronological order.

3.3.1 D_1 Deformation

Where the earliest recognized fabric occurs, it strikes 050°-060° and dips moderately (30°-40°) towards the north-west. In the southernmost part of the traverse s_1 forms part of the composite $s_{0,\ 1,\ 2}$ fabric and is only preserved in the fold hinges of isoclinal F_2 folds. Within domain C (Fig. 3) s_1 is a metamorphic banding cleavage which is almost as strong as the s_2 metamorphic banding cleavage in this area. Further north the relic nature of s_1 in domain D is expressed by its exclusive preservation in F_2 and F_3 fold hinges. Although there is some evidence for F_1 intrafolial folds, it is not yet clear if s_1 is developed in domain E.

F_1 folds are difficult to detect because of the strong overprint by the s_2 foliation. Only minor-scale tight to isoclinal folds could be observed in the central part of the traverse (Fig. 3).

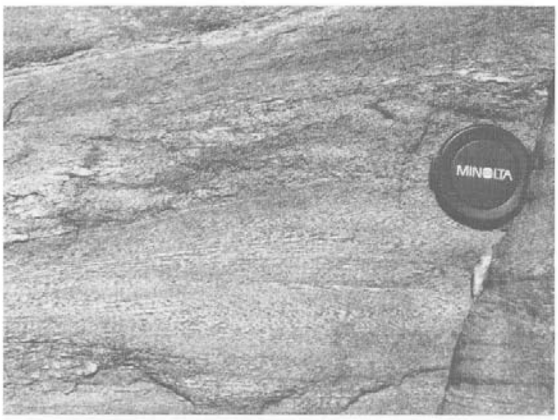


Fig. 7: Early intrafolial folds within an $s_{0,\ 1,\ 2}$ composite fabric in pelitic schist. Domain A, farm Usambara 304.

3.3.2 D_2 Deformation

The D_2 phase of deformation is of regional importance within the Khomas Trough and represents the only deformation with consistent characteristics over large parts of the Southern Zone. Its s_2 fabric therefore forms an excellent marker to correlate older and younger fabrics. The medium-to large-scale folds are a result of this deformational event.

The major feature of D_2 is the steeply north-west dipping s_2 metamorphic banding cleavage (Figs 3 and 8). The strong, penetrative nature of this fabric is defined by parallel orientation of biotite grains. Sillimanite knots are orientated within s_2 in the northern part. Calc-silicate spindles and amphibolite grains in the vicinity of the Matchless amphibolite are mainly orientated in the s_2 fabric as well. In the southern part of the traverse (domain A) s_2 forms part of the composite $s_{0,\ 1,\ 2}$ fabric.

The s_2 fabric is axial planar to F_2 folds which range from open or closed in the central parts (domains C and D) to tight and isoclinal in the north (domain E) and south (domains A and B; Fig. 5). Tight to isoclinal F_2 folds with a wavelength of approximately 10m in domain B and in the southern parts of domain C have north-westerly dipping axial planes and north-easterly and south-westerly plunging fold axes. On the farm Bergkrans 370 there is strong evidence from graded bedding that these folds are downward facing as described previously.

Further north the style of folding changes on the farm Kaan Dam 411 where medium- to large-scale asymmetric open folds build up major synformal and antiformal structures (Fig. 5). Interference patterns between F1 and F2 folds are present at different localities. A long, shallow dipping limb and a short, steeply inclined and in parts slightly overturned limb is the characteristic shape of these folds (Fig. 6). This wide zone of open folding continues up to the northernmost parts of domain D. Strongly isoclinal folding on the 5-10 m scale and east-south-eastward plunging fold axes characterize domain E in the north of the traverse (Fig. 3). The plunging nature of these folds contrasts sharply with those of other domains. Downward facing F_2 folds are again apparent within this domain. Finally the s_2 fabric follows the general trend of rotation of structural features in the aureole of the Donkerhoek Granite.

3.3.3 D_3 Deformation

The third phase of deformation is indicated by the presence of an s_3 crenulation cleavage (Fig. 3) and locally developed asymmetric kinks in domains A and B and a penetrative s_3 cleavage in domains D and E. A third phase of deformation could not be discerned in domain C (Fig. 3). The correlation of the D_3 deformation phases in the southern and the northern parts of the traverse is therefore tenuous.

In domains A and B the s_3 crenulation cleavage dips 40-80° north-west and changes in strike northwards from north-north-east (010°-020°) to north-east (060°) (Fig. 3). Near the Matchless amphibolite in the northern part of domain B the orientation of the fabric changes to a north-east strike (060°) and a nearly vertical dip. It is notable that the crenulation cleavage is intensely developed in this area. Some of the minor scale F_3 folds have south-easterly dipping axial planes (Fig. 3).

The main feature of the third deformation in domains D and E is an s_3 penetrative cleavage which strikes towards the north-north-east (030°) and dips 20-30° north-west (Fig. 3). Although distributed throughout the area, the D_3 deformation is apparent especially in pelitic successions such as the scapolite schists on the farms Dagbreek 365 and Keises 312 (Fig. 9). In these particular areas a distinct mineral reorientation of sillimanite knots, biotite aggregates and staurolite porphyroblasts occurs. The s_2 biotite fabric is characteristically deformed by F_3 folds (Fig. 10) and cut by schistosity planes which are locally developed as shear planes. Open and recumbent F_3 folds with shallow north-westerly dipping axial planes are evident in domain D (Fig. 3). Northwards into domain E, F_3 folds become isoclinal

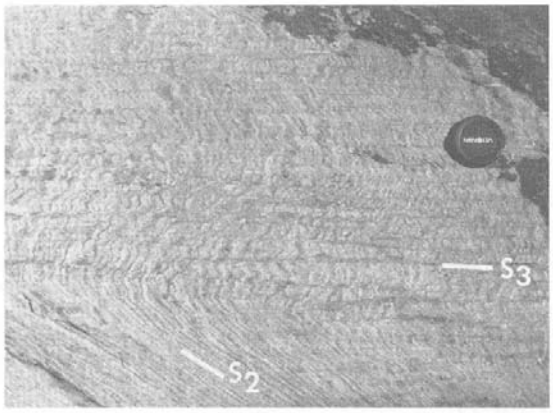


Fig. 9: S_2 metamorphic banding superimposed by intense s_3 spaced fabric in the high strain zone of the scapolite schist on farm Dagbreek 365.


Fig. 10: Typical minor F_3 fold in domain E. Calc-silicate layers within the s_2 fabric are deformed about F_3 folds. Notice minor shear plane parallel to the axial plane of the fold (indicated) on the right hand side. Farm Keises 312.

with steep attitudes. This coincides with the changing geometry of F_2 folds in this area. The rotation of fabrics close to the Donkerhoek Granite affects D_3 structures as well (Fig. 3).

3.3.4 D_4 Deformation

A fourth phase of deformation becomes discernible close to the Donkerhoek Granite. The major feature of D_4 is the almost east-south-east striking and nearly vertical dipping crenulation cleavage (Fig. 3); locally kinking occurs. Sillimanite knots are reorientated into S_4 close to the Donkerhoek Granite. The fact that it is more intense as one approaches the granite suggests that this deformational event might be attributed to the emplacement of this large batholith.

3.4 Thrusting

Field evidence indicates the presence of major structural discontinuities within the Kuiseb schists. These are marked by: (1) more intense overprinting of D_1 and D_2 fabrics by the third deformational event; (2) their association with the upright to overturned limbs of major

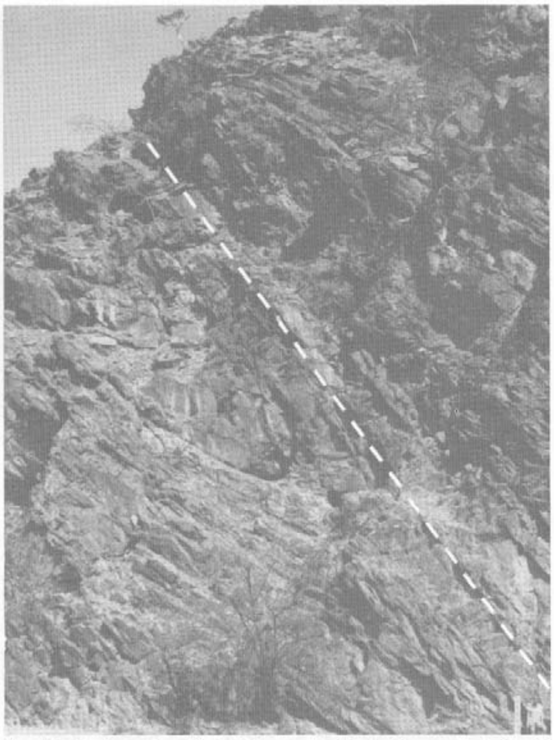


Fig. 11: Tight to isoclinal SE verging F_2 fold associated with a thrust zone (indicated by dashed line). The complementary anticline is sheared out. The outcrop is situated in the upright limb of the major syncline of domain C in Fig. 5. Height of scale is 1,8 m. Farm Tsawisis 308.

open fold structures representing sheared out anticlinoria; (3) associated thrusts in some cases; (4) their position in pelitic successions; and (5) discordant scapolite replacement in the northern part of the traverse. On the farms Bergkrans 370, Tsawisis 308 and Kaan 309 minor thrusts are recognizable by the displacement of layers and the sheared out limbs of isoclinal D_2 folds (Fig. 11). Occasionally downward facing folds are also developed adjacent to these discontinuities which are furthermore characteristic zones of high strain. The position of the major thrusts in association with sheared out antiformal limbs and the minor thrusts strongly suggest that the discontinuities are in fact thrust zones as shown in Fig. 5. The association of these structures with F_2 folds infer a syn- to post-D_2 age of thrusting.

4. SEDIMENTOLOGY

No detailed work has been undertaken so far on the sedimentology of the Kuiseb schists in the Khomas Trough which have been repeatedly referred to as a monotonous sequence of pelitic, semi-pelitic and psammitic schists. Sedimentological investigations within the metasediments of the Kuiseb Formation are seriously hampered by the combined effects of considerable deformation and amphibolite facies metamorphism. However, the common recognition of graded beds as well as the presence of sedimentary structures within domains C and D has confirmed the widespread preservation of original bedding (Fig. 12).

Sedimentological studies in the Kuiseb schists are based on detailed measured sections on a variety of scales from centimetres upward. Major sedimentary cycles are indicated in the field by pronounced changes in the topography which can easily be resolved on aerial photographs and the Landsat image of the area (Fig. 4). The position of these cycles within the traverse is shown in Fig. 13.

4.1 Sedimentary facies

The major attributes used to define facies in the Kuiseb schists are the lateral and vertical bed thickness distribution of psammites and pelites, variations in the psammite/pelite ratio and sedimentary structures.

Four basic facies classes were recognized within the Khomas Trough on the basis of the characteristics shown in Fig. 14.

Measured section data showed that bed thicknesses may be defined according to the scheme by Mutti and Ricci Lucchi (1975) with very thick beds greater than 100 cm; thick beds, 40-100 cm; medium beds, 10-40cm; and thin beds 1-10cm.

4.1.1 Facies class 1

The commonly sharp based psammites of facies class 1 are mostly structureless but may be plane-laminated or cross-laminated (Figs. 15 and 16). Amalgamation is quite common in very thick layers. Graded layering is rare or absent. Further sedimentary structures noted are flute casts (Fig. 16), rip-up clasts, load casts, ball-and-pillow structures, flame structures, 'sandstone' dykes and scour features. Channelling was observed only in the northern part of the study area on a small scale (up to 3 m deep). Where sedimentary structures can be recognized this facies class is organized into partial Bouma sequences, usually starting with a Ta unit.

A few measurements of trough cross-stratification and flute casts indicate palaeocurrent directions ranging between 230º and 250º.

4.1.2 Facies class 2

Interbedded psammite-pelite couplets of facies class 2 show a wide range of psammite/pelite ratios from> 10 : 1 to 1 : 10. Generally, graded layering is the most striking characteristic of this facies. Sedimentary structures preserved are flute casts, rip-up clasts, load casts (Fig. 17) and scour features.

4.1.3 Facies class 3

The fine-laminated siltstone facies occurs only in the central and northern parts of the traverse. It consists of up to 5 m thick sedimentary units which are built up

Fig. 12: Overturned graded psammite/pelite couplets in facies class 2 turbidites showing Bouma divisions A, B and D. Notice the calc-silicate composition at the base of the psammitic layers. Domain B, farm Okasume 304.

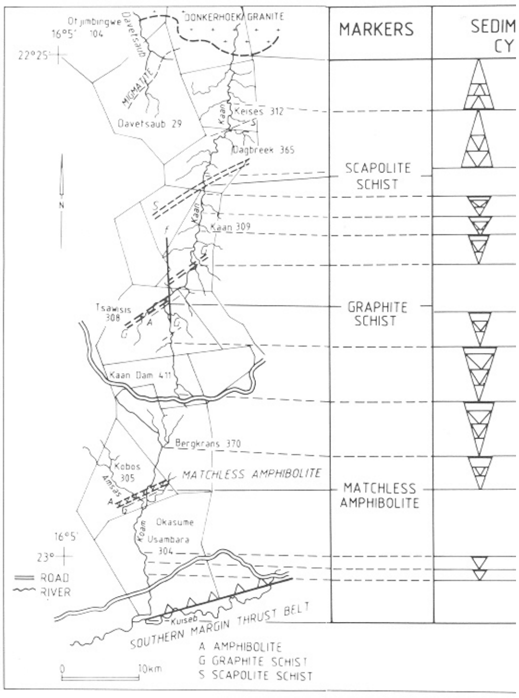


Fig. 13: Map of the study area showing the positi sedimentary cycles in relation to marker uni not recognizable in the southern part becaus transposition and depositional palaeoenvirc details see text).

Four basic facies classes were recognized Khomas Trough on the basis of the characteristi Fig. 14.

	THIS STUDY Facies Class	Pickering et al. (1986) Facies Class	Mutti & Ricci I (1975) Facies
2m	Facies Class (1) medium-to very thick-bedded psammites a) structureless, ungraded b) cross-stratified	 Facies B 1.1 SANDS Facies B 2.2 SANDS	Facies B SANDS
2m	Facies Class (2) graded psammite/pelite couplets a) very thick- to thick-bedded b) medium-bedded c) thin-bedded	 Facies C 2.1 Facies C 2.2 Facies C 2.3	Facies C1 and C
0.5m	Facies Class (3) fine-laminated siltstones	Facies D 2.3	Facies D1
	Facies Class (4)		

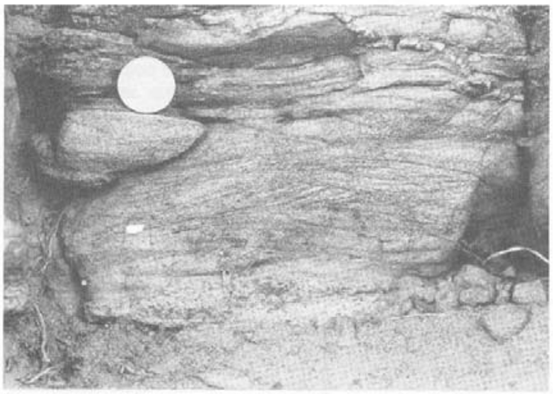


Fig. 15: Trough cross-lamination (Bouma C division) in a facies class 1 turbidite. Coin is 2,5 cm in diameter. Farm Dagbreek 365.

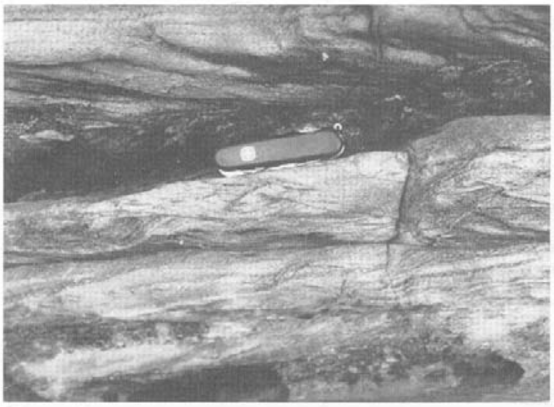


Fig. 16: Trough cross-lamination (Bouma C division) and flute casts (above the scale) in facies class 1 turbidite. Farm Dagbreek 365.

by thin-bedded (<10 cm), graded and ungraded silt and pelite beds. The horizontally bedded layers show some small scale scour features. The siltstone/pelite ratio commonly ranges from 3 : 1 to 2 : 3.

4.1.4 Faciesclass 4

Facies class 4 comprises pelitic layers ranging from several centimetres to tens of metres. The layers are structureless in most cases but lamination may be developed locally. Some of the pelitic layers are characterized by siltstone/pelite gradations with ratios of generally less than 1:3 (Fig. 18).

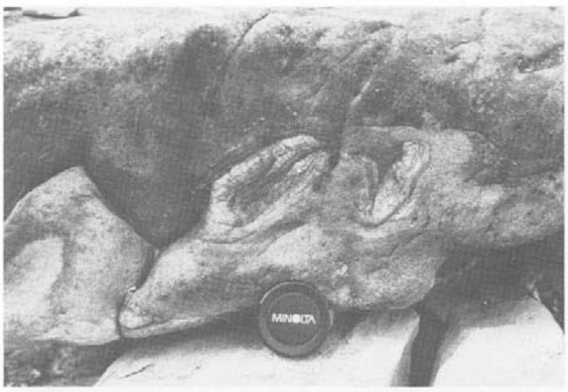
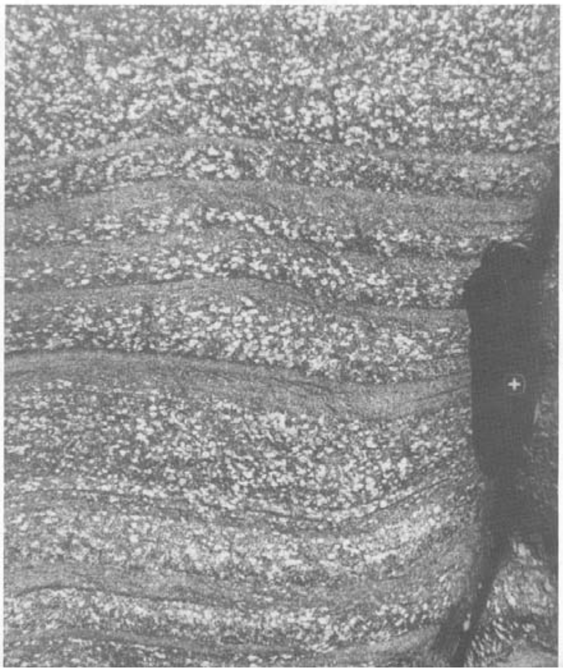


Fig. 17: Overturned load structures in facies class 2 turbidite. Farm Kaan 309.

Fig. 18: Overturned graded siltstone/pelite couplets in facies class 4 turbidites. Notice the selective development of sillimanite in pelite-rich layers. Farm Keises 312.



4.2 Interpretation of sedimentary facies and palaeoenvironment

The predominance of graded beds in large parts of the sequence, the presence of Bouma divisions and the alternation of distinct facies classes imply that the metasediments of the Kuiseb Formation have been deposited by turbidity currents. The facies described here compare with those defined by Pickering *et al.* (1986) and Mutti and Ricci Lucchi (1975) as shown in Fig. 14.

Our sedimentological studies in the western Khomas Trough show that the vertical arrangement of facies defines nested thinning and thickening upward cycles (Fig. 19) in major parts of the sequence (Fig. 13). Although there is a considerable amount of internal folding within these cycles, sequential lithofacies changes are obvious and can easily be traced laterally on all scales. Therefore the cycles may be regarded as coherent stratigraphic units extending over more than 100 km as recognized on the Landsat image (Fig. 4).

The organization into cyclic and non-cyclic successions on a variety of scales reflects progradational and retrogradational character. These, together with the different facies classes described above, indicate that the Kuiseb schists have been deposited within a submarine fan system. The lateral extent of major sedimentation units together with the uniformity of lithologies and the lack of coarse-grained material strongly suggest a mixed-sediment elongate fan system as defined by Nel-

Fig. 19: Minor scale (3 m) thickening-upward cycle in facies class 1 turbidites. Farm Tsawisis 308.

son and Nilsen (1984).

Elongate submarine fans differ from small-scale radial fans, in that they are generally characterized by a major sediment source. It is characteristic for most of the large deep-sea fan systems which are fed by a major river source that fine- to medium-grained sands and large amounts of mud are transported over several hundreds of kilometres parallel to the basin axis. It is typical for example in the Astoria fan off the Oregon shelf (Nelson, 1984) that sand is being transported efficiently by turbidity currents into the outer fan and even abyssal plains of the basin. The elongate shape of the fan is built up by extensive distributary-channel systems through which the sand-load is funnelled to the outer parts of the fan. The sand/mud ratio therefore increases characteristically downfan.

In comparison with modern and ancient deep-sea fan systems (Mutti and Ricci Lucchi, 1975; Nelson and Nilsen, 1984; Pickering *et al.*, 1986), the partly channellized and pelite-rich sequences which build up nested thinning-upward cycles in the northern part of the traverse (Fig. 13) could be referred to the middle-fan area of an idealized fan system. The major thinning-upward cycle containing nested minor scale thickening-upward cycles north of the scapolite schist (Fig. 13) is interpreted as the transition from middle-fan to outer-fan deposition. Further south the wide zone of nested thickening-upward cycles with high psammite/pelite ratios on the one hand and pelite-rich sequences on the other hand, can be related to deposition on the outer-fan, probably comprising mainly suprafan-lobe deposits (facies class 1 and 2 turbidites) characterized by great lateral extent and uniform palaeocurrent directions. Overbank deposits in this part of the fan are thin-bedded facies class 1, 3 and 4 turbidites and interchannel and fan fringe areas facies class 3 (Nelson *et al.*, 1978).

Basin plain deposits are developed south of the Matchless amphibolite where the metasediments are largely characterized by a lack of cyclicity, a high pelite content and a reduced layer thickness (Fig. 13).

5. CONCLUSIONS

Enough evidence is so far available from the Kuiseb Formation to give an initial appraisal of the depositional palaeoenvironment and structural history of the Khomas Trough.

The interpretation of the Kuiseb schists as the deposits of an elongate deep-sea fan system is indicated by the sedimentary facies and the great lateral extent of large scale sedimentary cycles which can be traced for more than 100 km along the Khomas Trough. The relative uniformity in lithology and grain size (i.e. no conglomeratic material) implies a rather consistent source area through space and time for the bulk of the Kuiseb schists. Palaeocurrents indicate that the major sediment source was situated towards the eastern end of the trough. With regard to the overall tectono-sedimentary setting it is more likely that the Kuiseb schists were deposited within an open ocean than within a restricted basin setting. The latter would differ and would be characterized by a large number of closely situated source areas which provide coarse-grained sediments. This setting inhibits a wide sediment dispersal and the development of elongate shapes (Normark and Piper, 1983).

The deformation events documented in this paper record the closure history of this open basin. The large scale open asymmetric D_2 folds in the middle of the Khomas Trough which consistently verge towards the south-east contrast with tight to isoclinal folds developed along the margins to the north and the south. These fold styles together with the recognized thrusts indicate that the submarine fan sediments were telescoped during this closing phase. The progressive closure of the basin is recorded by successive deformational events D_1, D_2 and D_3. The D_4 phase of deformation may probably be attributed to the late-tectonic emplacement of the Donkerhoek Granite.

6. ACKNOWLEDGEMENTS

This study forms part of a research project on the tectonics and sedimentation of the Kuiseb Formation in the south-western part of the Damara Orogen. The project is funded by the Geological Survey of South West Africa/Namibia and we have greatly benefited from discussions with our Survey colleagues, in particular Dr R.McG. Miller, Mr R. Swart and Mr K.H. Hoffmann. The Deutsche Forschungsgemeinschaft is thanked for additional funds. We also appreciate useful discussions with Prof. M. Okrusch and Mr H. Preussinger from Wurzburg University, Mr L. Kruger and Mr D. Corbett from Gold Fields/Namibia and Mr R. Schneeweiss from Rössing Uranium Ltd. Thanks also to Charlie Hoffmann and Tim Smalley for critical reading of the original manuscript. Mr M. Hudson, Mrs A. Workman-Davies and Miss A. Walker are thanked for the preparation of figures.

7. REFERENCES

Blaine, J.L. 1977. Tectonic evolution of the Waldau Ridge structure and the Okahandja Lineament in part of the Central Damara Orogen, west of Okahandja, South West Africa. *Bull. Precambr. Res. Unit, Univ. Cape Town*, **21**, 99 pp.

Gevers, T.W. 1963. Geology along the northwestem margin of the Khomas Highlands between Otjimbingwe-Karibib and Okahandja, South West Africa. *Trans. and Proc. geol. Soc. S. Afr*., **66**, 199-258.

Hälbich, I.W. 1977. Structure and tectonics along the southern margin of the Damara mobile belt, South West Africa. *Ann. Univ. Stellenbosch, Ser. AI (Geol)*, **2**, 149-247.

Hoffer, E. 1977. *Mineralparagenesen und Reaktionen in den Al-reichen Metapeliten des zentralen Damara-Orogen*. Ber. SondForschBers 48 (unpubl.), Univ. Göttingen, 170-183.

Hoffer, E. 1983. Compositional variations of minerals involved in low- to medium-grade isograd reactions in the Southern Damara Orogen, Namibia, South West Africa, 745-767. *In*: Martin, H., and Eder, F.W. (Eds), *Intracontinental Fold Belts - Case Studies in the Variscan Belt of Europe and the Damara Belt in Namibia*. Springer-Verlag, Berlin, 945 pp.

Hoffmann, K.H. 1983. Lithostratigraphy and Facies of the Swakop Group of the Southern Damara Belt, SWA/Namibia, 43-63. *In*: Miller, R.McG. (Ed.), *Evolution of the Damara Orogen of South West Africa/Namibia*. Geol. Soc. S. Afr. Spec. Publn, **11**, 515 pp.

Killick, A.M. 1983. Sulphide mineralization-at Gorob and its genetic relationship to the Matchless Member, Damara Sequence, SWA/Namibia, 381-384. *In*: Miller, R.McG. (Ed.), *Evolution of the Damara Orogen of South West Africa/Namibia*. Geol. Soc. S. Afr. Spec. Publn, **11**, 515 pp.

Klemd, R., Maiden, K.J., Okrusch, M., and Richter, P. 1988. Geochemistry of the metamorphosed massive sulphide deposit Matchless, South West Africa/Namibia: wall rock alteration during submarine oreforming processes. *Econ. Geol*., in press.

Martin, H. 1965. The Precambrian Geology of South West Africa and Namaqualand. *Precambr. Res. Unit, Univ. CapeTown*, 159 pp.

Martin, H. 1983. Overview of the Geosynclinal, Structural and Metamorphic Development of the Intracontinental Branch of the Damara Orogen, 473-502. *In*: Martin, H., and Eder, F.W. (Eds), *Intracontinental Fold Belts-Gase Studies in the Variscan Belt of Europe and the Damara Belt in Namibia*. Springer-Verlag, Berlin, 945 pp.

Miller, R.McG. 1979. The Okahandja Lineament, a fundamental tectonic boundary in the Damara Orogen of South West Africa/Namibia. *Trans. geol. Soc. S. Afr*., **82**, 349-361.

Miller, R.McG. 1983. The Pan-African Damara Orogen of South West Africa/Namibia, 431-515. *In*: Miller, R.McG. (Ed.), *Evolution of the Damara Orogen of South West Africa/Namibia*. Geol. Soc. S. Afr. Spec. Publn, **11**, 515 pp.

Miller, R.McG., Barnes, S.-J., and Balkwill, G. 1983. Possible Active Margin Deposits within the Southern Damara Orogen: The Kuiseb Formation between Okahandja and Windhoek, 73-88. *In*: Miller, R.McG. (Ed.), *Evolution of the Damara Orogen of South West Africa/Namibia*. Geol. Soc. S. Afr. Spec. Publn, **11**, 515 pp.

Miller, R.McG., and Hoffmann, K.H. 1981. Geology of the Damara Belt. *Excursion Guide, Geocongress '81, Geol. Soc. S. Afr*., 115 pp.

Mutti, E. and Ricci Lucchi, F. 1975. Turbidite facies and facies associations, 21-36. *In*: Mutti, E. *et al.* (Eds), *Examples of Turbidite Facies and Associations from Selected Formations of the Northern Apennines*. Field Trip Guidebook A-11, 9th International Association of Sedimentologists Congr., Nice.

Nelson, C.H. 1983/1984. The Astoria Fan: An Elongate Type Fan. *Geo-Marine Letters*, **3**, 65-70.

Nelson, C.H. and Nilsen, T. 1984. Modern and ancient deepsea fan sedimentation. *SEPM Short course No. 14*, 404 pp.

Nelson, C.H., Normark, W.R., Bouma, A.H. and Carlson, P.R. 1978. Thin-bedded turbidites in modern submarine canyons and fans, 177-189. *In*: Stanley, D.J. and Kelling, G.H. (Eds), *Sedimentation in submarine canyons, fans and trenches*. Stroudsburg, Pennsylvania, Dowden, Hutchinson and Ross, Inc.

Normark, W.R. and Piper, D.J.W. 1983/1984. Navy Fan, California Borderland: Growth pattern and depositional processes. *Geo-Marine Letters*, **3**, 101-108.

Pickering, K.T., Stow, D.A.V., Watson, M.P. and Hiscott, R.N. 1986. Deep-water facies, processes and models: a review and classification scheme for modern and ancient sediments. *Earth-sc. Rev*., **23**, 75-174.

Porada, H. 1973. Tektonisches verhalten und geologische Bedeutung von Kalksilikatfels-Lagen und-Spindeln im Damara-Orogen Südwest-Afrikas. *Geol. Rdsch*., **62**, 918-938.

Porada, H. 1983. Geodynamic Model for the Geosynclinal Development of the Damara Orogen, Namibia, South West Africa, 503-541. *In*: Martin, H. and Eder, F.W. (Eds), *Intracontinental Fold Belts - Case Studies in the Variscan Belt of Europe and the Damara Belt in Namibia*. Springer-Verlag, Berlin, 945 pp.

Preussinger, H. 1987. *Die geologische Situation der Erzlinse Vendome im Gorob-Bezirk, SWA/Namibia*. Diploma thesis (unpubl.), Univ. Würzburg, 137 pp.

Sawyer, E. W. 1981. Damaran structural and metamorphic geology of an area south-east of Walvis Bay, SWA/Namibia. *Mem. geol. Surv. S.W. Afr./Namibia*, **7**, 94 pp.

Sawyer, E. W. 1983. Structures in the contact strain aureole of the Donkerhuk Granite, Gross Barmen area, South West Africa/Namibia, 209-217. *In*: Miller, R.McG. (Ed.), *Evolution of the Damara Orogen of South West Africa/Namibia*. Geol. Soc. S. Afr. Spec. Publn, **11**, 515pp.

South African Committee for Stratigraphy (SACS), 1980. Stratigraphy of South Africa. Part 1 (Comp. Kent, L.E.) Lithostratigraphy of the Republic of South Africa, South West Africa/Namibia and the Republics of Bophuthatswana, Transkei and Venda. *Handb. geol. Surv. S. Afr.*, **8**, 690 pp.