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Mid-Proterozoic tectonic evolution along the Orange River on the border between South Africa and Namibia

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The border region between South Africa and Namibia straddles tectono-stratigraphic terranes that formed during different orogenic periods, these being 2.0 to 1.7 Ga (the Orange River Orogeny) and 1.4 to 1.1 Ga (the Namaqua Orogeny). Terranes of the western part of the Namaqua mobile belt situated in the Northern Cape Province were amalgamated during the latter orogeny and are easterly trending and lozenge shaped in plan (hundreds of km scale). These include the Grünau, Pofadder plus Steinkopf, Aggeneys and Okiep Terranes. They are bounded by major thrust zones that were subsequently re-activated during progressive ductile shear deformation. The Namaqua orogenic deformation has effectively overprinted the Orange River deformational features. The tectonic style and terrane evolution were dominated by horizontal movements during progressive ductile shear processes in a mid-crustal setting. Transport direction during the Namaqua Orogeny was from northeast to southwest and inter-terrane displacement exceeded 100 km. Nappes and southward verging folds are revealed by structural sections. Selected structures from the Pofadder and Aggeneys terranes are discussed as examples and are used to constrain a three-dimensional model for the entire region. It is concluded that the structural development of the region was dominated by northeasterly oriented compressional stress associated with plate convergence, resulting in the accretion of terranes onto the Kaapvaal Craton.

Introduction

The structural and stratigraphic features of the highly deformed and metamorphosed region along the Orange River, on the border between South Africa and Namibia, have been discussed in numerous papers over the last three decades (Joubert, 1971, 1974, 1986; Blignault, 1974; Beukes and Botha, 1975a and b; Kröner and Blignault, 1976; Tankard *et al.*, 1982; Blignault *et al.*, 1983; Hartnady *et al.*, 1985; Watkeys, 1986; van Aswegen *et al.*, 1987; Cilliers and Beukes, 1988; Moore, 1989; van der Merwe and Botha, 1989; Colliston *et al.*, 1991; van der Merwe, 1995; Colliston and Schoch, 1996, 1998; Visser, 1998).

The region consists of tectonites that were formed as a consequence of two distinct orogenies, the Orange River/Kheis Orogeny (2.0 to 1.7 Ga) and the Namaqua Orogeny (1.4 to 1.1 Ga) (Blignault *et al.*, 1983; Reid and Barton, 1983; Barton and Burger, 1983). Some authors have correlated these events respectively to the Eburnian and Kibaran of Central Africa. These interpretations are essentially supported by the most recent SHRIMP data (Robb *et al.*, 1988). The region consists of numerous lozenge-shaped terranes (Fig. 1) hundreds of kilometres in length. The present terrane assembly took place during the earlier part of

Table 1: Provisional correlation of plutonic and supracrustal rocks in the western part of the Namaqua mobile belt.

	DEFORMATION	AGE Ga	OKIEP TERRANE Suite/Subgroup	OKIEP TERRANE Unit/Formation	STEINKOPF TERRANE Suite/Subgroup	STEINKOPF TERRANE Unit/Formation	POFADDER TERRANE Suite/Subgroup	POFADDER TERRANE Unit/Formation	GRüNAU TERRANE Suite/Subgroup	GRüNAU TERRANE Unit/Formation	AGGENEYS TERRANE Suite/Subgroup	AGGENEYS TERRANE Unit/Formation
		0.90_{12}			Blesberg Suite	Pegmatites	Blesberg Suite	Pegmatites				
Namaqua Orogeny	Late shears, Late open folds.	1.05_{11}	Koperberg Suite						Tantalite Valley Suite	Metanorite/ gabbro		
Namaqua Orogeny	Terrane-bounding thrusts: Klein Fish River -, Groothoek -, Skelmfontein Thrust.		Terrane accretion ends									
Namaqua Orogeny		1.10_{10}	Spektakel Suite	Kweekfontein-, Rietberg -, Concordia Granite	Spektakel Suite	Middelplaat Dykes, Wyepoort-, Eyams Granite.				Schuitdrif Granite; Daberas Granodiorite; Naros Granite; Stolzenfels Enderbite; Witwater Granite		
Namaqua Orogeny	Early Namaqua deformation (including thrusts, isoclinal folds, sheath folds, L-S fabric).	1.20_9	Little Namaqualand Suite (?)	Modderfontein/Areb-, Nababeep Gneiss	Little Namaqualand Suite (?)	Konkyp Gneiss	Little Namaqualand Suite	Kabis-, Swartmodder-, Mission-, Boerputs Gneiss	Little Namaqualand Suite	Eendoorn Gneiss	Little Namaqualand Suite(?)	Aroams Gneiss, Koeipoort Gneiss (?)
Namaqua Orogeny		$\sim 1.3_8$	Terrane accretion begins									
Orange River Orogeny		1.60_7									Bushmanland Group	Koeris Fm.
Orange River Orogeny							Vioolsdrif Suite (VS)					
Orange River Orogeny	Pre-Namaqua Deformation.	1.73_6						Late leucophase "Coboop Gneiss"				
Orange River Orogeny		1.75_5										
Orange River Orogeny		1.85_4	Gladkop Suite		Gladkop Suite	Noenoemaasberg-, Brandewynsbank-, Steinkopf Gneiss.				Eendoorn Gneiss (?)		Migmatitic Achab Gneiss
Orange River Orogeny		1.95_3					Vioolsdrif Suite (VS)	VS Early phase granitoids, ultramafic rocks. Wortel mafic bodies.				Hotson Fm.
Orange River Orogeny	Pre-Vioolsdrif deformation (including thrusts and isoclinal folds).	1.99_2					Pella Subgroup	Cammas Fm; Kabas Fm; Dabenoris Fm.			Bushmanland Group	Thammaberg Fm ; Skelmpoort Fm; Witputs Fm; Wortel Fm.
Orange River Orogeny		2.00_1	Khurisberg Subgroup	Ratelpoort metasediments	Eenriet Subgroup?		Haib Subgroup	Nous/Guadom Fm; Gaidib/Boerputs Fm; Tsams Fm with metasediment (Koisabes-, Abbasas-, Naroep Succession); Hom Fm; Groothoek Fm.	Grünau Subgroup (Korannaland Succession)	Uitdraai Formation; Toeslaan Formation.		Koeipoort Gneiss?
Orange River Orogeny							Eenriet Subgroup	Kabina Fm; Besondermeid Fm.				

1-12: Reid, 1977; Reid and Barton 1983. 9-12: Robb et al., 1988.

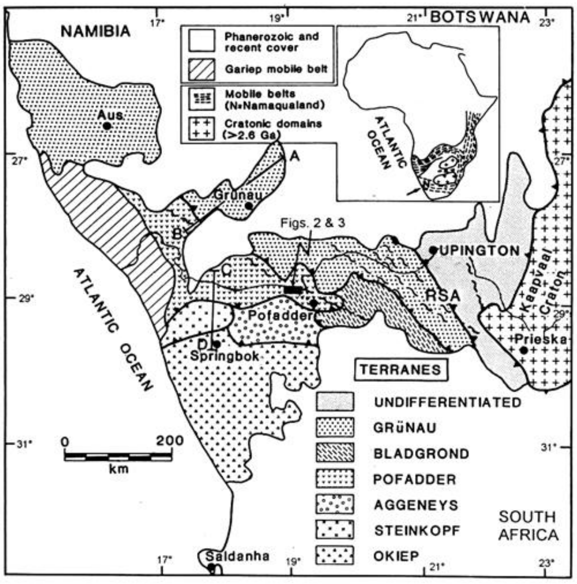


Figure 1: Locality map, indicating terranes of the Namaqua mobile belt and the position of a generalised section shown in Fig. 6.

the Namaqua Orogeny.

The existence of older deformation is revealed only in regions of particularly low strain in the Steinkopf, Pofadder and Grünau terranes. Elsewhere, the penetrative deformation caused by the Namaqua Orogeny has largely obliterated the older (Eburnian) structures. The penetrative deformation in the adjacent Okiep and Aggeneys terranes is Namaqua in age.

The terrane-bounding thrust zones of Namaqua age have themselves been deformed and locally re-activated during progressive deformation, resulting in superimposed folding and subvertical shear displacement. For this reason, the stratigraphy and structure can be unraveled only after completion of detailed sequence mapping (Colliston *et al.*, 1989). This paper summarises the stratigraphy, structure and evolution of the Namaqua mobile belt along the border between South Africa and Namibia using a few key structures as illustrative examples.

Stratigraphy

The terranes exhibit unique as well as communal stratigraphic characteristics (Tables 1 and 2). Felsic plutonic magmatism (e.g. Little Namaqualand Suite) that

Table 2: Lithological characteristics of some prominent supracrustal and intrusive rocks in the western part of the Namaqua mobile belt

SUPRACRUSTAL ROCKS		LITHOLOCIAL DESCRIPTION
Besondermeid Formation	-	Garnet-biotite-sillimanite schist.
Cammas Formation	-	Layered sequence of white and green coloured quartzite with biotite-sillimanite schist, iron formation and conglomerate.
Dabenoris Formation	-	White and grey coloured quartzite with interbanded quartz-muscovite schist.
Groothoek Formation	-	Mica-quartz schist.
Guadom Formation	-	Mainly mafic metavolcanic rocks.
Hom Formation	-	Mainly felsic metavolcanic rocks.
Hotson Formation	-	Feldspathic quartzite and rhythmites (includes Gams member, mineralised)
Kabas Formation	-	Biotite-sillimanite schist with interbanded iron-formation and calc-silicate rock.
Kabina Formation	-	Quartzite and minor aluminous schist.
Koeris Formation	-	Amphibolite/conglomerate units within a sequence of quartz-muscovite schist and feldspathic quartzite.
Nous Formation	-	Mainly felsic metavolcanic rocks.
Ratelpoort metasediments	-	Quartzite, feldspathic quartzite and aluminous schist.
Skelmpoort Formation	-	Quartz-muscovite-sillimanite schist with fuchsite, graphite and amphibole.
T'hammaberg Formation	-	Sulphide bearing quartzite and graphite schist
Toeslaan Formation	-	Cordierite-sillimanite rocks.
Tsams Formation	-	Mainly felsic metavolcanic rocks.
Uitdraai Formation	-	Cordierite-sillimanite rocks and biotite gneiss.
Witputs Formation	-	Layered sequence of metaquartzite with biotite-sillimanite schist.
Wortel Formation	-	Biotite-sillimanite schist with interbanded quartzite and amphibolite/calc-silicate units.

INTRUSIVE ROCKS		LITHOLOGICAL DESCRIPTION
Achab Gneiss	-	Migmatitic leucogneiss.
Aroams Gneiss	-	Megacrystic quartz-feldspar-biotite granite.
Eendoorn Gneiss	-	Well-foliated biotite-hornblende augen gneiss.
Gladkop Suite	-	Migmatitic leucogneiss.
Kabis Gneiss	-	Augen gneiss.
Koeipoort Gneiss	-	Augen gneiss.
Konkyp Gneiss	-	Augen gneiss.
Koperberg Suite	-	Copper bearing dyke-like bodies; mainly anorthosite, leucodiorite and leuconorite, with norite, micadiorite, ferrodiorite, hypersthenite and glimmerite.
Little Namaqualand Suite	-	Augen gneiss.
Naros Gneiss	-	Foliated porphyritic hornblende-biotite granite.
Pella Gneiss	-	Augen gneiss.
Spektakel Suite	-	Late tectonic leucogranites. Middelplaat Dykes are metalamprophyres.
Stolzenfels Enderbite	-	Foliated charnockitic rock.
Vioolsdrif Suite	-	Tholeiitic metagabbros and ultramafic rocks, diorite, granodiorite and granite. Leucogranite dominates younger phase.
Wortel Bodies	-	Partly foliated mafic intrusives.
Witwater Gneiss	-	Foliated, leucocratic (pegmatitic) granite.

was generated between 1.20 to 1.10 Ga during and after amalgamation, is generally common to all terranes. These intrusives contain xenoliths of older igneous material and metasediments. Most of the presently exposed rocks in the western Namaqua mobile belt are of igneous origin. Many of the quartzofeldspathic gneisses that were assumed to be of volcanic origin by some authors in the past (Moore, 1989) have been demonstrated to be deformed equivalents of plutonic rocks (van Aswegen, 1988).

The unique features of the terranes, such as the supracrustal successions that pre-date the Namaqua Orogeny, relate to depositional conditions (>1.2 Ga) in the provenance regions. Basin analysis of the metasediments has been attempted for the Aggeneys Terrane (Strydom and Visser, 1986; Praekelt and Schoch, 1997; Praekelt *et al.*, 1997) and in part for the Pofadder Terrane (Colliston, 1983; Colliston and Schoch, 1996). The provenance regions of these two terranes prove to be unrelated.

The Bushmanland Group in the Aggeneys Terrane (Table 1) represents deposits in a retro-arc foreland basin (Praekelt *et al.*, 1997). The Haib Subgroup in the Pofadder Terrane represents an island-arc depositional sequence associated with calc-alkaline magmatism (Vioolsdrif Suite) (Ritter, 1980). Specific sequences in the Haib Subgroup (Boerputs, Abbassas, Koisabes and Naroep Formations) and the Pella and Eenriet Subgroups (Table 1) represent deposits in second-order, back-arc basins (Colliston and Schoch, 1996). The sediments of these second-order basins are now represented by quartzite, calc-silicate rock, banded iron formation and peraluminous metasediment, with intercalated felsic and tholeiitic volcanic material (Colliston and Schoch, 1996; Strydom and Visser, 1986). The supracrustal sequence (Grünau Subgroup) in the Grünau terrane is characterised by a monotonous metapelite/metagreywacke succession, indicating a distal turbidite sequence (Blignault *et al.*, 1983), i.e. the type of environment associated with fore-arc domains.

The rock sequence in the Steinkopf Terrane (Gladkop Suite, Table 1) consists of highly deformed plutonic rocks and migmatites, reflecting a lower lithospheric origin (van Aswegen, 1988). The exact relationship between the Steinkopf Terrane and the adjacent Pofadder Terrane is obscured by the Groothoek thrust zone (terrane boundary; van der Merwe and Botha, 1989), but it is possible that the Steinkopf Terrane represents a deep crustal slice originally situated below the Pofadder terrane (van Aswegen *et al.*, 1987). The Okiep terrane is interpreted to be composite, comprising material that relates to the Steinkopf terrane as well as to fragments of other derivation. The Ratelpoort metasediments of the Khuriesberg Subgroup (Table 1) represent continental margin deposits, essentially similar to those of the Aggeneys Terrane (Blignault *et al.*, 1983; Strydom, 1985).

Structure

Correlation and dating of the early planar fabrics in the terranes poses a major structural problem because the use of structural style to define relative age ($F_1 – F_n$) in tectonites formed by progressive shear deformation usually leads to ambiguous interpretations (Colliston *et al.*, 1989). To resolve this problem it is necessary to make use of broad time markers such as intrusive suites. The use of such markers is however dependant on the quality of mapping and on the precision of geochronological dating. The structural history in the region under discussion is based on detailed mapping of the Vioolsdrif and Klein Namaqualand Suites and the radiometric dating of various members of the suites.

Detailed mapping has shown that the early phase of the progressive Namaqua deformation that is imprinted on the various terranes (Table 1), resulted in a composite LS fabric. The metamorphic grade varies from upper amphibolite to granulite (Beukes and Botha, 1975a; van Zyl, 1986; Pretorius, 1986; van Aswegen, 1988; Waters, 1988, 1989). This early phase of deformation resulted in:

(1) A composite planar structure with easterly strike, shallow northerly dip and composed of several foliated lithological layers (including syntectonic granite sheets). Isoclinal folds and thrusts of different ages are included in the foliation;
(2) A composite NE-trending linear structure that comprises various lineations (mineral lineations, long axes of clasts and boudins and the hinges of isoclinal, sheath and upright folds).

The later phase of the Namaqua deformation (Table 1) comprises deformation of the early LS-fabric and the development of:

(1) A set of macroscopic late folds with upright axial planes and with fold axes subparallel to the earlier NE-trending linear structure;
(2) Extensive late shears with associated high-grade fabrics that may be correlated regionally.

The styles of Orange River and Namaqua deformation will be illustrated by means of selected structures in the Pofadder and Aggeneys Terranes.

Orange River Deformation

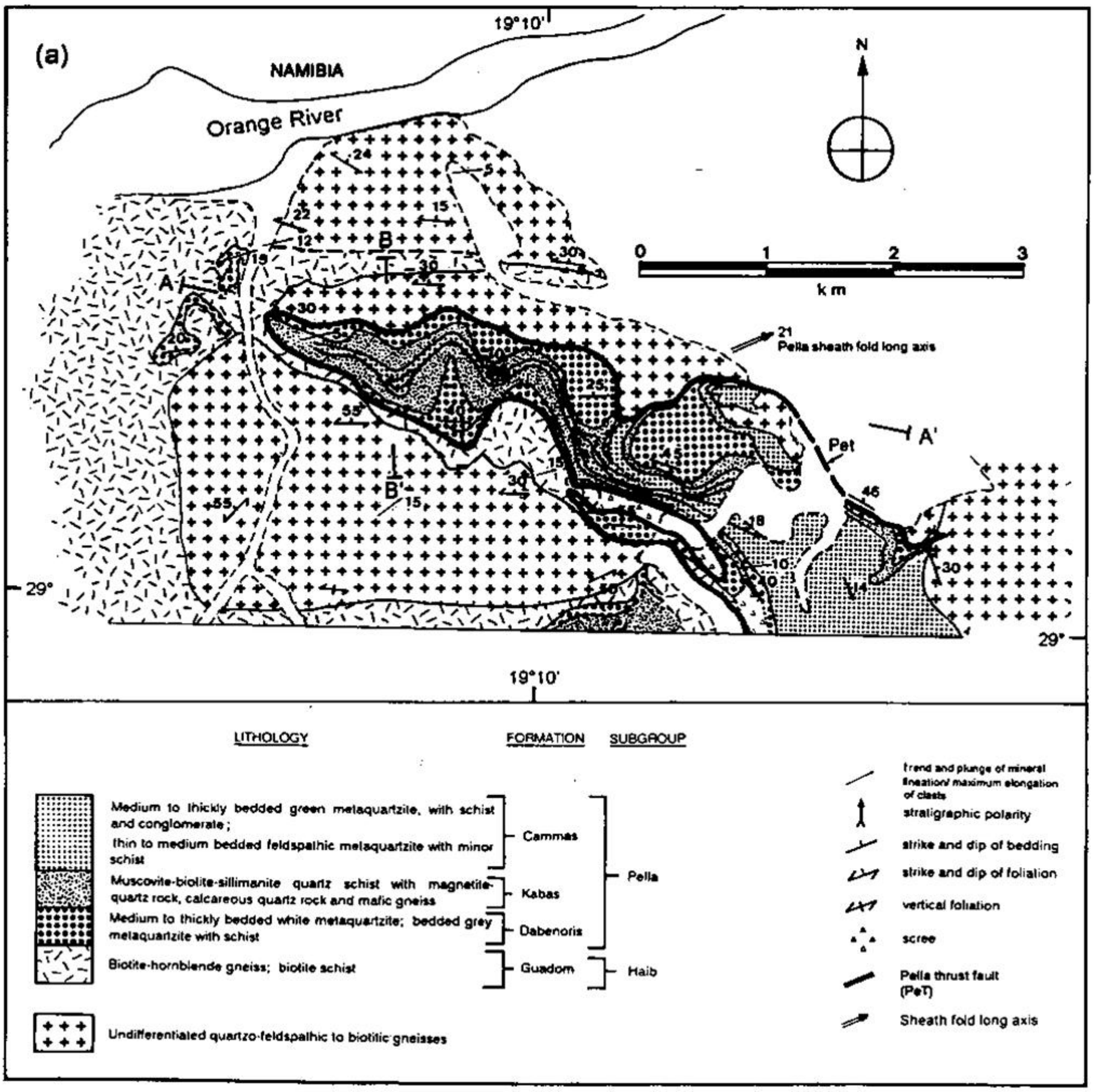
That part of the Pofadder Terrane where the Vioolsdrif Suite is undeformed, is sometimes referred to as the Richtersveld Province (Beukes, 1973, 1975; Beukes and Botha, 1975 a and b) or Richtersveld Domain (Blignault *et al.*, 1983). In this low strain zone, fabrics produced by the Orange River Orogeny are imprinted on the volcanic rocks of the Haib Subgroup. These are associated with mesoscopic to macroscopic isoclinal folding (e.g. the Nous structure, Fig. 3.8 in Blignault, 1977) and thrusting (Blignault *et al.*, 1983). The metamorphic grade is upper greenschist facies (Reid, 1977). The surrounding Vioolsdrif granitoids post-date this deformation and therefore lack this fabric imprint. The tectonic transport direction associated with the pre-Vioolsdrif deformation is directed to the southwest (Blignault *et al.*, 1983).

Namaqua Deformation

The Namaqua Orogeny produced the main regional penetrative LS fabric in the rest of the Pofadder Terrane and in all of the other terranes. It is recognized by its syntectonic association with the Little Namaqualand augen gneisses (Blignault *et al.*, 1983; Strydom, 1985; van Aswegen, 1988). Recognition of the Namaqua fabric in areas where the Little Namaqualand Suite is sparsely developed, is facilitated by the consistent NE-trending regional lineation pattern (van Aswegen *et al.*, 1987). The associated metamorphic grade varies from amphibolite facies in the Pofadder Terrane to granulite facies in the Okiep Terrane. Waters (1988, 1989) ascribed the heat source for this metamorphism to large volumes of magma. The Little Namaqualand augen gneisses, which represent a major silicic magmatic episode at 1.2 Ga during terrane accretion, are considered to have supplied the necessary heat. In the Pofadder Terrane, the grade of metamorphism increases from west to east (sillimanite-bearing rocks to migmatitic rocks) reflecting variation in the level of exhumation (Colliston, 1990).

The style of the early Namaqua deformation in the Pofadder Terrane is illustrated by means of the Pella structure (Figs. 2 and 3), a macroscopic sheath fold. This structure deforms early Namaqua fabrics and thrust faults. The componental shear movement within the terrane, northwest to southeast, is indicated by the long axes of macroscopic sheath folds such as the Pella sheath fold shown on the map.

The Aggeneys Terrane exhibits only the fabrics produced by the Namaqua deformation, which is believed



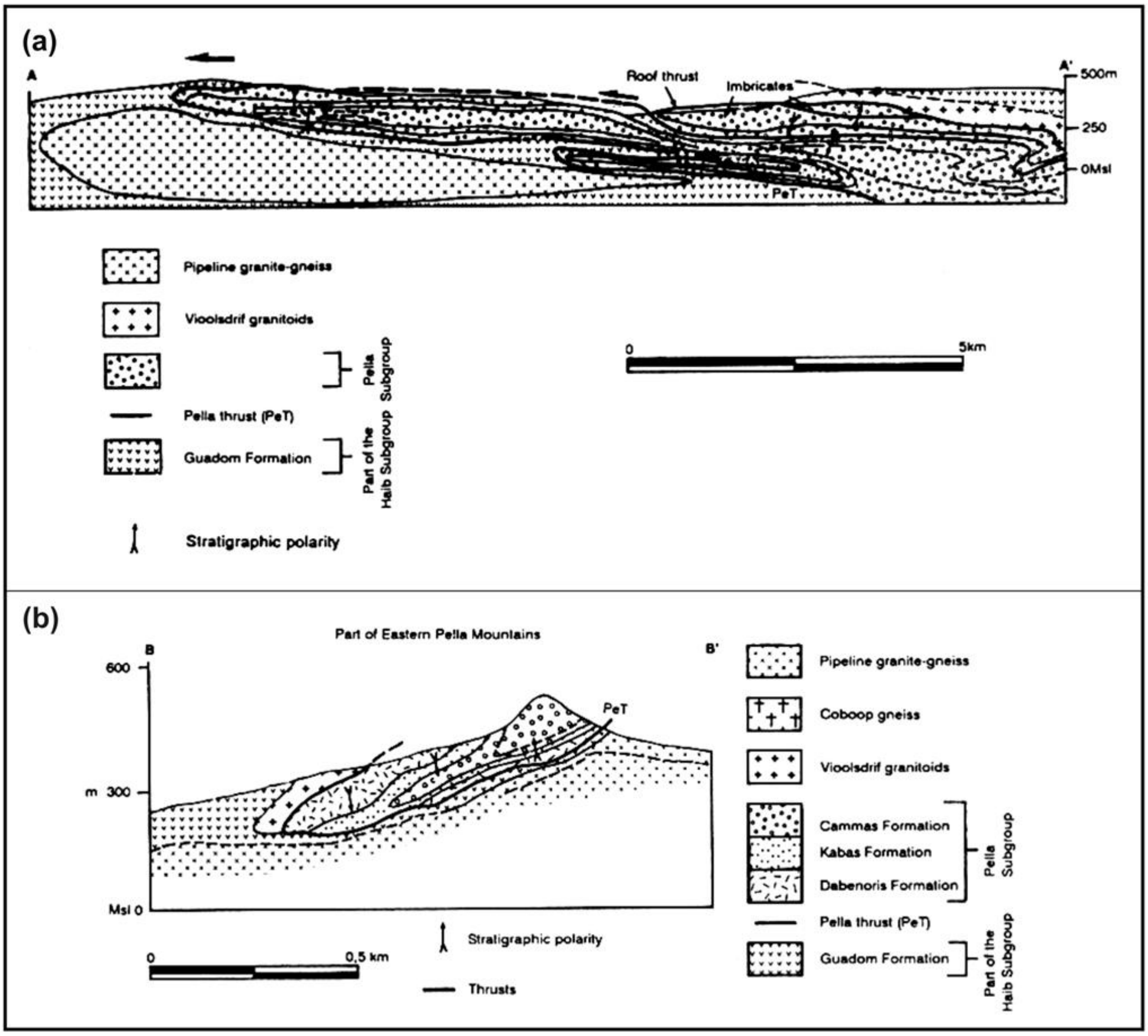


Figure 3: Geometrically controlled sections across the Pella structure, showing the western isoclinal hinge and folded thrust plane (PeT) (Early Namaqua deformation, Table 1): a. Cross section; b. Long section (section perpendicular to the tectonic transport direction).

to have pervasively overprinted and obliterated older fabrics. It is characterized by coplanar and colinear structural elements. A structural map for the central part of the Aggeneys Terrane (Fig. 4) illustrates the consistent colinearity of linear elements and structures (fold axes, long axes of sheath folds, fold hinges and mineral lineations) as well as the coplanarity of planar structures (lithological boundaries, foliations, axial planes of isoclinal folds and thrust planes).

The Big Syncline structure in the Aggeneys Terrane is an example of a macroscopic open fold that formed during the late stages of the progressive Namaqua deformation. This structure deforms a series of sheath fold nappe structures that represent earlier products of the same progressive deformation process (Fig. 5). These fold nappes were transported in a southwesterly direction parallel to the general tectonic transport direction for the Aggeneys terrane. Restoration of the nappes suggest a minimum of 57 km displacement (unpublished restoration by WP Colliston, 1984), but excludes the large amount of shear displacement associated with the high strain required for sheath fold generation (minimum of 15γ; Skjernaa, 1980). Notwithstanding the high strain, primary features such as conglomerates can still be recognised owing to inhomogeneous strain partitioning (ductility contrast between layers of different lithological composition).

With the exception of the Groothoek thrust separating the Pofadder from the Steinkopf and Aggeneys Terranes, the terrane bounding thrusts are yet to be studied structurally in detail. Van der Merwe (1995) and van der Merwe and Botha (1989) showed that the Groothoek thrust is a lateral ramp structure that was formed under ductile conditions and resulted in a minimum of 75 km oblique displacement.

The late Namaqua deformation is manifested by a family of open folds (Table 1) with subvertical axial planes and with fold axes parallel to the transport direction. These structures are superimposed on the regional Namaqua thrust fabric. The Koperberg Suite (1050

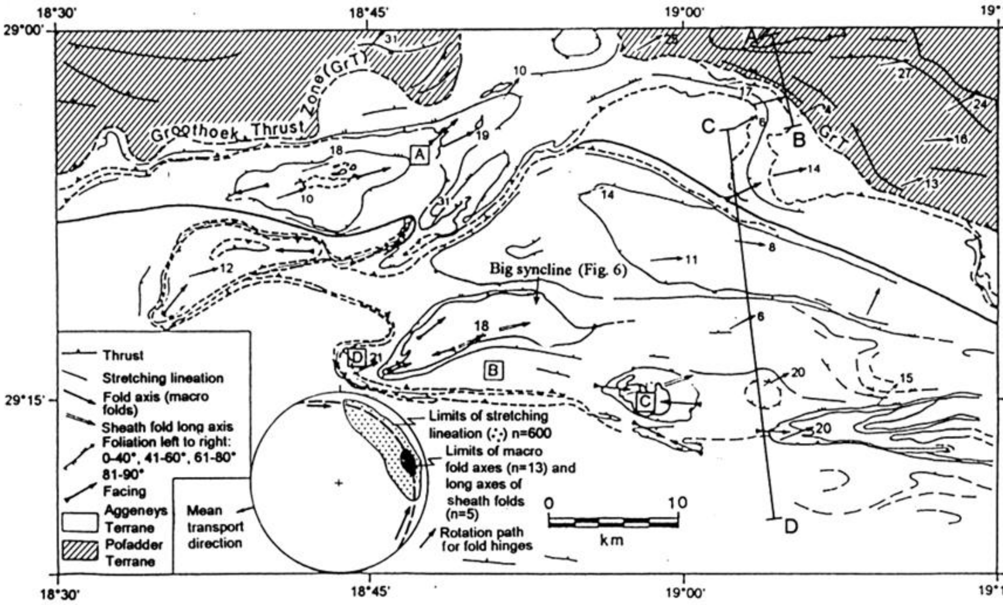


Figure 4: Structural map of the central part of the Aggeneys Terrane (compiled from published maps by Colliston *et al.* (1986) and Strydom *et al.* (1987). The Groothoek Thrust Zone (GrT) in the upper part of the diagram represents a lateral ramp boundary between the Aggeneys and Pofadder Terranes. The great circle girdle shown as a broken line on the stereonet represents the orientation of the regional fabric formed by progressive shear processes during the Early Namaqua deformation (Table 1). The southwesterly tectonic transport direction is indicated by the colinearity of linear elements (fold axes, long axes of sheath folds, stretching lineations; collectively represented by the ornamented field in the stereogram). A section perpendicular to the tectonic transport direction (ABCD), (long section) is shown in Fig. 7).

A few of prominent structures that were formed during the Early Namaqua deformation are labelled: A. Haramoep antiform; B. Big Syncline fold nappe structures (details shown in Fig. 5); C. Gamsberg sheath fold; D. Black Mountain/Broken Hill fold and thrust structures.

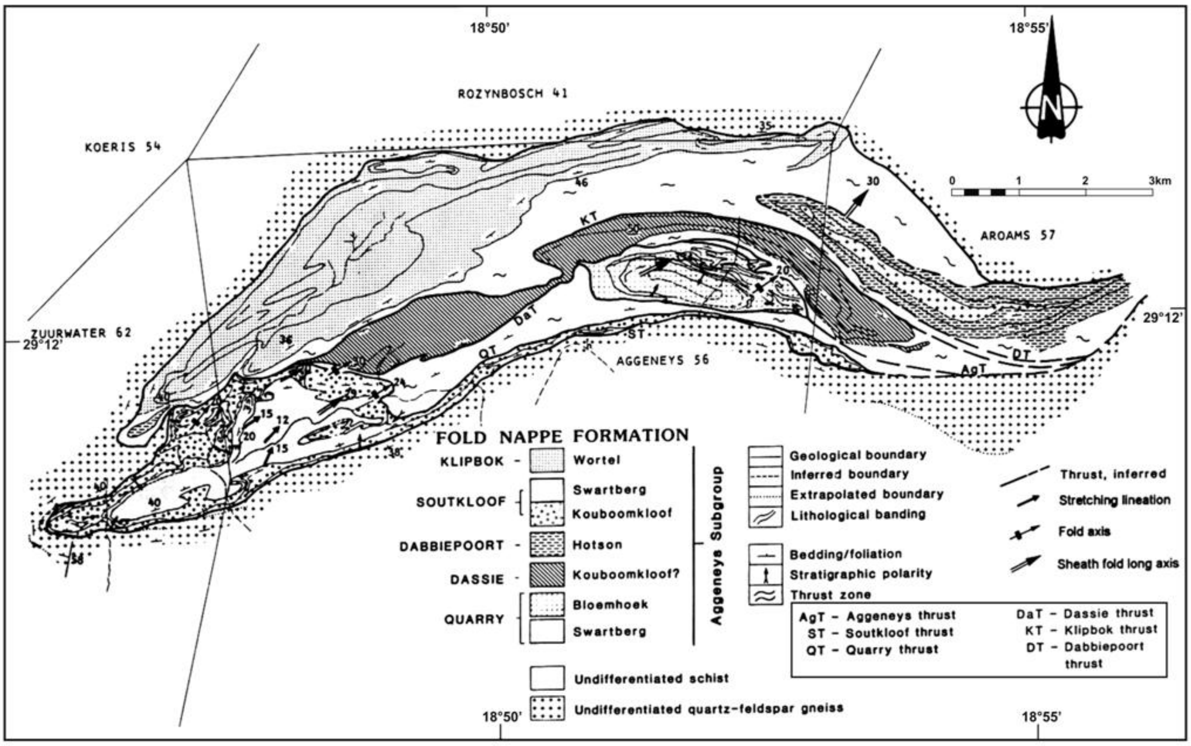


Figure 5: Map of nappe structures in the Big Syncline, Aggeneys Terrane. The Big Syncline represents a duplex structure that involves a series of large (kilometre scale) sheath folds. Each of the sheath folds consists of different thrusted sequences belonging to the Aggeneys Subgroup. The presently exposed surface (map area) is oblique to the northeasterly plunge of the sheath fold nappes. This implies that the map view is equivalent to an oblique long section (nearly parallel to the tectonic transport direction, northeast to southwest).

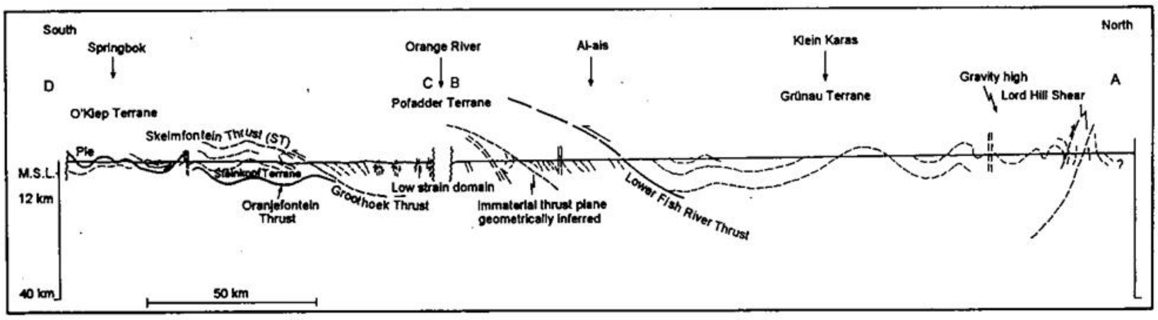


Figure 6: Regional cross section of the westernmost terranes of the Namaqua mobile belt (modified after Blignault *et al.*, 1983). The location of the section is provided in Fig. 1. The structural juxtaposition of the Grünau Terrane against the Pofadder Terrane and of the Pofadder Terrane against the Steinkopf and Okiep Terranes are illustrated.

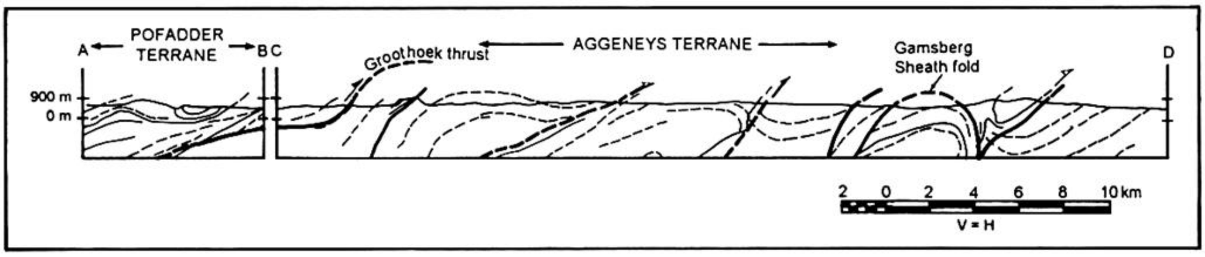


Figure 7: Structural section across the Pofadder and Aggeneys Terranes. The location of the section is provided in Fig. 5. Note that the Pofadder Terrane is juxtaposed against the Aggeneys Terrane (compare Fig. 6).

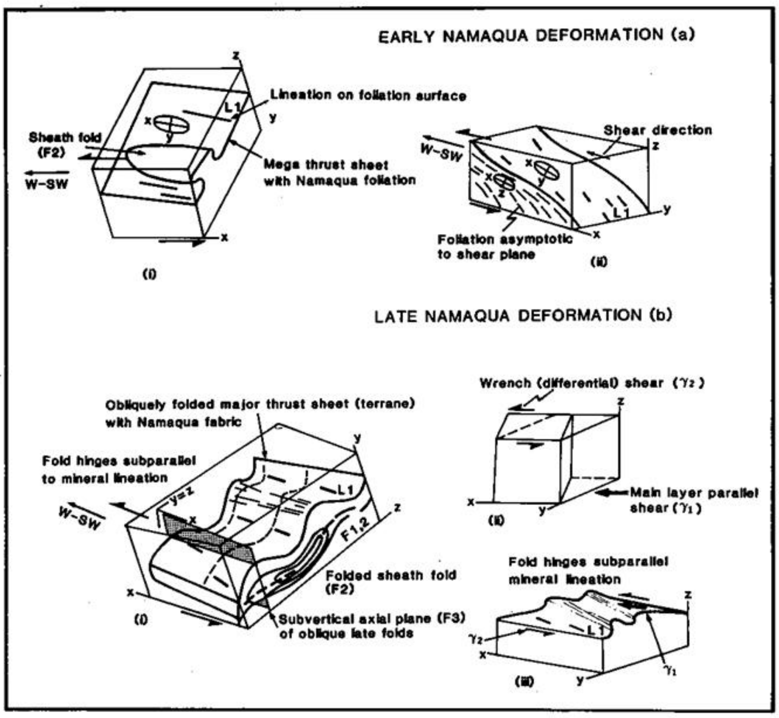


Figure 8: Schematics of the Namaqua deformation.

a. Early Namaqua deformation. The subhorizontal LS tectonite fabric containing sheath folds and coplanar thrust sheets depicted in (i) are interpreted in terms of a ductile shear model (ii) involving southwesterly directed overthrusting of large thrust sheets (terranes).

b. Late Namaqua deformation. The characteristic feature is the occurrence of macroscopic upright folds. Both the large-scale thrust sheets and the early tectonite fabric are folded. The fold hinges of the late folds are colinear with the early linear fabric and tectonic transport direction depicted in (i). The genesis of these folds is explained in terms of a wrench shear model involving layer-parallel shear followed by differential shear on a plane normal to the foliation/layering but with the same shear direction as before, depicted in (ii). The differential (wrench) shear produces oblique trending folds with fold hinges that rotate towards the shear transport direction during increasing shear strain, as depicted in (iii).

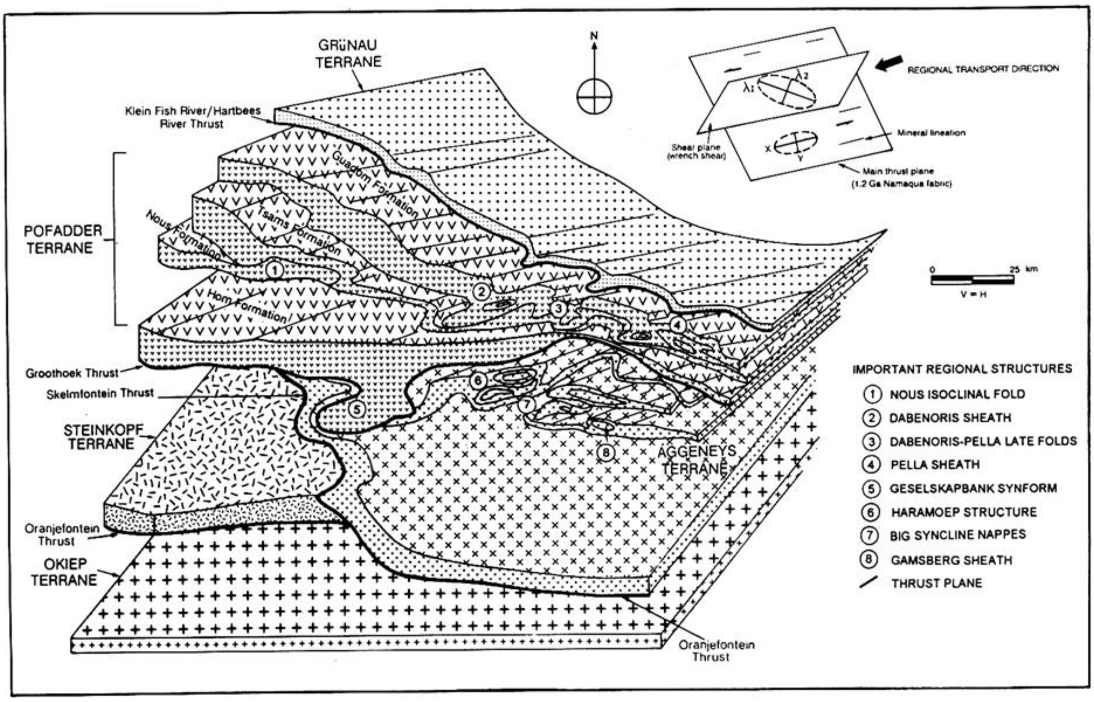


Figure 9: Schematic three-dimensional representation of structural features for the western part of the Namaqua mobile belt (based on regional map and geometric data). The boundary thrusts of the terranes may be considered to be lateral ramp structures. Only the Skelmfontein thrust has the appearance of a frontal ramp. This diagram illustrates the structural juxtaposition of the Pofadder and Aggeneys Terranes, with the former overthrusted over the latter. The figure also shows the intra-terrane structural development (folds, thrusts and sheath folds, related to the Namaqua deformation. Note the effects of the late stages of the progressive Namaqua deformation, i.e. open folding of the inter-terrane Groothoek thrust).

– 1100 Ma) is believed to be co-eval with these late open folds (Kisters *et al.*, 1996). Another manifestation of the late Namaqua deformation is the development of easterly trending subvertical shears superimposed on the limbs of the late folds and on the thrust faults. The minimum lateral displacement is of the order of 30 km (unpubl. reconstruction by WP Colliston, 1984).

Discussion and Conclusions

The temporal relationship between the main magmatic events and deformation of the various terranes are summarized in Table 1. The geometrical relationships of the terranes juxtaposed during the Namaqua Orogeny are illustrated in appropriate sections (Figs. 6 and 7). A north-south section, marked on Figure 1, across the Grünau, Pofadder, Steinkopf and Okiep Terranes is illustrated in Figure 6. The orientation of the section is oblique with respect to the southwesterly directed tectonic movement (see stereonet, Fig. 4; van der Merwe, 1989). The juxtaposition of terranes that is apparent in the figure is due to the ramping and flat configurations of the bounding thrust faults. This transport direction is indicated by linear elements, the rotation of foliations and the orientation of the long axes of sheath folds (van der Merwe and Botha, 1989; Strydom and Visser, 1986; Colliston *et al.*, 1991). The southward dip of the ramps corroborates the southwesterly directed transport direction.

The section across the Pofadder and Aggeneys Terranes (Fig. 7) has been constructed perpendicular to the southwesterly directed tectonic transport direction. The Pofadder Terrane has been overthrust onto the Aggeneys Terrane along the Groothoek thrust. The folding of the thrust plane reflects the late Namaqua deformation (open folds discussed in the previous section).

The Namaqua deformation can be explained by a progressive ductile shear process lasting from ca. 1350 to 1100 Ma that involved folding and thrusting/shearing events at both early and late stages. The early part of this deformation involved the development of a LS tectonite fabric dipping at a shallow angle northwards (comprising stretching lineations, isoclinal folds, sheath folds and coplanar thrust sheets). This deformation is compatible with the effects associated with progressively increasing strain in ductile shear zones under mid-crustal conditions (layer parallel shear, Fig. 8a).

The late deformation is characterized by the upright folding of terranes and the early Namaqua fabric. Morphologically the late folds are asymmetric (Z-shaped) with fold axes subparallel to the northeasterly trending linear structure. The continuation of the progressive shear process led to the mechanical locking of all pre-existing structures. Differential (wrench) shear then developed on planes normal to the foliation/layering but with the same sense of shear as before, i.e. from NE to SW. This explains the geometry of the observed asymmetric "Z" fold structures, in which the fold hinges of the late structures have been rotated into the shear transport direction during incrementally increasing shear strain, parallel to the early linear fabric (Fig. 8).

A schematic block diagram illustrating the essential megascopic structural features of the deformation model is provided in Figure 9. The model shows details of the contiguous Grünau, Pofadder and Aggeneys Terranes. For the sake of diagrammatic clarity, details of the Steinkopf and Okiep Terranes have been omitted. The mechanics of the shear and strain relationships are indicated. Because the western part of the Namaqua mobile belt is an important base metal province in South Africa, the proposed model is also an exploration model. Exploration targets similar to Broken Hill and Gamsberg (Aggeneys Terrane) can be looked for in both Namibia and South Africa, constrained by correct terrane recognition and tectonic transport direction. Ore occurrences of the type seen in the Okiep Terrane will probably not be exposed to the north but could well be present to the east and south of the Copper District.

In conclusion: the structural development described above is indicative of a southwesterly directed compressional stress regime. This was part of a northeasterly-directed plate convergence that resulted in terrane amalgamation during the accretion of the Namaqua Belt onto the Kaapvaal Craton at ca. 1.0 Ga.

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