

# Structural history of the southwestern corner of the Kaapvaal Craton and the adjacent Namaqua realm: new observations and a reappraisal

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## ABSTRACT

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The rocks along the southwestern margin of the Kaapvaal Craton were deformed up to 7 times during the Early to Middle Proterozoic. The oldest deformation  $D_1$  is recorded in the N–S-trending Uitkoms cataclasite of pre-Makganyene age ( $> 2.24$  Ga) on the craton, and interpreted as a bedding-parallel thrust. It is assumed to be a branch rising towards the surface from a blind sole thrust that initiated early N–S-trending  $F_1$ -folds above it.  $D_2$  is represented by mainly N–S but also NE–SW and NW–SE-trending imbricates and recumbent fold zones ranging in size from small gravity slumps to large tectonic décollements in Asbesheuvel BIF and the Koegas Subgroup, and is younger than  $D_1$  or equals  $D_1$  in age. These structures pre-date the Westerberg dyke-sheet intrusion.  $D_3$  south-verging folds and thrusts are the oldest post-Matsap deformations, just less than 2.07–1.88 Ga.  $D_4$  are upright to east vergent and N–S-trending folds deforming all previous structures.  $D_4$  post-dates the Westerberg dyke-sheet and probably reactivates N–S folds above the earlier sole thrust during renewed E–W compression.  $D_5$ , producing the main NW-trending Namaqua structures, is only very feebly developed in the Kheis terrain and absent from the cratonic areas overlain by Olifantshoek and older strata, i.e. NE, E and SE of the Marydale High. Very gentle  $D_6$  E–W to ENE–WSW folds produce culminations and depressions in all NW-trending older structures. During  $D_7$  the NW–SE-trending Doornberg Lineament, an oblique left-lateral wrench, and smaller N-trending faults such as the Westerberg Fault developed. These and similar, but right-lateral faults are the last movements along the rim of the craton and occurred around 1.0 Ga.

Multiple folding and thrusting with riebeckite mobilization happened prior to Namaqua events and resulted inter alia in discernable duplication and thickening of the Transvaal Supergroup along the southwestern margin of the Kaapvaal Craton and at least some 130 km into the craton interior. This complicates stratigraphic correlation as well as true thickness estimates of BIF units in Griqualand West, and affects the model for the environmental evolution of the Ghaap Group. A structural model of thin-skin decoupling at the base of the Transvaal Supergroup and starting in the Middle–Early Proterozoic is proposed.

## Introduction

The Transvaal Basin sediments in Griqualand West, northern Cape Province are bordered by multiply folded orogenic realms of the Namaqua Mobile Belt (Vajner, 1974a) and the Kheis Tectonic Province (Stowe, 1986). Nevertheless, the southwestern margin of the

Kaapvaal Craton is stated to be “overlain by only slightly deformed Early Proterozoic cover successions” (Stowe, 1986, p. 186). Beukes (1983) correlated parts of the Ghaap Group (Table 1) from north to south across Griqualand West regardless of possible structural complications. This correlation is based mainly on borehole data gathered between Koegas (Westerberg) and Kuruman (Whitebank) (Fig. 1). However, recent work along the

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**TABLE 1: STRATIGRAPHIC COLUMN FOR THE SOUTH-WESTERN KAAPVAAL CRATON AND SURROUNDING PROVINCES.**

SEQUENCE GROUP	SUBGROUP	FORMATION and AGE (Ma) in Uppington Terrane (U), Kheis Subprovince (K1) and Kaapvaal Craton (K)	LITHOLOGY, and possible thrust or decollement horizons - D	Possible correlates in Kakamas (KA), and Uppington (U) Terranes, in Kaapvaal Craton (K). Possible thrust horizons - D	DEFORMATION EPISODE
WILGE-NHOUT-DRIF		Leeckanz (U) and Zondcrhuis (KH), (1330 ± 100, Barton and Burger, 1983)	Schist, quartzite, phyllite, conglomerate, jaspilite, pillow basalts	Jannelspan (KA) (c. 1350 Ma on calc-alkaline amphibolite)	D <sub>1</sub> + D <sub>2</sub> and late Namaqua U, wrench faulting = D <sub>2</sub> along Doornberg lineament, <1.35 up to 1.0 Ga.
		Groblershoop (K1) (1780 Ma SACS, 1980 - probably metamorphic age, (Stowe, personal communication)) Verwiter (Bruksand) (K1) [Glen Lyon, Elites Rus, Masing Grp. (K1) Fuller] Hartley (KH) (1881 ± 57, Armstrong, 1987) Lucknow (K1) Mapepe (KH)	Phyllite, micaceous quartzite, chlorite schist and amphibolite Mainly white quartzite. Course, brown-grey pebbly quartzite	Korannaland sequence, Toeslaan Formation (KA)? Ulidraan? (Kaapen) + Sullivanoord + Dugbreek (U) (1800-2100 Ma detrital zircons, Barton & Burger, 1983)	D <sub>4</sub> Brittle thrusts. Post-dating Westerberg dyke-sheet, post Matsap. Associated with N-S trending and E-vergent folds. <2,07 to 1,88 Ga. D <sub>3</sub> First post Matsap deformation, S to SE verging thrusts and folds late Kheis-Koranna? = 2.2 - 2.0 Ga only in north-west of study area.
OLIFANTSHOEK	VOI.OP		Andesite Quartzite Shale (140 - 200m) - D		
	WATER	Ongeluk (K) (2239 ± 90/-92, Armstrong, 1987)	Dolomite, chert, jaspilite, lava As above, with BIF		
POST-MASBURG		Makganyene	Andesitic lavas and tuff Diamictite	UNCONFORMITY	
		Nelini Roonekke Naragas Kwakwas Dorodite Pannetje	Jaspilites, flagstones, quartzite, dolomite, BIF, Mudstone, amphibolite, quartzite, jaspilite, conglomerate, crocidolite	LOW ANGLE UNCONFORMITY	
GHAAP	ASBES	Griquatown and Kuruman, 2432 ± 31 zircons from tuff in Kuruman (Trendall et al. 1990)	Allochemical BIF + croc. -D Orthochemical BIF + croc.-D	REGIONAL HIGH ANGLE UNCONFORMITY	D <sub>2</sub> Fold-thrust zones in BIF. Pre-Matsap, pre-Westerberg dyke-sheet (amphibolised age unknown), syn- to post- Ashbeshuvels Subgroup. Equivalent to D <sub>1</sub> ? D <sub>1</sub> = Uitkoms thrust, pre-Makganyene, post-Koegas >> 2,24 Ga (Ongeluk), <2432 of Kuruman BIF.
		Gamoohan Kogelbeen Kippun Papkuil Klippfontein Fairfield Retwib Monteville	Alternating stromatolitic and cherty limestones and dolomites. Thin shale, mudstone and proto-BIF intercalations towards top. (± 800m) - D		
GROENLAND WEST SEQUENCE	SCHEIDINGS-DRIF	Lokomona Boomplaas (K) Vryburg (in press)	Interaliated shales and carbonates. -D Shales, siltst. quartzites, lava (100m) -D	UNCONFORMITY	
		Zeekebaart (K) 2135 ± 74/-71, Pb/Pb-metamorphic, 2745 ± 6,28 Rb/Sr (Armstrong, 1987)	Andesitic lavas, tuffites, conglomerates and quartzites	Parts of Veniersdorp Supergroup (K) 2371 ± 102/-106 (Armstrong, 1987)	Mild folding and/or tilting? NON CONFORMITY
MARDYDAL		Marydale Group. Intruded by Archean Draighoender granite (2900 Ma Burger & Coetzee, 1973) and Skalksput granite (2600 Ma Burger & Coetzee, 1973) and Steenkoppie granite west of Doornberg lineament (2600 Ma Burger & Polgister, 1979), (K)	Metabasites quartzites, thin BIF. (2990 Sm/Nd, Cornell et al., 1986; Barton et al., 1986). Sienkoppie granite Sm/Nd model age 3100 (Cornell et al., 1986) = basement to Marydale Group		Deformed twice in Archean times, before and during intrusion of 2,6 Ga granite.

southwestern margin of the Kaapvaal Craton between Prieska and Boegoeb Dam (Fig. 1) reveals a strong multiple tectonic imprint on Transvaal cover rocks including possible blind thrusts, stacked thrust-sheets and recumbent folds. Some of these structures have now been

found as far as Koupoort and Griquatown, up to 130 km across the craton boundary. Present stratigraphic correlations, especially within the Asbesheuwels Subgroup (Table 1), are therefore questioned.

Detailed structural descriptions are pre-

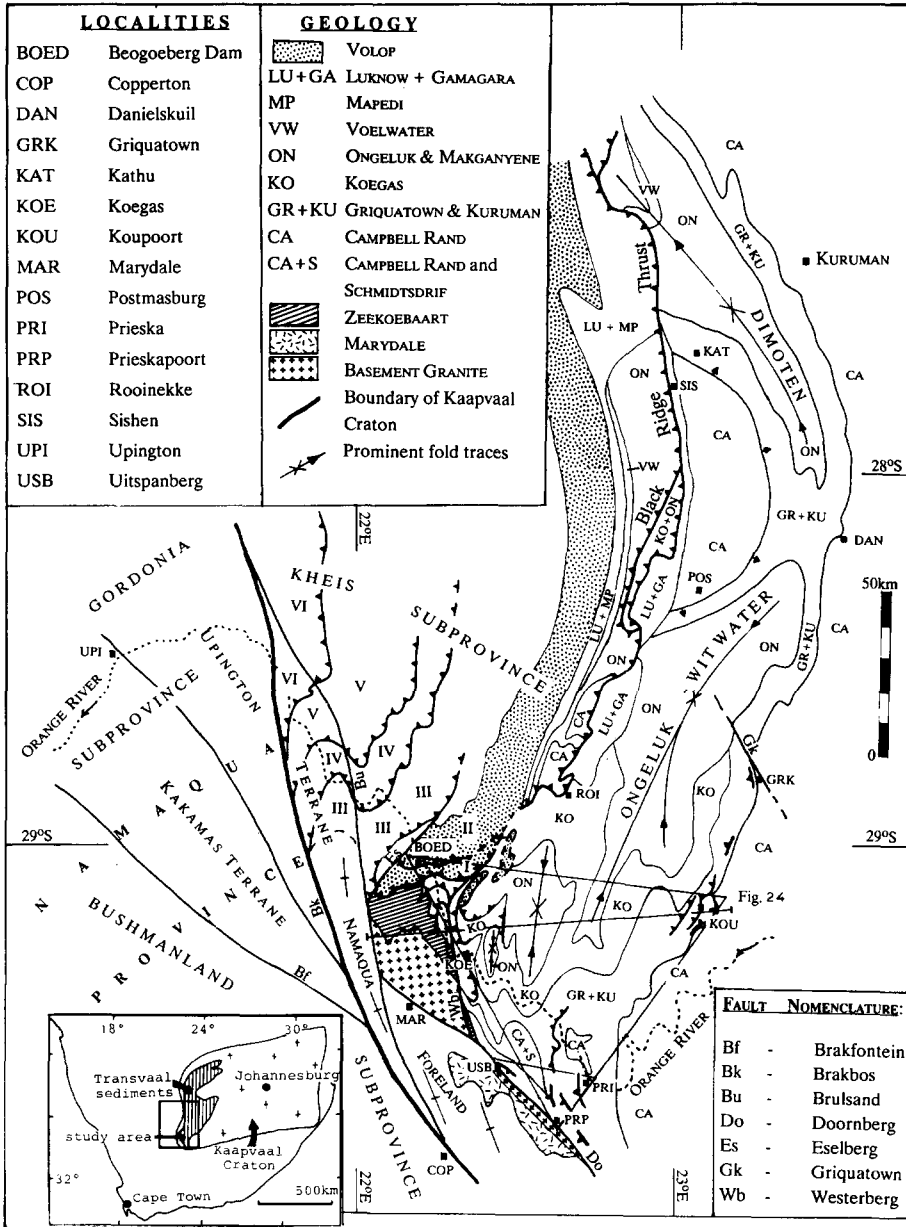


Fig. 1. Location of the study area (between Koupoort, Prieskapoort and Boegoeb Dam) along the southwestern margin of the Kaapvaal Craton and of the structural model of Fig. 24. Geology after Vajner (1974), Stowe (1986), Beukes and Smit (1987), modified, and after our own observations.

sented elsewhere (Altermann and Hälbich, 1990). Here we use the essence of that information and present it together with new data to discuss these in the light of the objectives of this paper. This is, to compare the deformational and erosional episodes found in the cover rocks of the craton and correlate them with published information of the surrounding Kheis, Gordonia and Bushmanland sub-provinces. The main new evidence presented is threefold. (a) The first deformation ( $D_1$ ) on the Kaapvaal Craton pre-dates the Makganyene diamictite and is therefore older than the Ongeluk lava (2.24 Ga). (b) These cataclases could very well represent the eroded branch of a blind sole thrust. Both were inactive during  $D_2$  and  $D_3$ , but the sole thrust was reactivated and extended eastwards during  $D_4$ , producing  $F_4$  folds in its hanging wall over large areas in Griqualand West with craton-ward convex trends. (c) Evidence of intense folding and thrusting is observed up to the Griquatown Fault.

A wide variety of stratigraphic names exists in the literature for local units and facies changes of the Transvaal Supergroup. Throughout this paper we stick to the stratigraphic column of Beukes and Smit (1987) as expanded to include strata from the subprovinces around the craton (Table 1, Fig. 1).

## Geological background

The Lower Proterozoic I (Vaalian) Transvaal Supergroup of Beukes (1980, 1983), i.e. the Ghaap, the Postmasburg and the Olifantshoek Groups (Table 1) are described in many papers and unpublished M.Sc. and Ph.D. theses of which the most important are by Rogers and Du Toit (1909), Du Toit (1945), Cilliers (1961), Hanekom (1966), Fockema (1967), Vajner (1974a, b) and Beukes (1980, 1983).

The age of this sequence is determined by

radiometric dating of the associated volcanic rocks. In the Transvaal the Ghaap Group is underlain by the Ventersdorp Supergroup. Judging from stratigraphic relationships, the Ventersdorp appears equivalent to Vajner's (1974a) Zeekoebaart Formation in the south-western part of the Kaapvaal Craton. However, the Ventersdorp Supergroup dates at 2.7 Ga (Armstrong et al., 1986), while Armstrong (1987) dated the Zeekoebaart Formation at  $2135^{+71}_{-74}$  Ma by the Pb/Pb method and at  $2745 \pm 628$  Ma by Rb/Sr. Walraven et al. (1982) dated parts of the Zeekoebaart Formation at around 2.2 Ga, which is comparable to the more reliable age of the Ongeluk Andesite Formation above the Ghaap Group. However, the Asbesheuwels Subgroup (Kuruman IF) has been dated at  $2432 \pm 31$  Ma (Trendall et al., 1990) and the Schmidtsdrif Subgroup (lowest Ghaap Group) has been dated by Jahn et al. (1990) at  $2557 \pm 49$  Ma. Therefore, the Zeekoebaart must be of Archaean age.

The Ongeluk Andesite Formation of the Postmasburg Group in Griqualand West has been dated at  $2240 \pm 57$  Ma (Walraven et al., 1982) and at  $2239^{+69}_{-72}$  Ma (Armstrong, 1987). The possibly equivalent Hekpoort lavas from the Transvaal sequence have an age of  $2224 \pm 21$  Ma (SACS, 1980).

The Hartley Formation which forms the lower part of the Olifantshoek Group, has an age of  $2070 \pm 90$  Ma (SACS, 1980) or  $1881 \pm 57$  (Armstrong, 1987) and the Groblershoop Formation lavas which overlie the Olifantshoek Group (Beukes and Smit, 1987) and outcrop in the Kheis Subprovince (Fig. 1) have a minimum age of 1780 Ma (SACS, 1980) thought by C.W. Stowe to be metamorphic (pers. commun., 1989). Thus, the Olifantshoek Group is at least between 1.881 Ga and 1.78 Ga old. The Dagbreek Formation underlying parts of the Upington Terrain (Fig. 1 and Table 1) has a maximum age of 1.8 to 2.1 Ga (U/Pb-detrital zircons—Barton and Burger, 1983)

**TABLE 2: POSSIBLE CORRELATION OF STRUCTURAL EVENTS AS PERCEIVED BY VARIOUS AU**

VAJNER (1974) In Kheis and Gordonia Subprovinces and Kaapvaal Craton between 29°S and 29°30'S, west of 22°30'E	POTGIETER (1982) South of 29°30'S and west of 23°E from Kaapvaal Craton in to Namaqua Province (Fig. 1)	THEART (1985) AND HUMPHREYS et al. (1988a + b) in Copperton area, Namaqua Province (Fig. 1).	STOWE (1986), HARRIS (1988) Upington and Kakamas Terranes (Fig. 1)	STOWE (1986) Kheis Subprovince north of Marydale High (Fig. 1)	SC Na po
Marydale Group, deformed prior to intrusion of 2,9 and 2,6 Ga granites					
Zeekoebaart Fm. resting non-conformably on 2,6 Ga granite. Deformed twice prior to the deposition of the Ghaap Group. NE trending schistosity = D <sub>2</sub> in present paper, N-S trending cleavage = D <sub>4</sub> in present paper.					
Gravity folding slumps in BIF by subsidence of "intra-geosyncline" on the craton - two episodes.	Slump folded BIF (Asbesheuwel Subgroup)				
			NF <sub>1a</sub> and NF <sub>1b</sub> SE and SSW-verging isoclines respectively. C. 1,75 Ga and <1,35 Ga respectively.	KD <sub>1</sub> and KD <sub>2</sub> E to SE verging folds and thrusts. Tight "Z"-KF <sub>2</sub> -folds develop in zones.	
Open NE-folding, vertical axial planes in Transvaal Supergroup. Considered pre-Matsap.	DN horizontal, N-S, open folds, upright, no cleavage, in Zeekoebaart Formation and Griqualand West Sequence. (Also found post Matsap by present authors) e.g. Ongeluk - Witwater syncline (Fig.1)		Only remnants recognisable. Almost totally transformed by NF <sub>2</sub>	KF <sub>3</sub> NNE to N-trending folds in discrete zones. Refolding KT <sub>1</sub> and KT <sub>2</sub> thrusts.	
F <sub>1</sub> Sharp hinged. S <sub>1</sub> axial planar cleavage in Kaaien Group considered Archean by Vajner. Now Sultanaoord-Dagbreek equivalents in domain III (Table 1, Fig. 1) (Stowe 1986)	DN + 1. Most intense folding west of Bn (Fig. 1) NW in south, NNE in N. Orientation changing around Marydale High.	FN <sub>1a</sub> and FN <sub>1b</sub> Both isoclinal, horizontal, co-axial. Produced by west vergent back-folding during east-directed thrusting <1,3 Ga = age of Areachab = Kaaien = Uitdraai Groups	Upington Terrane: NF <sub>2</sub> NW-trend, NE-verging tight, main Namaqua phase.  Kakamas Terrane: SW-verging recumbents in a south-westerly zone; reclined, subvertical NF <sub>2</sub> isoclines in central zone (1,2 to 1,1 Ga).	KF <sub>4</sub> -open folds at SW-margin of Kheis Subprovince c. 1,2-1,1 Ga. eg. Orange River Synform (Fig. 1).	
F <sub>2</sub> Round hinged, upright, isoclinal. Deforming F <sub>1</sub> and S <sub>1</sub> in Gordonia Subprovince (considered Archean by Vajner because it affects Kaaien and Marydale Groups).	DN + 2. NW-striking, upright deforming SN + 1. Horizontal axes. Co-axial with FN + 1, no concomitant foliation.	FN <sub>2</sub> NW-trending, upright and SE plunging. Main Namaqua phase.	Pre- NF <sub>3</sub> thrusts along Bf (Fig. 1) not related to transpression during late Namaqua dextral shear (Harris, 1988)		F <sub>1</sub> verg plar lith duri
F <sub>3</sub> Post Matsap. NNE-plunging axes on Kaapvaal Cr. NE-plunging in Namaqua Foreland and Kheis Subprov. (Fig. 1)	DN + 3. NE-striking, upright, open, zonally developed folds in Namaqua Foreland (Fig. 1).	FN <sub>3</sub> N to NE-striking, interference with FN <sub>2</sub> to form domes and basins with NW or SE plunging axes.	NF <sub>3</sub> ENE-trending, open, (e.g. Graafwater synform. - Harris, 1988) refolding NF <sub>2</sub> into "recumbent" and steep zones		F <sub>2</sub> ding eloir
F <sub>4</sub> NW-alignment of structural elements everywhere, associated with Doornberg Lineament.	DN + 4. Doornberg wrench fault zone, left lateral.		NF <sub>4</sub> NW-trending monoclines interfering with NF <sub>3</sub> antiforms. NW-trending shear zones c. 1,0 Ga	Doornberg Fault Zone.	F <sub>3</sub> elo Gri Do

\* Note: Coward and Potgieter (1983) gave no chronological order of events across all 5 of thei



EDITED BY VARIOUS AUTHORS AROUND AND ON THE SOUTH-WESTERN KAAPVAAL CRATON

STOWE (1986) Kheis Subprovince north of Marydale High (Fig. 1)	SCOTT (1987) Namaqua Foreland - Prieska- poort to Copperton (Fig. 1)	BEUKES AND SMIT (1987) Griqualand West Sequence, east of Kheis Subprovince (Fig. 1)	COWARD AND POTGIETER (1983) Kheis, Gordonia and Bushmanland Subprovinces, Namaqua Foreland.	PRESENT AUTHORS Kaapvaal Craton up to Matsap thrusts, Marydale High and Doornberg Lineament (Fig. 1)
			Marydale Group (2,99 Ga) foliated before granite intrusion. Early syntectonic Marydale granite (2,6 Ga) foliated NW-SE	
			Minor folds in Zeekoebaart Formation unconformably overlain by Griqualand West Sequence. Several younger cleavages destroy older structures in Zeekoebaart Formation.	Mild folding in Zeekoebaart Formation prior to erosion and deposition of Griqualand West Sequence. Older foliation(s) with southerly dips deformed by S <sub>4</sub> ; latter dips steeply WNW with down dip lineation.
				<b>D<sub>1</sub></b> Uitkoms Thrust. > > 2,24 Ga, < 2,5 Ga. Bedding parallel cataclases in Koegas Subgroup following limbs of early N-S (F <sub>1</sub> ?) folds reactivated during D <sub>4</sub> by post-humous folding of Ongeluk. Probably branch of sole structure following Vryburg shale horizon. Movement to E.
				<b>D<sub>2</sub></b> Recumbent fold zones, thrusts, imbricates, décollements in BIF on all scales. Varying cleavage in BIF-lutites. Movement to SE, E, and NE. Syn- to post-Asbesheuwels Subgroup, pre-Westerberg dyke sheet, pre-Magkanyene. Equivalent to or incorporating D <sub>1</sub> ?
D <sub>1</sub> and KD <sub>2</sub> E to SE verging folds and thrusts. It "Z"-KF <sub>2</sub> -folds develop in these areas.		<b>Black Ridge Thrust Zone.</b> Movement to E and SE. (Merging with basal thrust of Matsap in study area. Oldest rocks thrust are Matsap. Thrust post-dates Hartley lava (<2,07 - 1,88 Ga), deformed by D <sub>4</sub> N-S trending folds in Boegoeberg Dam area (Fig. 1) as reinterpreted by present authors).	SE-vergent thrusts and imbricates N of Uitspanberg, E of Doornberg Lineament. West of the latter the Doornberg Shear in basement granite is equivalent of thrusts but back-folded. Age: Post Hartley (<2,07 - 1,88 Ga)	<b>D<sub>3</sub></b> First post-Matsap deformation(s). S to SE vergent near horizontal folds and thrusts in Boegoeberg Dam area. North dipping axial planar cleavage. <2,07 - 1,88Ga
D <sub>1</sub> NNE to N-trending folds in discrete zones. Refolding KT <sub>1</sub> KT <sub>2</sub> thrusts.			N-S to NE-SW-trending asymmetric SE- verging folds with varying plunges (refolded by D <sub>6</sub> , present authors) Local axial planar cleavage dipping NW found N of Prieska	<b>D<sub>4</sub></b> Upright to E-vergent folds and limited brittle thrusts trending N-S. Folds deform D <sub>3</sub> thrusts. Post humous folding along early N-S F <sub>1</sub> -folds. Post dating Westerberg dyke. Steeply west dipping cleavage. <2,07 - 1,88 Ga. Some reactivation of T <sub>1</sub> - T <sub>2</sub> is possible.
D <sub>1</sub> open folds at SW-margin of Kheis Subprovince c. 1,2-1,1 Ga. Orange River Synform (Fig. 1).			Doornberg Thrust, back-folded into near vertical attitude with down-dip lineations and vertical sheath folds. Situated along and just E of Doornberg- NW-SE Fault. Originally with NE vergence and movement	<b>D<sub>5</sub></b> The main Namaqua NW-SE trending NF <sub>2</sub> of Stowe (1986) has not developed in the study area, i.e. east of the Doornberg Lineament and the Westerberg Fault. Shielded by proto-Marydale High?
	F <sub>1</sub> NW-trending steep isoclinal folds verging NE. Penetrative axial planar cleavage. T <sub>1</sub> thrusts along lithological contacts reactivated during F <sub>3</sub> .		NW-SE to N-S folds & crenulation, axial planar cleavage, verging SW in Griqualand West Sequence. NW or SE plunging lineation folded by NW folds in Bushmanland Subprovince.	
	F <sub>2</sub> Refolds F <sub>1</sub> along NE-trending subvertical planes producing elongate interference domes		E-W trending set of folds in Griqualand West Sequence; age relationship to N-S or NE-SW trends in some rocks is uncertain	<b>D<sub>6</sub></b> E-W to ENE-WSW-trending very open folds producing culminations and depressions in F <sub>4</sub> . Associated with E-W crenulations and vertical cleavage in Volop and Schmidtsdrif strata along northern edge of Marydale High.
Doornberg Fault Zone.	F <sub>3</sub> Steep fold axes refolding NW elongated domes of F <sub>1</sub> -F <sub>2</sub> in Griqualand West Sequence along Doornberg Lineament		NW-trending right-lateral wrenches (or tilted thrusts?) e.g. Copperton Fault. Drags axial planes of just older NW-folds in Bushmanland Subprovince. (Back - folding episode?, present authors )	<b>D<sub>7</sub></b> Doornberg Lineament, a major long-lived left-lateral oblique wrench. Westerberg Fault is a smaller branch. Marydale High lifted up by scissor-type movement between both. Between Prieska-Prieskopoort-Uitspanberg produces deflection and re-orientation by drag and transpression of F <sub>4</sub> and T <sub>4</sub> in up to 8km wide zone of Lineament ± 1,0 Ga.

across all 5 of their structural zones.





## Review of previous structural work

The tectonic evolution of the Transvaal Supergroup in Griqualand West was discussed by Visser (1944), who recognized up to six thrust planes along which slabs of the Transvaal strata were pushed eastwards onto the craton. However, Visser's (1944) investigations remained unaccepted among most of the later workers.

More recently Beukes and Smit (1987) presented stratigraphic and structural evidence for post-Olifantshoek (1.8–2.1 Ga—Barton and Burger, 1983) thrusting along the northwestern margin of the Kaapvaal Craton. Their Blackridge thrust system (Table 2 and Fig. 1) has been traced intermittently over a distance of 180 km in a N–S direction and they suggested that the low-angle thrusts accompanied by mylonite zones are related to the Koranna–Kheis (1.8 to 2.2 Ga) orogeny.

Vajner (1974a) recognized two pre-Matsap deformation episodes affecting the Griqualand West Sequence. The first is gravity folding of BIF by subsidence of the “intraeogyncline” on the craton, and the second is a post-consolidation folding resulting in open fold structures. Post-Matsap  $F_3$  are N- to NE-plunging structures with E to SE vergency and  $F_4$  produces mainly gentle upright folds with a northwesterly trend. A final overprint of the area was thought to be related to the Doornberg Fault Zone (Fig. 1), which is a major NW–SE-striking tectonic lineament along the southwestern rim of the Kaapvaal Craton. According to Vajner (1974b), the Doornberg Fault Zone is genetically related to the upright, northwest-trending folds. It has a dextral, oblique slip inferred to be produced by anticlockwise rotation of the craton relative to the Namaqua Mobile Belt.

A re-interpretation of Vajner's  $F_1$  and  $F_2$  (pre-Matsap) in Kaaien rocks (Table 2), some of which are now known as the Uitdraai Formation, equivalent to the Sultanaoord and Dagbreek Formation (1800–2100 Ma, Barton and Burger, 1983) makes these deformations

much younger and probably correlatable with DN+1 and DN+2 (Potgieter, 1981), FN+1 and FN+2 (Theart, 1985) and  $NF_1$  and  $NF_2$  (Stowe, 1986) and with the Doornberg thrust episode followed by backfolding (Coward and Potgieter, 1983). Vajner's observation on pre-Proterozoic deformations in Archaean Marydale granite and metabasites remain valid (Table 2).

Stowe (1983, 1986) described the tectonic frame of the Namaqua Province and the Kheis and Gordonia Subprovinces off the Kaapvaal Craton (Fig. 1 and Table 2). He recognized up to three main folding events ( $KF_1$ – $KF_3$ ) in the Kheis Subprovince located north and northwest of our area of investigation. In the younger Namaqua Province to the south and west, Stowe (1986) recognized four folding events ( $NF_1$ – $NF_4$ ).

According to Stowe (1986), the  $KF_1$  produced E to SE-vergent recumbent isoclinal and eastward directed thrusting ~1750 Ma ago. The  $KF_2$  event resulted in “Z”-folds and renewed thrusting <1350 Ma ago and the  $KF_3$  produced NNE- to N-trending folds in discrete zones. The  $NF_1$  is age equivalent to  $KF_1$ – $KF_2$  and resulted in SSW to SE-verging isoclinal. The  $NF_2$ -folds are recumbent to isoclinal and may be SW- to NE-verging in different localities. Because  $NF_2$  refolded and rotated  $KF_1$ – $KF_3$  structures it must be younger than these (1200–1100 Ma).  $NF_3$  resulted in ENE-trending open folds and  $NF_4$  in NW-trending shear zones and locally in NW-trending monoclines. The age of  $NF_4$  is estimated as ~1000 Ma (Stowe, 1986).

The findings of Theart (1985) and Scott (1987) as well as Humphreys et al. (1988) are based on field work done in part much earlier during the eighties. Their results are based on a high intensity of localized data and an attempt was therefore made to include their conclusions (Table 2). The findings of Coward and Potgieter (1983) (Table 2) which summarize and provide new outlooks are treated further below.

**Structure of the study area**

The area described in the present paper is outlined in Fig. 1. Apart from covering new ground, it includes parts of the Kaapvaal Craton investigated by Vajner (1974a) and parts of the Namaqua Foreland mapped by Potgieter (1981) and is located south of the Griquatown growth fault. The entire Griqualand West Sequence of the Transvaal Supergroup (Table 1) is present in the region investigated. The latter rests with a basal conglomerate on the Zeekoebaart Formation. The cratonic basement underlying the Zeekoebaart Formation is exposed in the extreme southwest, bordering the Namaqua Province across the Doornberg Lineament (Fig. 1). The presently accepted boundary of the craton is the Brakbos Fault.

**Structural relationships between Prieskapaort, Prieska and Uitspanberg (Fig. 2)**

Coward and Potgieter (1983) described thrusting of two ages in this area. They suggest an older Kheis orogeny (shown by Stowe, 1986, to have two components,  $KF_1$  and  $KF_2$  in the Kheis Subprovince, Table 2) with thrusting to the SE, that probably occurred around 1.75 Ga ago (Stowe, 1986). A minimum displacement of 120 km to the south was determined for this episode. According to them, a younger Namaqua episode has folds and thrusts verging NE. Both thrust systems converge between Boegoeberg and Marydale to form a double system along the Doornberg Lineament farther south (Fig. 1). This was then steepened along NW-trending back-folds that

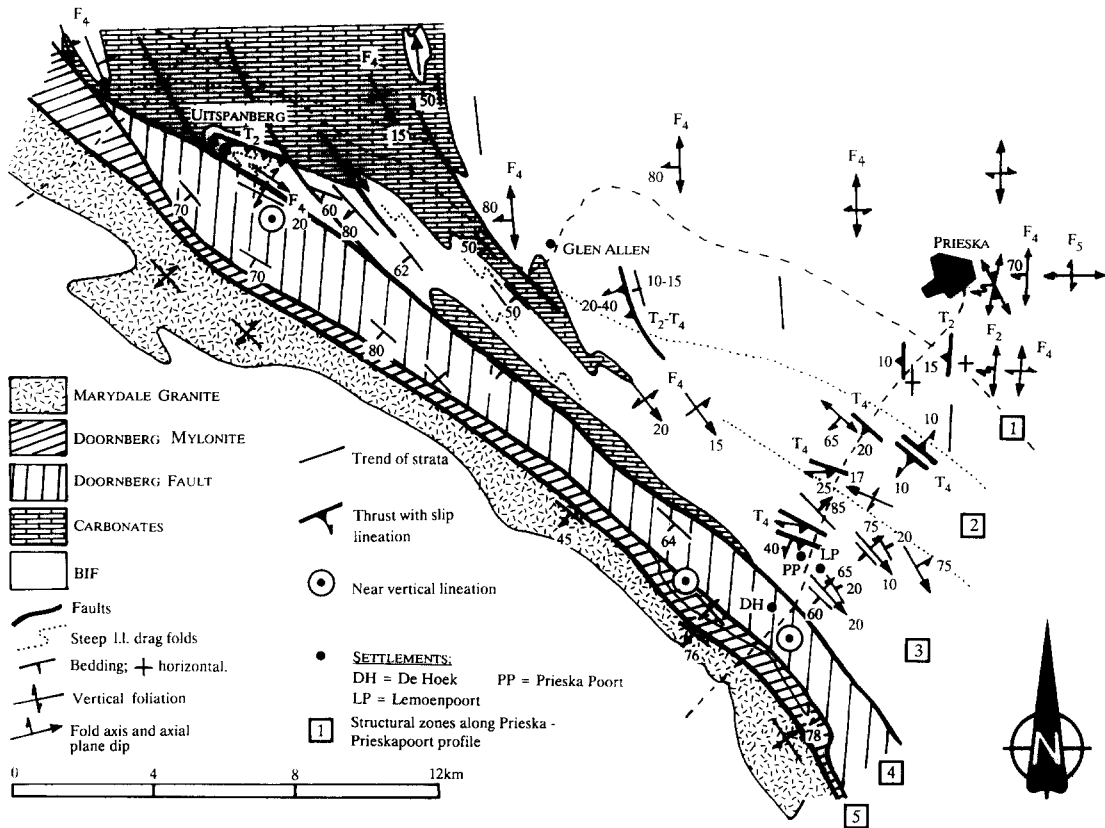


Fig. 2. Geological map of the Prieska-Prieskapaort-Uitspanberg area. See Figs. 1 and 7 for location. Dotted lines separate domains mentioned in text.



Fig. 3.  $T_2$ – $T_4$  thrust formed in Kuruman BIF on Glen Allen (Fig. 2). The structure cuts upwards in the stratigraphy from right to left (W to E) and the iron-formation is folded with vergency to the E above and below the decoupling plane. Phyllonitization of BIF occurs up to 1 m thick above the thrust plane. Highest part of cliff is 15 m above base. For fabric see Fig. 4A.

developed parallel to the craton rim towards the end of the younger thrust episode. Late Namaqua right-lateral wrenching seems to have occurred at least along the Brakfontein–Copperton fault. Coward and Potgieter (1983) also interpreted the mylonitised Doornberg Shear Zone (Fig. 2) as an oblique slip left-lateral shear-thrust belonging to the early phase of SE-directed movements prior to back-folding. Stowe (1983) found several NW-trending mega-shear zones with left- and right-lateral movements along the Orange River in the Uptington area (Fig. 1).

Potgieter (1981) showed two thrust planes in the Uitspanberg mountain (Fig. 2). Folds above these dislocations verge NE with low plunges but both thrust planes are clearly not backfolded. Just west and north of this locality Coward and Potgieter (1983) reported steeply dipping faults that duplicate the carbonate–BIF

succession (Fig. 2) and interpreted these structures as back-folded thrusts.

We have found low angle, west dipping  $T_2$ – $T_4$  thrusts in BIF around the Glen Allen mountain farther south (Fig. 2) with phyllonites drag-folds and lineations that clearly prove thrust movement from W to E (Figs. 3 and 4A). From Prieska to Prieskapoort (Fig. 2) five structural zones can be recognized. In zone 1 at Prieska three fold phases are seen in BIF.  $D_2$  folds are recumbents on a metre scale, zonally developed and parallel to bedding, with axes plunging into the NW and SE quadrants along bedding planes deformed by  $D_4$  and  $D_5$  (B and C of Fig. 4).  $F_4$  are open to isoclinal, upright to asymmetric E-vergent NNE–SSW-trending structures, and  $F_5$  are open upright NW-trending (A and B of Fig. 5). The  $F_4$  folds may even develop into injection structures and sheared box folds, revealing plastic as well as

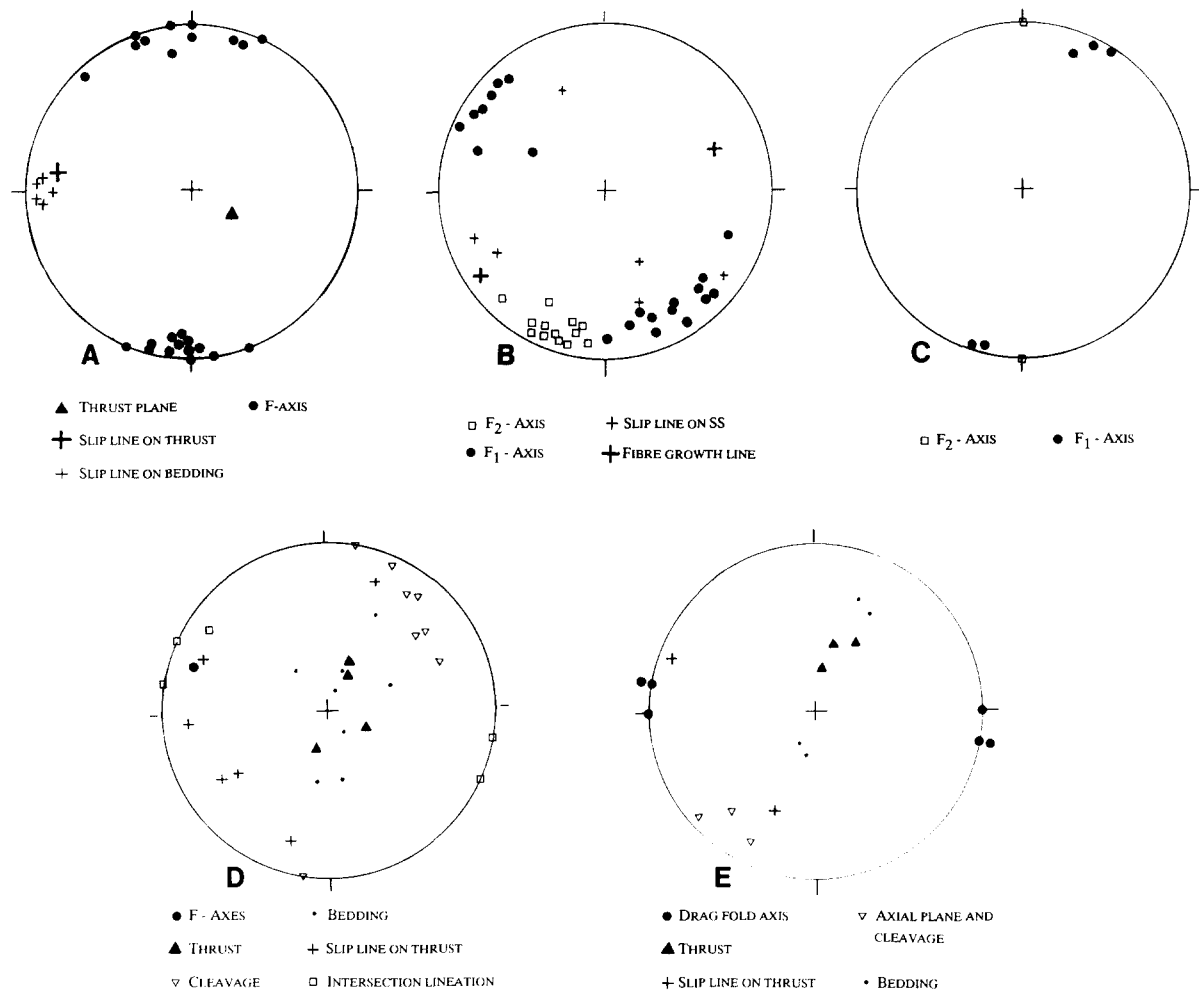


Fig. 4. Structural fabric from various localities: (A) Glen Allen on T<sub>2</sub>-T<sub>4</sub> thrust; (B) Prieska town; (C) highway outcrops SW of Prieska town; (D) zone 2 of Fig. 2; (E) zone 3 of Fig. 2.

elastic behaviour. D<sub>2</sub>-fold zones preferably develop in riebeckite lutite-rich thinly bedded units, whereas the thicker chert and sideritic chert layers ride on these dislocation zones. Movement above the decollements is to the east. The style and orientation of these D<sub>2</sub>, D<sub>4</sub> and D<sub>5</sub> structures is very similar to that found in BIF of the entire study area.

In zone 2 (Fig. 2), NW-SE-trending folds and thrusts (C and D of Fig. 5) verge NE and have quartz and asbestos slip fibre lineation zones up to 25 cm thick, trending across as well as parallel to the strike of thrusts. The axial plane foliation in riebeckite lutite bands al-

ways dips westerly (Fig. 4D). In zone 3, strike stays NW-SE but the vergency of large folds with a low plunge is clearly to the SW and riebeckite lutite foliation dips at 80° to the NE (Fig. 4E). The rotated thrusts have steeper dips to the SW (Figs. 4E, 5D). This is the zone of back-folding of Coward and Potgieter (1983). Next we find a 2 km wide zone 4, in which a near-vertical NW-SE-trending foliation and near-vertical lineation of shear fold closures appear as transformed structures. Then follows zone 5 with mylonites of Schmidtsdrif quartzite and Marydale granite (2.6 Ga—Potgieter, 1982). We prefer to call zone 4 the

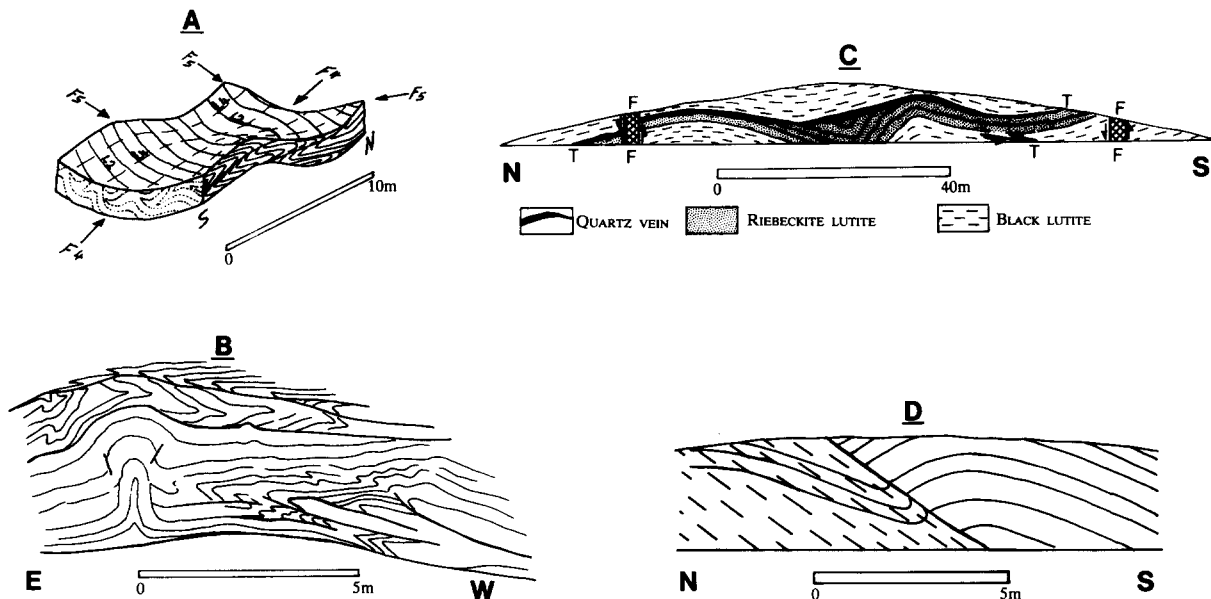


Fig. 5. Field sketches of specific structures. (A) Structural relationships at Prieska town. For fabric see Fig. 4. B. (B) Highway outcrops SW of Prieska.  $F_4$  upright fold deforms  $F_2$  thrusts and recumbents. For fabric see Fig. 4C. Looking south. (C) Fold and thrust behavior in zone 2 (Fig. 2) looking SW. Note folds are verging NE. For fabric see Fig. 4D. (D) "Thrust" with synthetic foliation in zone 3 (Fig. 2), rotated to SW and with slip movement nearly parallel to strike. For fabric see Fig. 4E.

Doornberg Fault Zone and zone 5 the Doornberg Mylonite. Together they form the Doornberg Lineament. Coward and Potgieter interpret zone 4 as vertically back folded thrusts and zone 5 as a left-lateral oblique shear-thrust (oblique wrench). In our opinion they both have a very similar origin. This is apparent in both cases from the relationship of shear folds to an older mylonite lineation.

S-shaped asymmetric meso shear folds in mylonitized Schmidtsdrif quartzite (Fig. 6A) bordering the Doornberg Fault Zone have a near vertical axis with a penetrative b-lineation parallel to the shear fold axes (Fig. 6B). They bear a set of older deformed penetrative mineral lineations orientated along a plane (Fig. 6B). No foliation occurs along this plane. The mylonite lineation is therefore definitely older than the b-lineation. Its plunge on the long, undisturbed limb of shear folds varies from moderate to steep in a northwesterly direction. "S" macro-folds have been mapped

and "Z" inferred by Potgieter (1981), the former with deformed older lineations, on the transition between quartzite-mylonite and granite-mylonite. This combination suggests sheath folds but is no proof of their existence. No closed sheaths could be followed out or seen in outcrop in the Doornberg Lineament. Some large S-shaped folds in zone 3, plunge steeply (Fig. 2). The simplest interpretation of these structural relationships together with the anti-clockwise drag of  $D_4$  structures in zones 2 and 3 and with what looks like "back-folding" in zone 3, is a first order left-lateral oblique wrench. To the west of this structure, movement was obliquely up to the SE at first, with closer to horizontal wrenching later on. Both phases were associated with compression across the shear zone. The first probably produced more displacement than the second. The latter was more compressive, however, with near-vertical extension along shear fold axes. This is clearly displayed by strings of horizon-

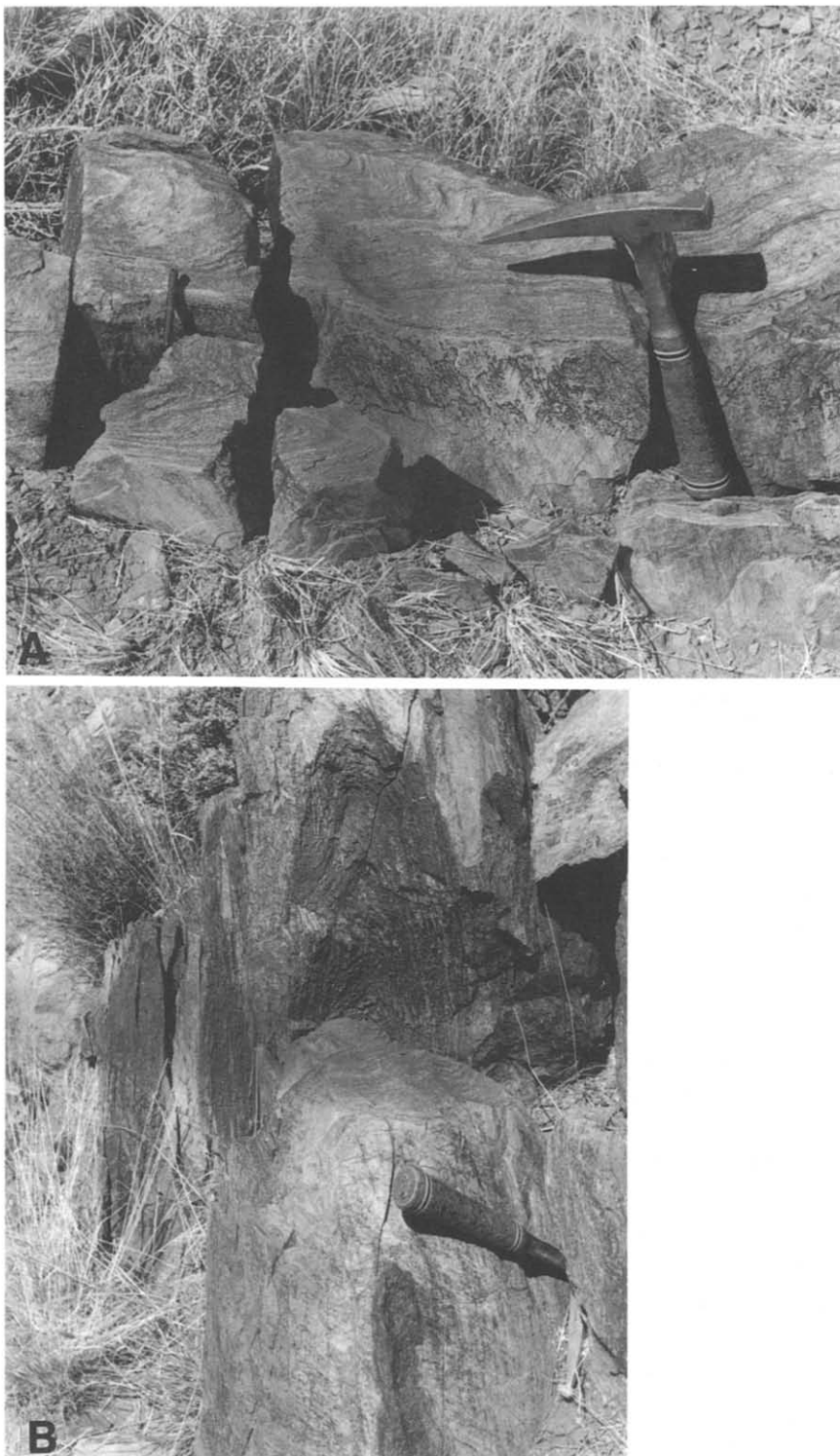


Fig. 6. Mylonitized Schmidtstrif quartzite. (A) S-shaped shear folds looking SW with near-vertical axes (parallel to pencil). Older mylonitic lineation is parallel to hammer handle. (B) Closer look at hinge of S-shaped shear fold with b-lineation parallel to hinge and older deformed mylonitic lineation lying in a plane parallel to hammer handle. Looking NW.

tally oriented tension gashes in competent chert (quartz) bands of vertically plunging shear folds in BIF of zone 4, the Doornberg Fault Zone.

Contrary to Coward and Potgieter's (1983) explanation of back-folding of earlier thrusts, which must have tilted many kilometres if not some tens of kilometres of crust between the Copperton and Doornberg Faults (Fig. 1) and which now simulates sinistral shear, we think that the bulk of the evidence is in favour of oblique left-lateral wrenching (Potgieter, 1981) along the Doornberg Lineament. This is responsible for the juxtaposition of Archaean granites against the Early Proterozoic Campbell Group, and most satisfactorily explains a gradual syntaxial change in strike of the early formed  $D_4$  thrusts and folds on the craton into the northwesterly direction with re-activation of some deflected thrusts that now bear strike-slip lineations in zones 2 and 3 (Fig. 2).

### Structures in the remaining study area

Four different types of  $D_2$  thrust were found in the Asbesheuwels Subgroup (Table 1) and fully described by Altermann and Hälbig (1990).

They are very common and briefly summarized here in order of increasing size. Their recorded distribution and relationship to other structural elements are shown in Fig. 7.

(1) Discrete slip planes that gradually cross from one bedding plane to the next can be followed for several metres and occur at frequencies of about one per metre thickness of strata in some sequences.

(2) Mylonitic, ferruginous carbonate and chert breccias and lenticular jaspilites and quartz veins, centimetres to decimetres thick occur subparallel to bedding, with shear phenomena clearly indicating the sense of movement which is always towards the craton. These dislocations are commonly accompanied by higher-angle synthetic splay faults. They can be followed in outcrop for up to many hundreds

of metres at a time and occur at a frequency of about one per several tens of metres. These thrusts may separate units that differ in lithology.

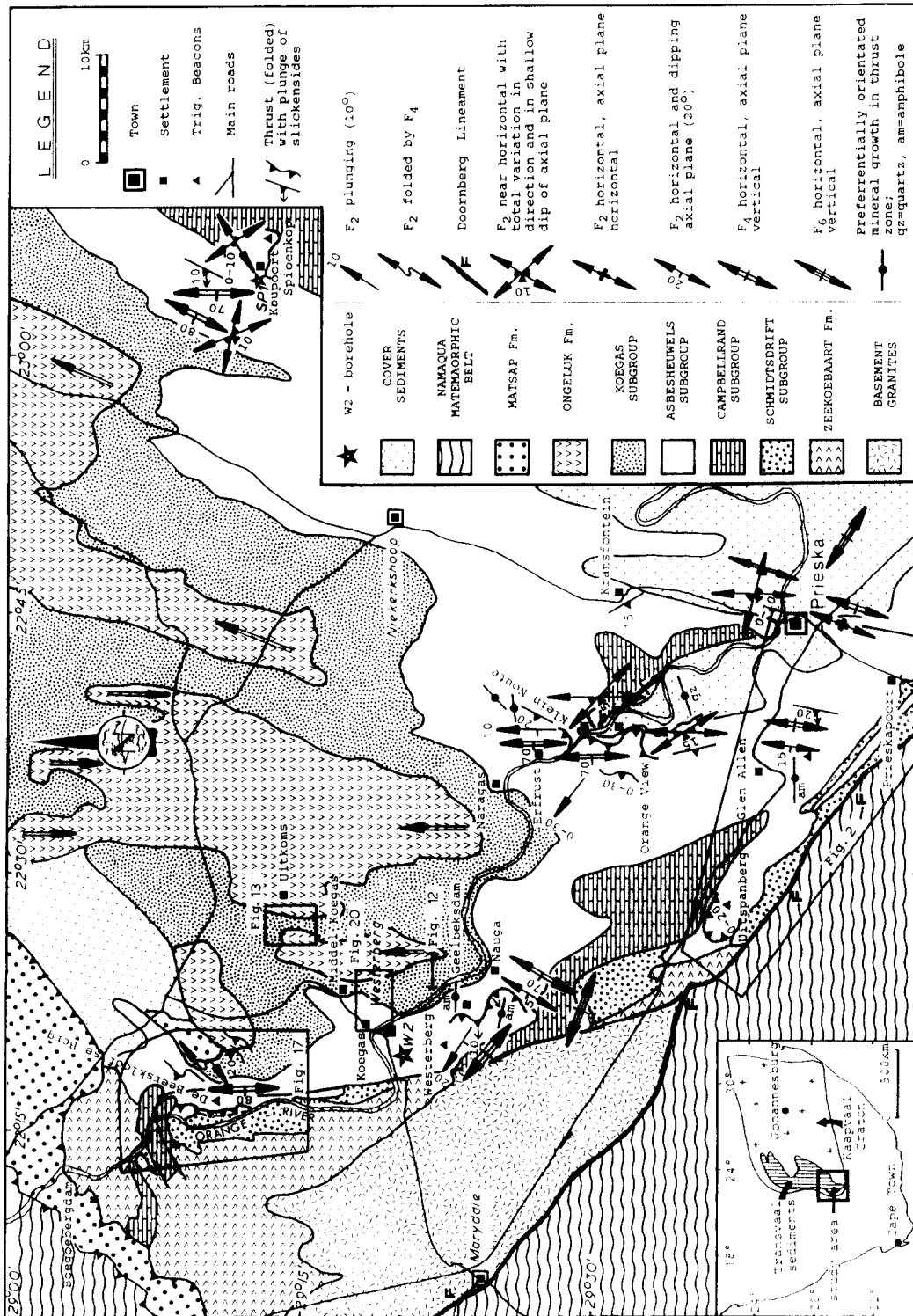
(3) Recumbent folds are found in sheet-like zones, which can be traced between nearby outcrops. They are subparallel to bedding. Discrete shear planes have developed within these zones parallel to axial planes and at their base. The vergency and direction of folds always indicate a movement of the hanging wall towards the craton (Fig. 4B). From 0.5 to several tens of metres of strata may be deformed in this way. They may be encased above and below by an envelope of asymmetric shear folds.

(4) Bedding-parallel as well as obliquely cross-cutting zones of totally phyllonitised BIF contain subzones of chaotic folds. They may grade laterally into jaspilitic breccias or develop a very distinct "augen"-structure up to several tens of metres thick in the Orange River area.

The structures of types (3) and (4) above can be traced for kilometres and are commonly separated by 50 to 100 m of strata. In drill cores they appear as a profusion of small folds associated with an axial planar cleavage over considerable core lengths, whereas the mylonitic meso-augen-structure might easily be mistaken for primary "pillow and billow structures" (Beukes, 1980) that also occur in the BIF. Types (1) and (2) thrusts occur intermittently in outcrops near the base of the Asbesheuwels Subgroup between Griquatown and Kuruman (Fig. 1).

The first three types have been found as far north as Griquatown, some 130 km northeast and east of the craton edge (Fig. 1), with movement directed NE, E and SE.

Directly southwest of the Griquatown Fault erosion-valley NW-trending thrusts dipping SW have stacks of NE-verging folds overlying quartz and crocidolite slip fibre dislocation zones alternating with zones of tension gashes (Figs. 8A and 9A).







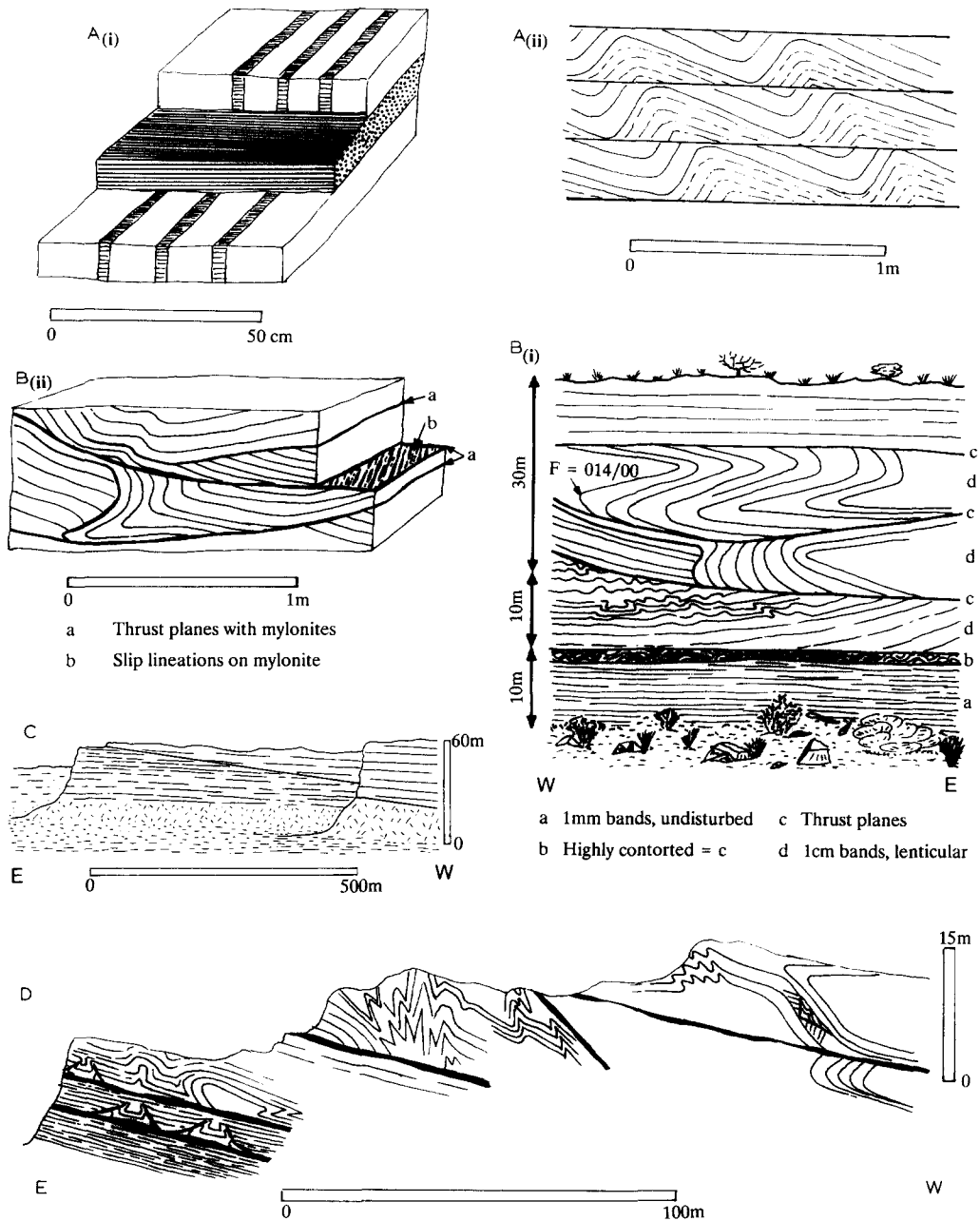


Fig. 9. Field sketches of folds and thrusts between Koupoort and Griquatown. Refer to Fig. 1. (A) Bordering the Griquatown Fault erosion-valley to the SW: (i) slip lineation zones and transverse tension gashes mark thrust zones, looking NW; (ii) stacks of thrusts and decapitated drag folds; looking SW. (B) Elandsfontein, 20 km north of Koupoort. Fold and thrust piles at the base of a lithologic unit in Griquatown BIF. For fabric see Fig. 8B. (C) Doornlaagte and Spioenkop 5–10 km east and north of Koupoort. Fold and thrust relationship to lithology and bedding in lower Griquatown BIF. For location see Fig. 10. For fabric see Fig. 8B.

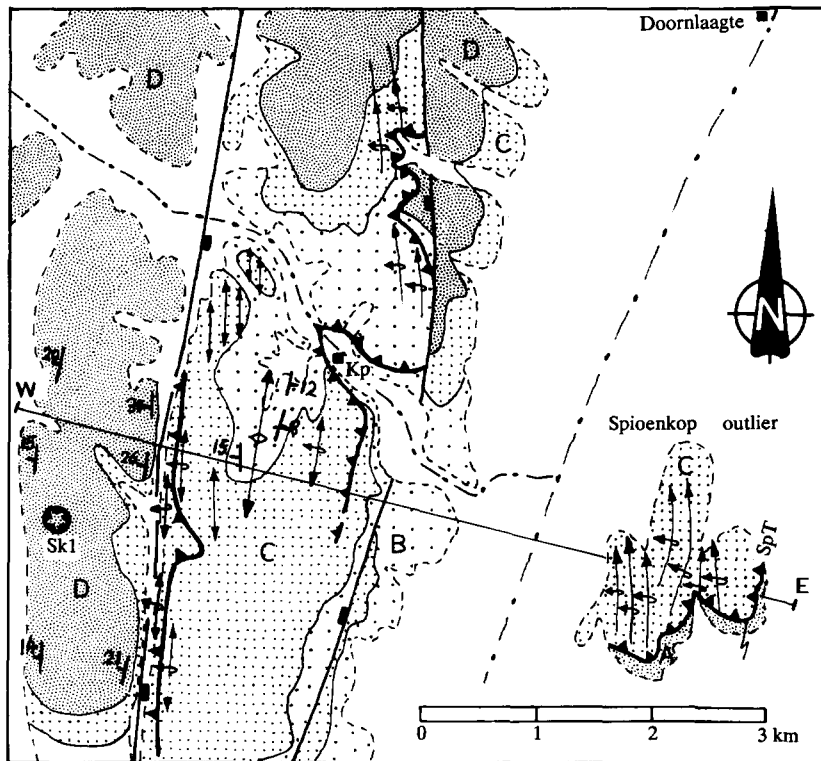


Fig. 10. Geological map of Doornlaagte-Koupoort area. After du Plooy (1986), amended, and the authors' own work. Various mappable units of mainly allochemical banded iron-formation overly each other from bottom to top in the order A, B, C, D. The general dip is between 5 and 10 degrees to the west and has been omitted, except where it deviates significantly from these limits. One larger anticline and numerous fold zones with asymmetric to recumbent east-verging folds are indicated schematically. Thrusts shown were mapped. Koupoort (*KpT*) thrust, and Spioenkop (*SpT*) thrust are cutting upwards through the lithology to the east. Most bedding plane thrusts as inferred from fold zones and correlation with data from borehole Sp 1, are not shown on the map. See also Fig. 11 for an interpretation of the structure. *Kp* = Koupoort farm house.

between 2500 and 2240 Ma in age, and possibly initiated N-S-trending  $F_1$ -folds in its hanging wall from Kuruman to Prieska (Fig. 1). The eastward convex shape of these  $F_1$  axial traces around the Maremane double-plunging anticline is seen as part of this development. Re-activation of these structures may have occurred during  $D_4$  N-S folding. This is also suggested by the two unconformities separating the Koegas, Makganyene and Ongeluk units (Fig. 12). The Ongeluk seems to have undergone posthumous folding along older trends. Aggressive fluids have moved along only one other dislocation plane in the study area. It is a  $T_2$  thrust separating carbonates verging W and facing E from Schmidtsdrif shales facing

and verging east in leg AB, of the profile in Fig. 18. This is the ideal stratigraphic horizon for a sole thrust to develop relative to all younger units. Thus the Uitkoms cataclasite with its evidence for fluid involvement may be closely linked to a sole thrust.

The fabric of bedding and lineations (Fig. 19) from the Koegas-Westerberg area (Fig. 7) reveals that N-S-trending folds plunging at low angles dominate. These are mainly  $F_4$  folds, many of which are E-vergent (Figs. 19A and 19C). But some interference of  $F_4$  with  $F_2$  recumbents and  $F_6$  (Table 2) occurs producing fold plunges at larger angles and in many directions (Figs. 19B and 19D).

In this same area, 200 m thick decollement

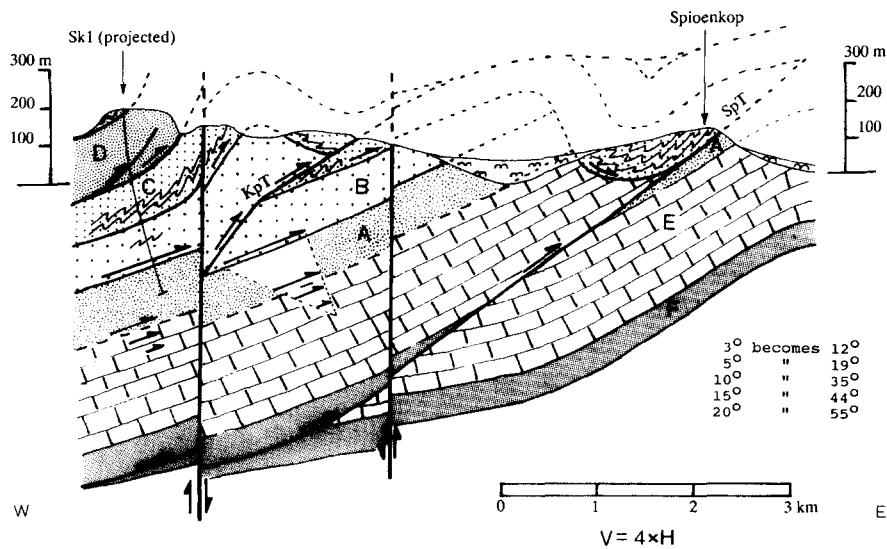


Fig. 11. Interpreted cross-section through the map, Fig. 10. Lithology as for Fig. 10. Unit A was apparently intersected at the bottom of hole Sp 1. This and the interpretation that A (and not any other horizon) overlies carbonates at the eastern slopes of Spioenkop, determines the reconstruction of the lower half of the figure. Thicknesses of units. Campbell Rand carbonates (E) and Schmidtsdrif shales + quartzite (F) are estimates. The interpretation is based on the surface and the drill-hole data, assuming that the lithological correlation across the valley to Spioenkop is correct. This correlation is neatly corroborated by the presence of a well-developed fold zone that consistently occurs near the base of unit C. The reconstruction assumes considerable differential bedding thrust slip (shown schematically by the slip-vector triangle) as is evident on meso- to macro-scales from Fig. 9B, (i) and (ii). This affects an earlier thrust cutting down the lithology to the east, and placing unit C on A at Spioenkop. A logical deflection of Sp 1 is assumed because in doing so it brings intersected horizons into very good alignment with surface data and because of observed dip angles relative to core. Note that the details shown here, differ from those that can be shown in Fig. 24.

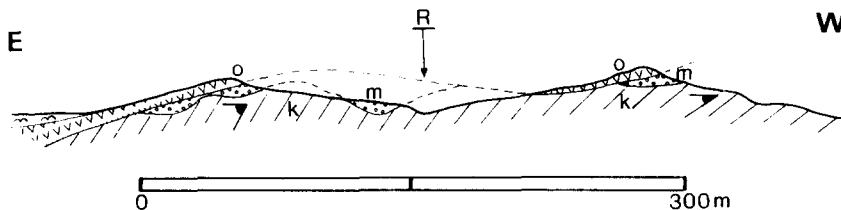


Fig. 12. Sketch profile through the western flank of the Libertas syncline. For location see Fig. 7. Two erosional episodes are in evidence. The earliest pre-Makganyene erosion occurred during or after considerable tilting of Koegas beds to form a high-angle unconformity. The later, pre-Ongeluk erosion produced a low-angle unconformity with the Makganyene. Note that dips in the Koegas Subgroup become steeper to the east as the axial plane of the syncline is approached. *K* = Koegas Subgroup, *M* = Makganyene mixtite, *O* = Ongeluk lava, *R* = river.

zones with recumbent  $D_2$  fold stacks exist in BIF (Altermann and Hälbich, 1990).

The largest folds that developed during  $D_2$  are the originally north-plunging, now reclined north-plunging mega-anticlines with Schmidtsdrif and Campbell Rand cores found on Bo

Seekoebaard (Fig. 17). The intervening synclines were thrust-out during  $D_2$  and the structures were co-axially refolded by  $F_4$  producing type (3) (Ramsay, 1967) interference patterns.  $F_2$  and  $F_4$  both plunge north to day in this area.

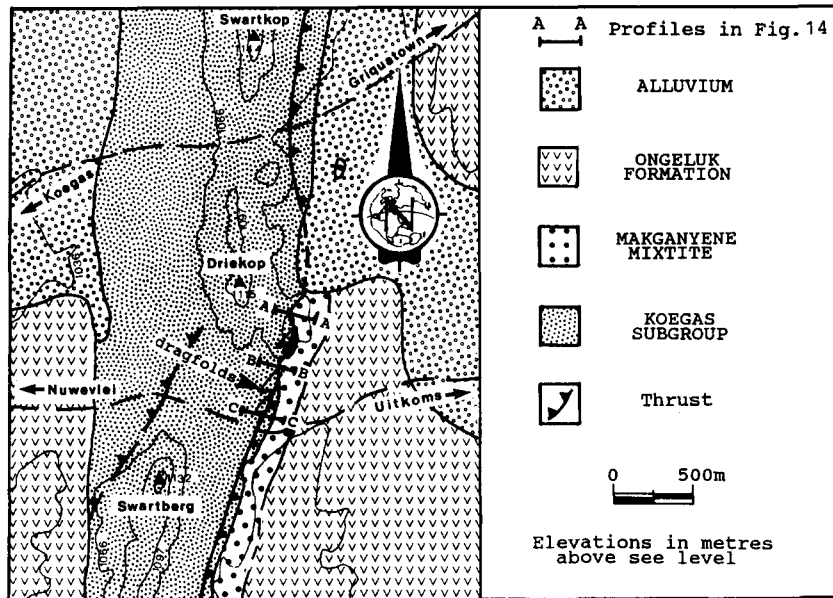


Fig. 13. Map of the Nuwevei-Uitkoms area. For location see Fig. 7.

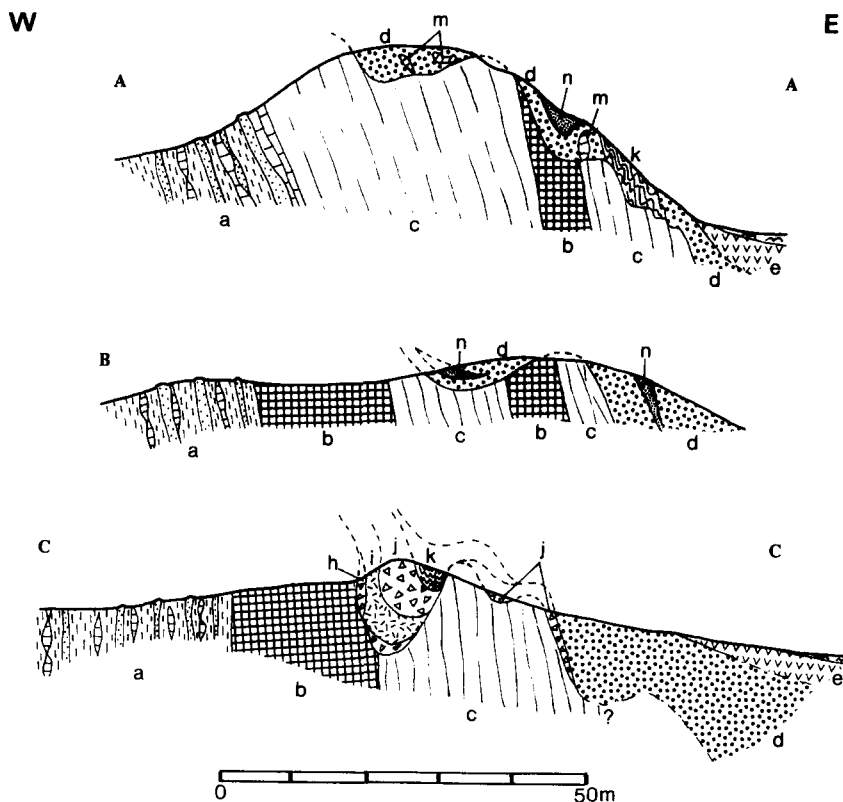


Fig. 14. Three short sections across the western limb of the asymmetric  $F_4$  Uitkoms syncline. For location see Fig. 13. The bedding-parallel cataclasite in Koegas beds predates later  $F_4$  folding and the angular unconformity on which the Makganyene mixtite was deposited. a=Koegas Subgroup; b=totally recrystallised carbonate and/or siliceous cataclasite partly with an augen structure in the Koegas Subgroup; c=Koegas Subgroup limestone with chert lenses (parent rock of b); d=Makganyene mixtite; e=Ongeluk lava; h-j=basal conglomerate of Makganyene; i has a black carbonaceous matrix containing angular fragments of cataclasite; k=contorted laminae of magnetic chert and limestone (varvite?); m=carbonate clasts floating in mixtite; n=lenses of sandstone floating in mixtite.



Fig. 15. Outcrop of the Uitkoms cataclasite zone on Uitkoms. Dark = carbonate recrystallisation. White = siliceous recrystallisation. Note irregular, lenticular form and near vertical attitude. Looking south. Difference in elevation is 15 m.

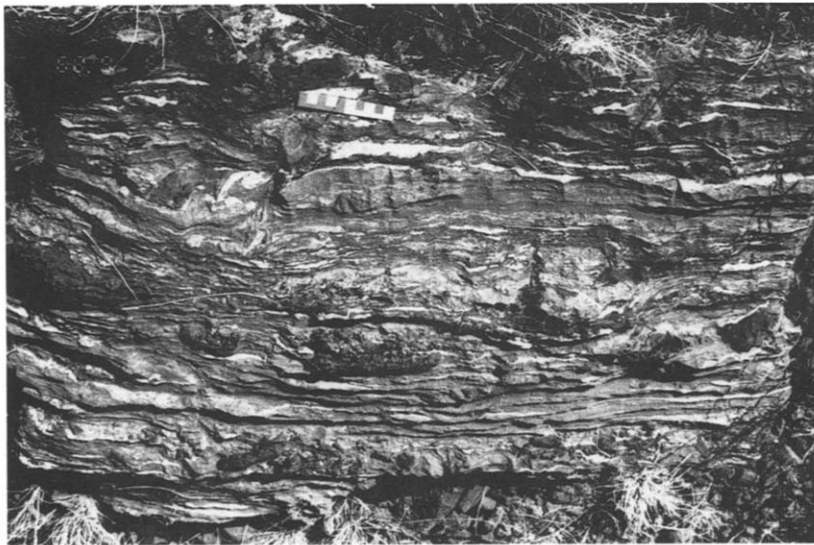


Fig. 16. Uitkoms cataclasite—detail showing lenticular structure. Scale is in centimetres.

Stacking of  $F_2$ -folds and thrusts, tectonic duplication of Koegas and BIF strata as well as refolding of  $F_2$  by  $F_4$  is also seen in other areas (Figs. 20 and 21).

$T_4$  thrusts displacing  $T_2$  and  $T_3$  are shown in Fig. 17. The relationship of  $T_3$  to  $T_2$  structures is also clear from Figs. 17 and 22. Matsap beds

(Table 1) tectonically overlie Koegas, Makganyene and Ongeluk strata that were thrust and sheared previously. The Matsap klippe has a basal  $T_3$  thrust breccia consisting of very small angular fragments of Koegas and BIF derivation in a ferruginous matrix.

$T_3$  thrusts and S- to SE-verging horizontal  $F_3$

folds have developed in the Matsap beds as described by Vajner (1974b) for the area around Boegoeborg Dam (Fig. 7). These structures very rapidly die out or are absent in older strata southwards and it seems that the Volop Group is tectonically decoupled from the older strata by a  $T_3$  sole thrust south of Boegoeborg Dam. Several klippees are outcropping to the south (Figs. 1 and 7), one of which underlies Groot Witberg (Fig. 17). The  $F_2$  folds in Asbesheuwels Subgroup on Bo Seekoebaard (Fig. 17) have north-plunging axes and form type (3) interference (Ramsay, 1967) with  $F_4$  as outlined above. One would expect type (2) interference patterns if they were refolded  $F_3$  structures.

In the area between Seekoebaard 1 and Boegoeborg Dam west of the Orange River (Figs. 7 and 17), Zeekoebaart, Schmidtsdrif and Matsap strata all display two cleavages in fine-grained rocks. The younger, non-penetrative and spaced  $S_6$  cleavage trends E–W and is approximately vertical everywhere. On Seekoebaard 1 and 2 it crenulates an older  $S_2$  that is axial planar to remnants of large reclined NE-trending  $F_2$  folds in Schmidtsdrif meta-quartzites. They plunge to the NW or N and are transected by thick bedding-parallel quartzite mylonites (Figs. 23A and 23B). Farther north, grey Matsap conglomerates and quartzites tectonically overlie the Zeekoebaart meta-lava with a different style of  $D_3$  folds, thrusts and cleavages (Fig. 23C).

$F_4$  N–S-trending folds refolded the Matsap and all older cover rocks. The intensity of these folds of which the Orange River syncline (Fig. 1) and the synclines in the Ongeluk Formation (Figs. 1 and 7) are examples, decreases from W to E. Those in Ongeluk and older rocks seem to be posthumous folds following older  $F_1$  synclines.

The Westerberg dextral oblique-slip fault (WF—Fig. 17), described by Vajner (1974b) as the Doringberg Fault, is probably the

youngest tectonic feature in the area under investigation. Altermann and Hälbich (1990) discuss the possibility that this feature which is a splay-fault off the Doornberg Lineament (Fig. 1), has rejuvenated previously refolded older thrust planes. This happens in the south of Fig. 17. Farther north on this figure, older  $D_2$ -recumbents and  $T_2$ -thrusts are refolded by N–S-trending  $F_4$  and the Westerberg Fault merges with  $T_2$  and  $T_4$  structures.

The Schmidtsdrif and Naute shales and phyllites each have only one N–S-trending steeply west dipping axial plane  $S_2$  cleavage (Fig. 17). This structure cannot be genetically linked to the Westerberg Fault because in both cases the cleavage is developed with equal intensity and attitude next to and several kilometres away from it.

The age of the Uitkoms cataclasites ( $D_1$ ) relative to the oldest deformations ( $D_2$ ) seen in the BIF of the Orange River of Fig. 17 is not certain.  $D_2$  and  $D_1$  may be of very similar age, but the intensely recrystallised nature of the Uitkoms zone in thin section, and without a prominent lineation suggests that it may have a different origin, possibly as a splay thrust rising from a sole in Schmidtsdrif shales.

## Discussion

### *Age of deformations*

The absolute age of deformation events described above can only be roughly comprehended from dated volcanic rocks which often have overlapping error margins of hundreds of Ma, probably in part because they were dynamically metamorphosed at least once. Seven events are recorded (Table 2)













### $D_1$

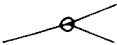

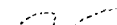


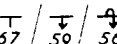
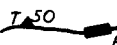

It is now certain that the deformations on the craton predate the deposition of the Makganyene diamictite and the extrusion of the On-

# Geological Map of the Bo Seekoebaard, Lelikstad, Pypwater area

Sources: Own mapping, photo interpretation and re-interpretation of the map of Vajner (1974)

## LEGEND

-  ALLUVIUM
-  WESTERBERG DYKE  
basic intrusion
-  MATSAP FORMATION  
conglomerates, grits and sandstones
-  ONGELUK FORMATION  
basic lava
- ~~~~~ UNCONFORMITY
-  MAKGANYENE DIAMICTITE
- ~~~~~ UNCONFORMITY
-  KOEGAS SUBGROUP  
siltstones, shales and limestones
-  ASBESHEUWELS SUBGROUP  
orthochemical and allochemical BIF
-  NAUTE FORMATION  
shale with chert bands
-  CAMPBELLRAND SUBGROUP  
carbonates and rare tuffs
-  mainly shales and phyllites  
with chert bands
-  SCHMIDTSDRIF SUBGROUP  
mainly quartzites
- ~~~~~ UNCONFORMITY
-  ZEEKOEBAART FORMATION  
basic lava

- SBA Seekoebaard Antiform
- HBS Hardeberg Synform
- WIF Witberg Fault
- WF Westerberg Fault
- / ■ / △ Survey spot; farm house; trig. beacon
-  Farm boundaries
-  Geological boundary known -  
extrapolated
-  Form lines - photo interpretation
- Axial planes: Number refers to  
relative age.
-  Open arrows: General plunge of axis  
and dip of axial plane.
-  Closed arrows: Specific plunge.
-   $\frac{T}{67} / \frac{F}{59} / \frac{F}{56}$  Strike and dip of beds, sense unknown;  
known; overturned
-   $\frac{T}{50}$  Thrust and thrust-fold plane (T),  
fault (F), - observed, dip direction  
indicated
-   $\frac{T}{-} / \frac{F}{-} / \frac{T}{-}$  Thrust and thrust-fold plane (T),  
fault (F), - extrapolated, re-  
interpreted or inferred



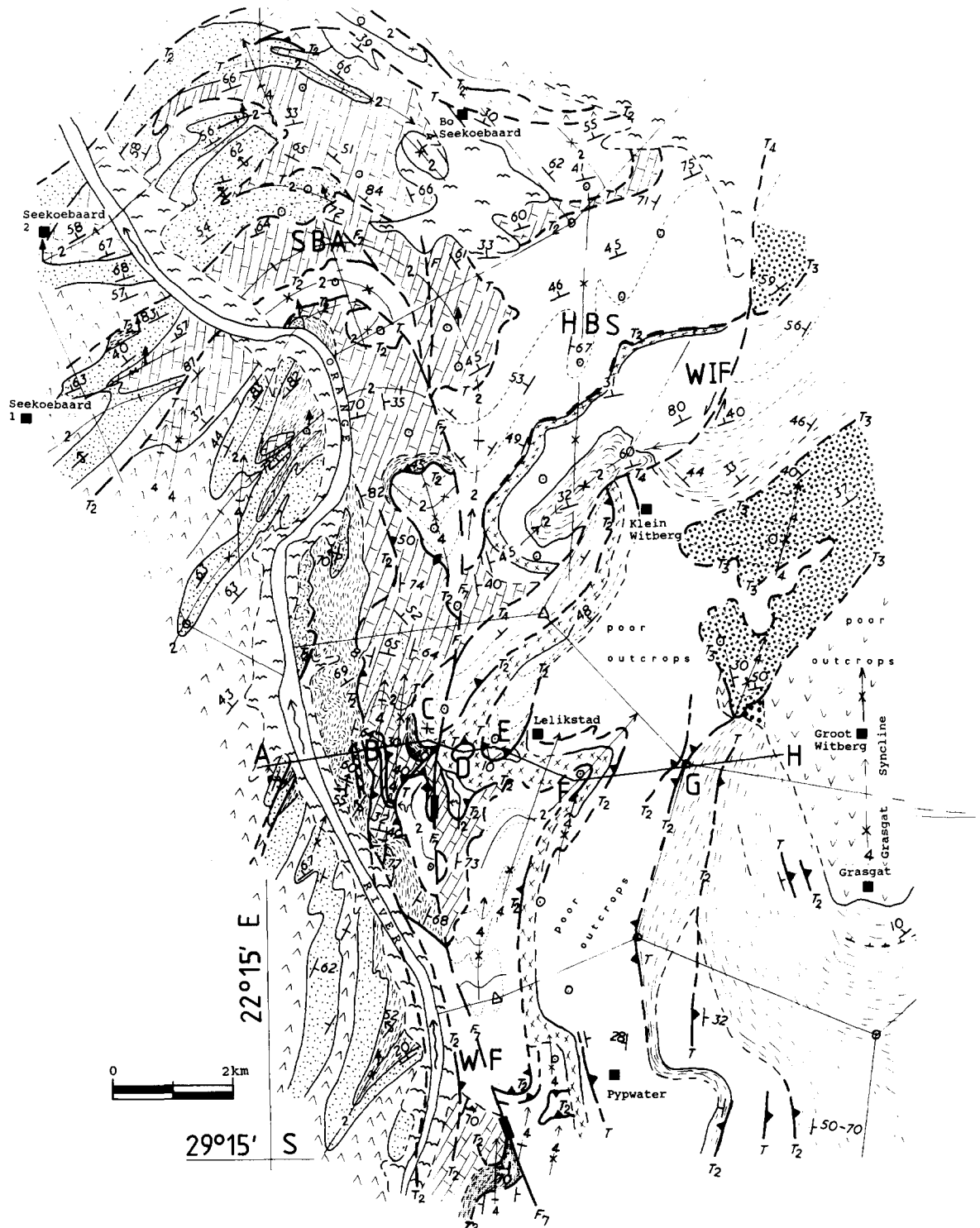


Fig. 17. Geological map of the Bo Seekoebaard-Lelikstad-Pypwater area after Vajner (1974) as amended, and the authors' own mapping. For location see Fig. 7. For description see text.

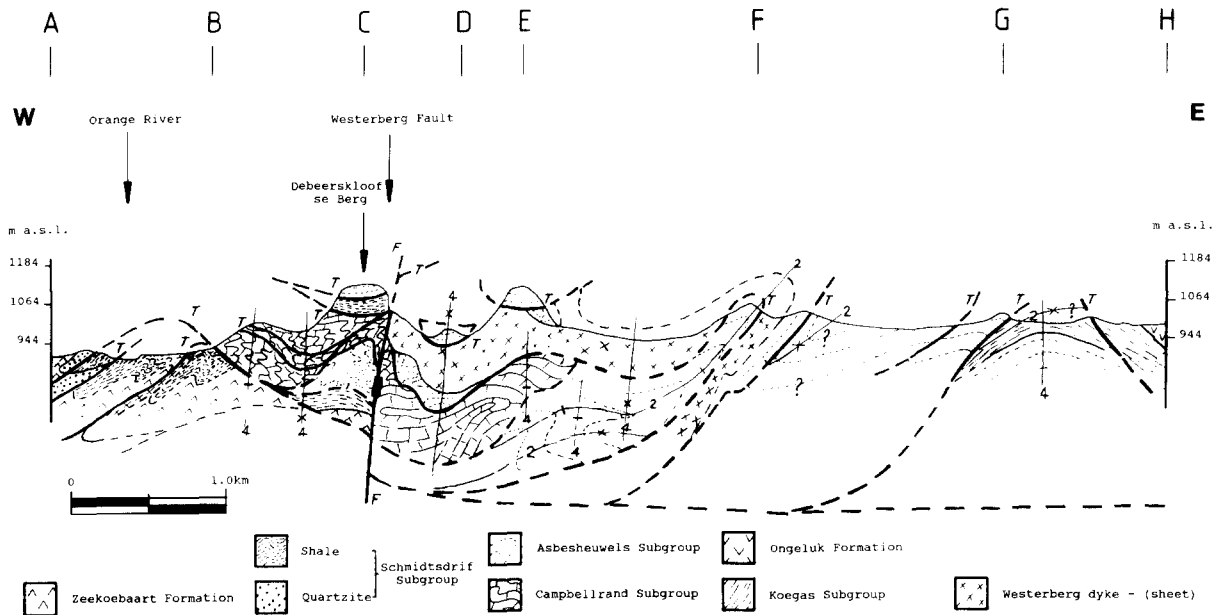


Fig. 18. Sections A–H from Fig. 17. Note the style of deformation of  $F_2$  (recumbent north-plunging folds) and thrusts refolded by upright to E-vergent  $F_4$ . Late Westerberg faulting transects all older structures.

geluk Andesite Formation with an age of  $2240 \pm 57$  Ma (Walraven et al., 1982) or  $2239 \pm_{92}^{90}$  Ma (Armstrong, 1987), but postdate the deposition of the Koegas Subgroup (2400–2300 Ma?) The  $D_1$ -episode is therefore older than the Kheis–Koranna orogeny (2.2–2.0 Ga; Barton et al., 1986), and thus the first orogenic event of post-Archaean but pre-Ongeluk age so far known in the region under investigation.

## $D_2$

The slump folds, decollements, mega recumbents, recumbent fold stacks and thrusts that are considered to belong to this episode, seem to represent an extended period of movements that started just after sedimentation of the Kuruman BIF, and in the present study area finally affected the entire Ghaap Group (Table 1).  $D_2$  structures have not been observed in Makganyene or Ongeluk strata. However, a set of shear planes displacing  $D_2$  thrust breccias also affects the Makganyene Formation (Fig. 22), but not the Matsap Group. The cor-

relation of  $D_2$  with  $D_1$  is possible but uncertain and it is preferable to keep them separated (Tables 1 and 2). It is also possible that some of the earliest slump folds classed as  $D_2$  here are earlier than  $D_1$  and that some of the latest  $D_2$  cataclasites in BIF only just pre-date the deposition of the Makganyene diamictite.

$D_2$  movements are therefore younger than the age of deposition of the Kuruman BIF ( $2432 \pm 31$  Ma, Trendall et al., 1990), but apparently older than the Ongeluk lava (2239 Ma). They also pre-date the intrusion of the metamorphosed Westerberg dyke-sheet (Fig. 17). Certainly  $D_1$ , but parts of  $D_2$  as well, are older than the earliest deformations (Stowe, 1986;  $KF_1$ ) recorded from the Kheis Subprovince (Table 2 and Fig. 1), thought to have happened about 1750 Ma ago. The movement directions and vergencies of  $KF_1$ ,  $KF_2$ ,  $D_1$  and  $D_2$ , however, are comparable. We conclude that already in Early Proterozoic times several easterly (cratonward) directed pulses deformed pre- and post- Makganyene strata. A

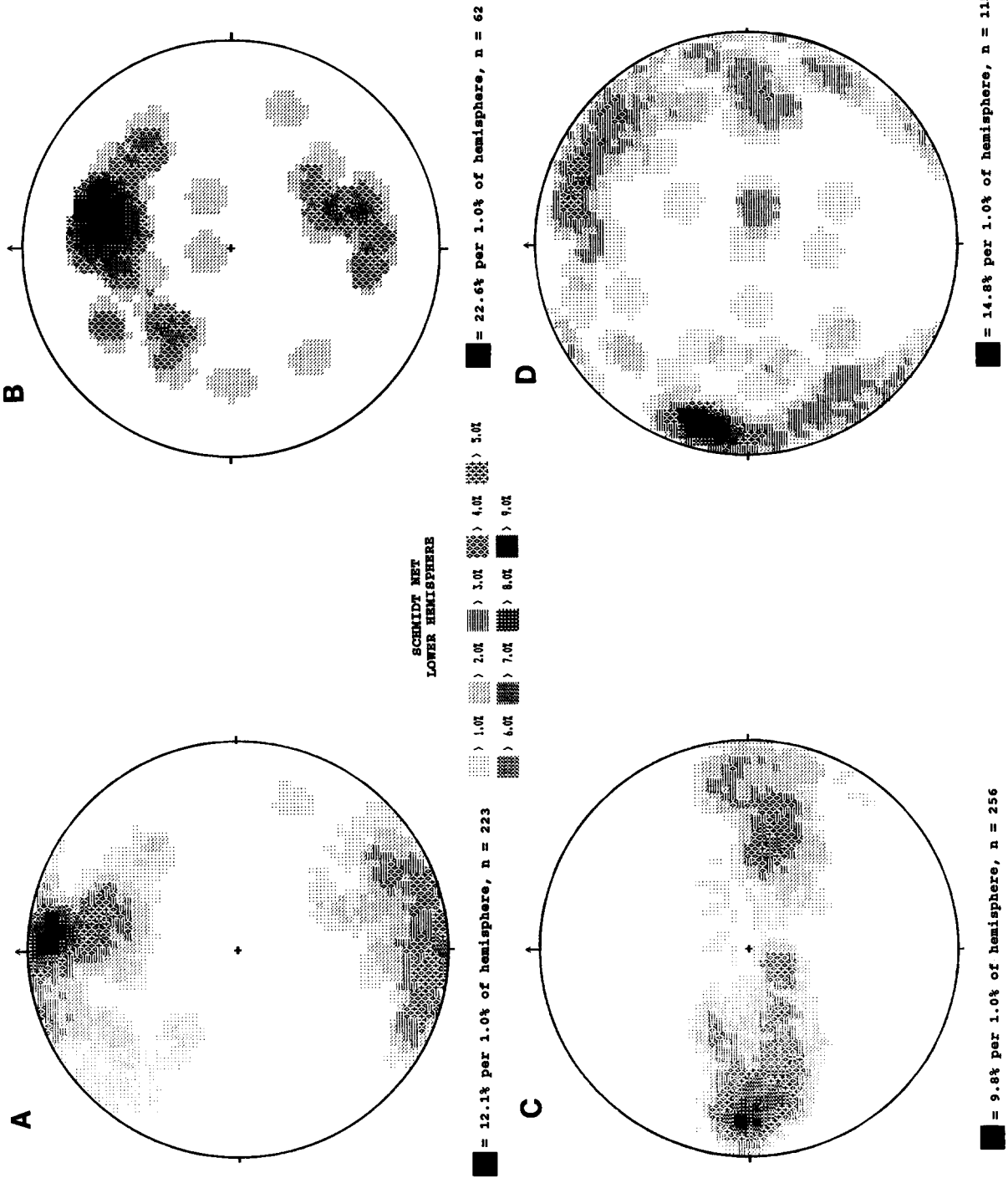


Fig. 19. Structural fabric of the area Koegas-Westerberg. (A) Measured fold axes of meso ( $F_2$ - $F_4$ ). (B) Measured fold axes of refolded  $F_2$  folds only. (C)  $\pi_{SS}$  to bedding of large  $F_4$  folds. (D)  $\pi_{SS}$  to bedding of larger  $F_1$  folds.

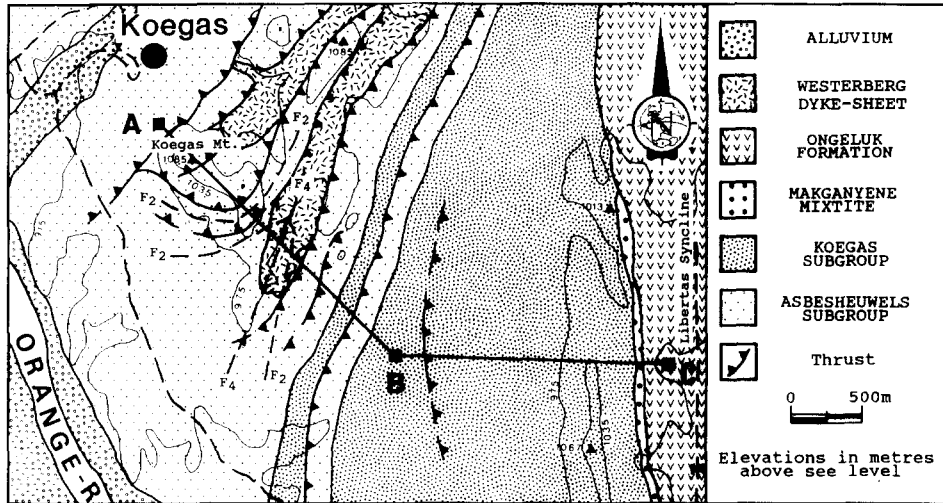


Fig. 20. The geology southeast of Koegas showing difference in style and intensity of  $D_2$  as controlled by lithology. For location see Fig. 7.

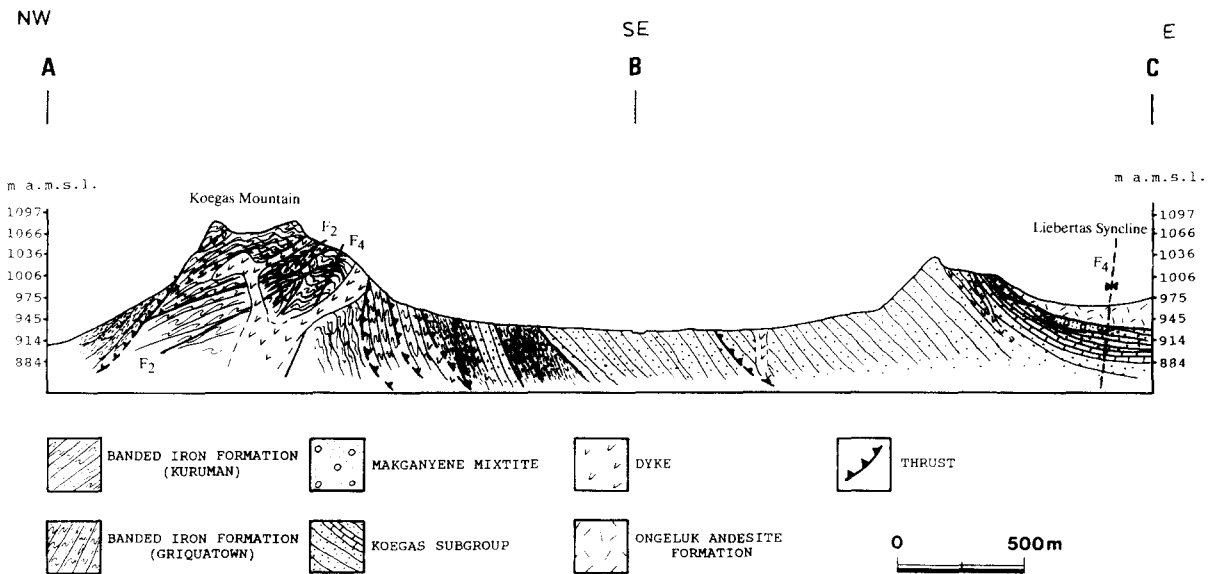


Fig. 21. Section A-B-C of Fig. 20. Note the difference in style of deformation between iron formation in Koegas Mountain and Koegas sediments to the east. Lithological duplication occurs along the eastern flank of Koegas Mountain, and the dips of  $T_2$ -thrusts vary across the mountain because of asymmetric E-vergent  $F_4$  anticlinal refolding with a steep eastern limb.

long time-span could have separated the earlier from the later episodes because of the size of the pre-Makganyene high-angle unconformity.

$D_3$

The thrust below the Groot Witberg tectonic outlier of Matsap rocks could have happened

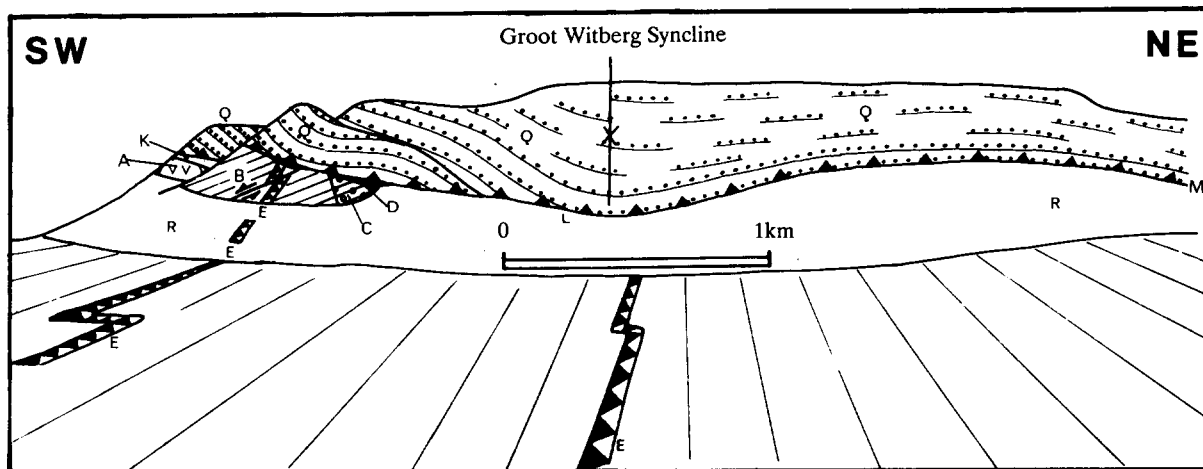


Fig. 22. Panoramic sketch of Groot Witberg Mountain looking north from near the dwelling on farm Grasgat (Fig. 17). The tectonic contact KDL at the base of the Matsap (Q) is folded by  $F_4$ , as are the Matsap beds themselves, to form the Groot Witberg syncline (Fig. 17). A = Ongeluk amygdaloidal lava. B = Koegas Subgroup of north striking siltstones and tectonically intercalated BIF, isoclinally folded and east-vergent. C = Makganyene mixtite. Both B and C are affected by a set of post  $D_1$  and  $D_2$  shear planes striking NE and absent from Ongeluk and Matsap. D = lenses of thrust fault breccia along contact to Matsap sediments. This breccia truncates both over and underlying beds. E = bedding-parallel  $D_1$ - $D_2$  thrust breccia in Koegas. R = scree. Time sequence: (1) folding and thrusting of Koegas Subgroup (B) during  $D_1$ - $D_2$ ; (2) erosion and deposition of Makganyene (C); (3) shearing of B and C; (4) erosion and deposition of Ongeluk (A) (2240 Ma); (5) erosion and deposition of Matsap (Q); (6) emplacement of Matsap allochthon ( $T_3$ ); (7) N-S ( $F_4$ ) folding of Matsap and  $T_4$  thrusting.

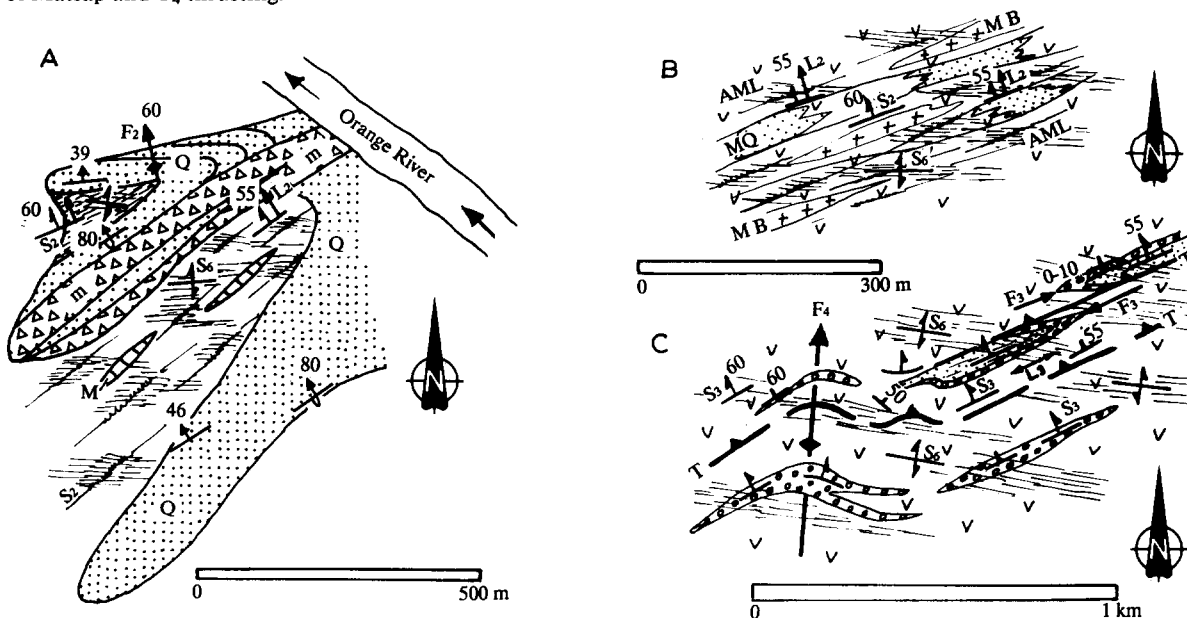


Fig. 23. Structural relationships in rocks west of the Orange River in Fig. 17. Note that  $S_6$  has a constant attitude and is the youngest structure in all these outcrops.  $F_3$  are not developed in strata older than Matsap beds and  $F_2$  are not developed in Matsap strata. The decoupling thrust plane between Matsap and older strata is not exposed in this area. (A) On Seekoebaard 1, in Vryburg quartzites (Q) and Zeekoebaard lava (V). M = lenses of marble; m = thick quartzite mylonite. (B) On Seekoebaard 2, lenses of metabasites (MB) and metaquartzites (MQ) drift in sheared amygdaloidal meta-lava (AML). For (A) and (B),  $S_2$  is equivalent to Vajners (1974, pp. 104-105, fig. 10b) main schistosity in the Zeekoebaard Formation of pre-Matsap age. (C) Synclines of Matsap quartzites and conglomerates, overlying older meta-lavas north of Seekoebaard 2.

late in the Kheis–Koranna orogeny (2.2–2.0 Ga, Barton and Burger, 1983) but is more likely to be of post-Hartley lava age (2.07 to 1.88 Ga).  $KF_1$  and  $NF_{1a}$  (Table 2) from the Kheis and Gordonia subprovinces are comparable or somewhat younger in age. A somewhat younger  $KF_2$  and  $NF_{1b}$  (Table 2) recorded by Stowe (1986) from these areas respectively have not been detected elsewhere around and on the craton. They must have had a restricted distribution due to specialized, local circumstances. Beukes and Smit (1987) suggested that the Blackridge Thrust Fault system is of Kheis–Koranna age. However, from their stratigraphic table it is evident that this system duplicates the Mapedi Formation and the conformable strata of the Olifantshoek Group, including the Hartley lavas, above it. Consequently, the Blackridge Thrust system is of post-Matsap age or younger than the  $2070 \pm 90$  Ma ( $1881 \pm 57$  Ma, Armstrong, 1987) of Hartley lava. Therefore, the Blackridge fault system of Beukes and Smit (1987) is probably  $D_3$ -related (Table 2). The thrust below Groot Witberg described above seems to belong to this episode.

#### $D_4$

These N–S-trending upright and asymmetric E-vergent folds and associated minor brittle thrusts post-date the intrusion of the Westerberg dyke-sheet (e.g. the Witberg oblique fault, Fig. 17), and are associated with a steeply west-dipping cleavage. They deform the Groot Witberg klippe and the  $D_3$ -thrust and folded Matsap strata around Boegoeberg Dam. They also develop the most prominent N-trending mega-anticlines and synclines in the Griqualand West sequence (Figs. 1, 7 and 17). The age of  $D_4$  structures is less than 2.07 to 1.88 Ga. Some re-activation of  $D_1$ – $D_2$ -structures may have occurred during this episode.

#### $D_5$

$D_5$  structures comparable to the main  $NF_2$  Namaqua phase (Stowe, 1986) in the Uping-

ton terrain (Fig. 1 and Table 2) are feebly developed in the Kheis Subprovince (Stowe, 1986) and do not occur on the Marydale High and east thereof probably because of effective shielding of a proto-Marydale High.

#### $D_6$

These very open E–W to ENE–WSW folds produce type (1) interference patterns (Ramsay, 1967) with  $F_4$  and  $F_5$  (Figs. 1 and 7). All the other subprovinces underwent a very similar late Namaqua folding (e.g. Graafwater synform, Harris, 1988, Table 2). It is estimated to be 1.1 Ga old (Stowe, 1986).

#### $D_7$

The Doornberg Lineament is an oblique wrench fault with a transpression component transporting up in the SW, along the NW–SE Doornberg Fault Zone, and the Westerberg Fault is a very similar but right-lateral splay fault of lesser effect. The age is considered to be just less than 1.0 Ga (Stowe, 1986).

### Structural model

An attempt has been made to combine the new evidence for mid-Early Proterozoic regional thrusting described here with well known regional fold structures of the  $F_4$ , N–S-trending set, by assuming a sole thrust at the shale horizon of the Schmidtsdrif Subgroup (Fig. 24). From 15 km east of the Westerberg Fault the principle of balanced cross-sections (Dahlstrom, 1969; Woodward et al., 1989) has been applied for the construction. It appears that not more than about 25% of cumulative horizontal shortening has occurred by thrusting and homogeneous deformation (cleavage development, especially in riebeckite lutites during ramp climb) over about 100 km of section.

The westernmost part underwent considerable ductile deformation at amphibolite facies metamorphism. The diagram does not show the full extent of possible overriding of the



Zeekoebaart Formation and Marydale Granite onto the craton because of the younger  $T_3$ -thrusts coming from the north and which probably follow a major post-Postmasburg pre-Olifantshoek erosion surface in this area.

Figure 24 implies that the Early Proterozoic  $D_1$ - $D_2$  deformations ( $> 2240$  Ma and  $< 2432$  Ma) have come from root zones on the Marydale High and beyond it to the west, where the Namaqua Province (deformed much later at high-grade metamorphism), is found today. The many macro-structures and the riebeckite mobilization along thrust zones of course can not be depicted on this scale. However, riebeckite mobilization is borne out by the following facts:

(i) Only riebeckite lutites developed a penetrative cleavage in folds in and above dislocation planes.

(ii) Selective solution along these cleavage planes supplies the necessary material to be transported into riebeckite halos that accompany many of the fold-thrust zones.

(iii) Riebeckite lutites are also physically the most mobile stratigraphic units, injected into and along thrust planes (Altermann and Hälbich, 1990).

(iv) Commercial quantities of crocidolite grow as secondary fibre across dilating tension fissures parallel to bedding planes. They concentrate in fold zones that are associated with thrusts and decollements.

(v) South of the Griquatown Fault, quartz is mobilized together with riebeckite, and tigers eye appears as a pseudomorphic replacement of crocidolite along slip- and transverse-fibre. North of the Griquatown Fault, crocidolite is not regularly replaced by  $SiO_2$ .

## Conclusion

Substantial evidence exists that duplication of Transvaal strata by complex thrust-faulting and -folding occurred all over the southwestern Kaapvaal Craton in Griqualand West. The thrust planes can be found at least 130 km away

from the present craton margin (Figs. 1 and 24). Stowe (1986) found several phases of thin-skinned thrusting that developed from 1.75 Ga onwards in Middle Proterozoic rocks overlying the Kaapvaal Craton in the Kheis Subprovince. Because of competency differences, still older thrusts and folds have developed mainly in the Asbesheuwels but also in the Koegas Subgroups and the apparently simple lithological sequence (Beukes, 1980, 1983) actually represents a tectonically thickened and partly duplicated pile (Fig. 24). Stratigraphic thickness of various units that have so far been recorded from the western Kaapvaal Craton are therefore definitely overestimated, which has certainly led to some stratigraphic and environmental misinterpretations in the past. The treatment of this effect is beyond the scope of this paper.

If the Griquatown Fault (Fig. 1) is viewed in the light of tectonic complications reported here, it seems likely that further thickening of the stratigraphic column to the south of it was influenced by thrusting and decollement, possibly following an older growth fault.

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