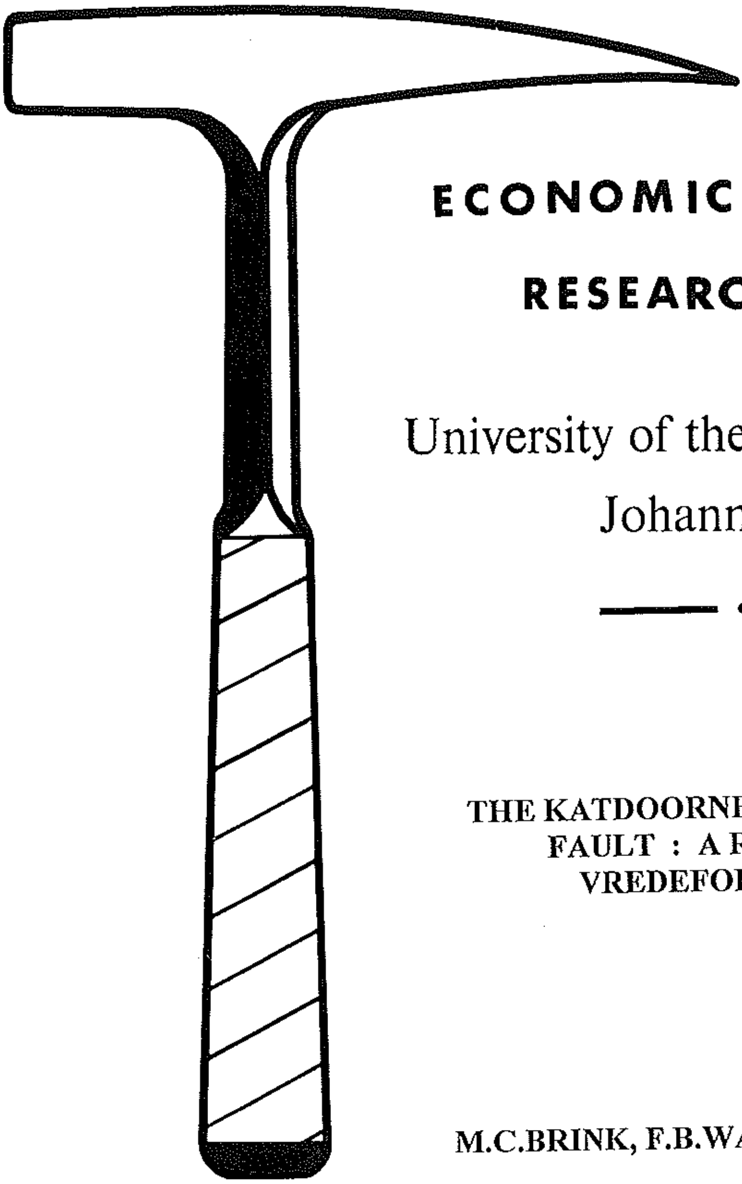

ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
Johannesburg

THE KATDOORNBOSCH-WITPOORTJIE FAULT : A RING THRUST OF VREDEFORT EVENT AGE

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UNIVERSITY OF THE WITWATERSRAND
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by

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ABSTRACT

A fault, designated the Katdoornbosch-Witpoortjie Thrust, was traced in the field continuously from the area north of Klerksdorp to the West Rand. It is shown that the Katdoornbosch Thrust and the Witpoortjie Fault form parts of the same structure. Evidence is presented as to why the Witpoortjie Fault should be designated a thrust. It is shown further, that the chert horizons of the Malmani Subgroup are characterised by a very recognizable type of brecciation, formed by chocolate-tablet-type boudinage, where they are intersected by thrust faults related to the Vredefort meteorite impact event. The recognition of this type of brecciation along the plane of the Katdoornbosch Thrust provides an age for the Witpoortjie Thrust. The Witpoortjie Thrust may be only one of a set of similarly orientated thrusts, formed around the Central Rand and the Johannesburg Dome, during the Vredefort impact event.

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INTRODUCTION

A multi-ring structure, centred around Vredefort, South Africa, is recognizable on mapping published in 1986 by the Geological Survey of South Africa (now the Council for Geoscience. Strata belonging to the Witwatersrand (2970-2914 Ma), Ventersdorp (ca 2714 Ma, for the basaltic lavas and 2709 Ma for the quartz porphyries) and the Transvaal (2560-2250 Ma) Supergroups (dates according to Reimold and Gibson, 1996), are found within the structure (Brink et al., 1997). The Witwatersrand Supergroup consists of a lower division, designated the West Rand Group, and an upper division, designated the Central Rand Group. The Ventersdorp Supergroup is divided into: (1) a lower division, called the Klipriviersberg Group, consisting mainly of lava; (2) a middle division, consisting mainly of sediments (Kameeldoorns and Rietgat Formations) and pyroclastic rocks (Makwassie Formation) belonging to the Platberg Group; and (3) an uppermost division, consisting of sediments (Bothaville Formation) and lava (Allanridge Formation), designated the Pniel Succession by Winter (1965). Overlying a regional unconformity, the base of the Transvaal Supergroup is formed by the Black Reef Group. The Black Reef is overlain by the Malmani Subgroup, consisting mainly of dolomitic rocks (the basal Oaktree Formation and the upper middle Lyttelton Formation), with two cherty formations (Monte Christo and Eccles) occurring towards the middle and at the top. The overlying Pretoria Group comprises the youngest assemblage of strata affected by the Vredefort Structure.

The Vredefort Structure was recognised by authors such as Reimold and Gibson (1996) and Brink et al. (1997) to be a multi-ring basin (Melosh, 1995), formed by the impact of a large body from outer space. Outlines of the main elements of the structure are shown in Figure 1. The structure is similar to the Orientale Basin on the hidden side of the Moon and the Lise Meitner structure on Venus (Melosh, 1995). Multi-ring basins are large, complex astroblemes (Dietz, 1960; Melosh, 1955; Grieve and Pesonen, 1992) and the theory of their formation is described by authors such as Gault et al. (1968), Grieve and Head (1981), Melosh (1989, 1995), and Spray and Thompson (1995). Multi-ring basins are formed on planets or their moons by the impact of large bodies such as comets or asteroids. During impact, material is accelerated centrifugally away from the impact point to attain, in places, a velocity approaching a significant fraction of that of the impactor. In large astroblemes, structural forms are created that resemble those formed in the Earth's crust under the influence of a compressional tectonic stress system. These include folds, distinguished from those of "classical" tectonic systems by their ringform, annular shapes, and imbricate thrust systems, that detach over the ramps provided by the impactward-facing limbs of the anticlinal rings. Around and below the point of impact, a transient crater is excavated, with unstable walls that collapse inward immediately after their formation, presumably under the influence of rebound and elastic wave action assisted by gravity. A much wider, final crater is formed, that may eventually be modified further by isostatic uplift and erosion.

A model for the morphology of the Vredefort basin was derived by Brink et al. (1997) from data obtained from surface mapping, exploration borehole intersections

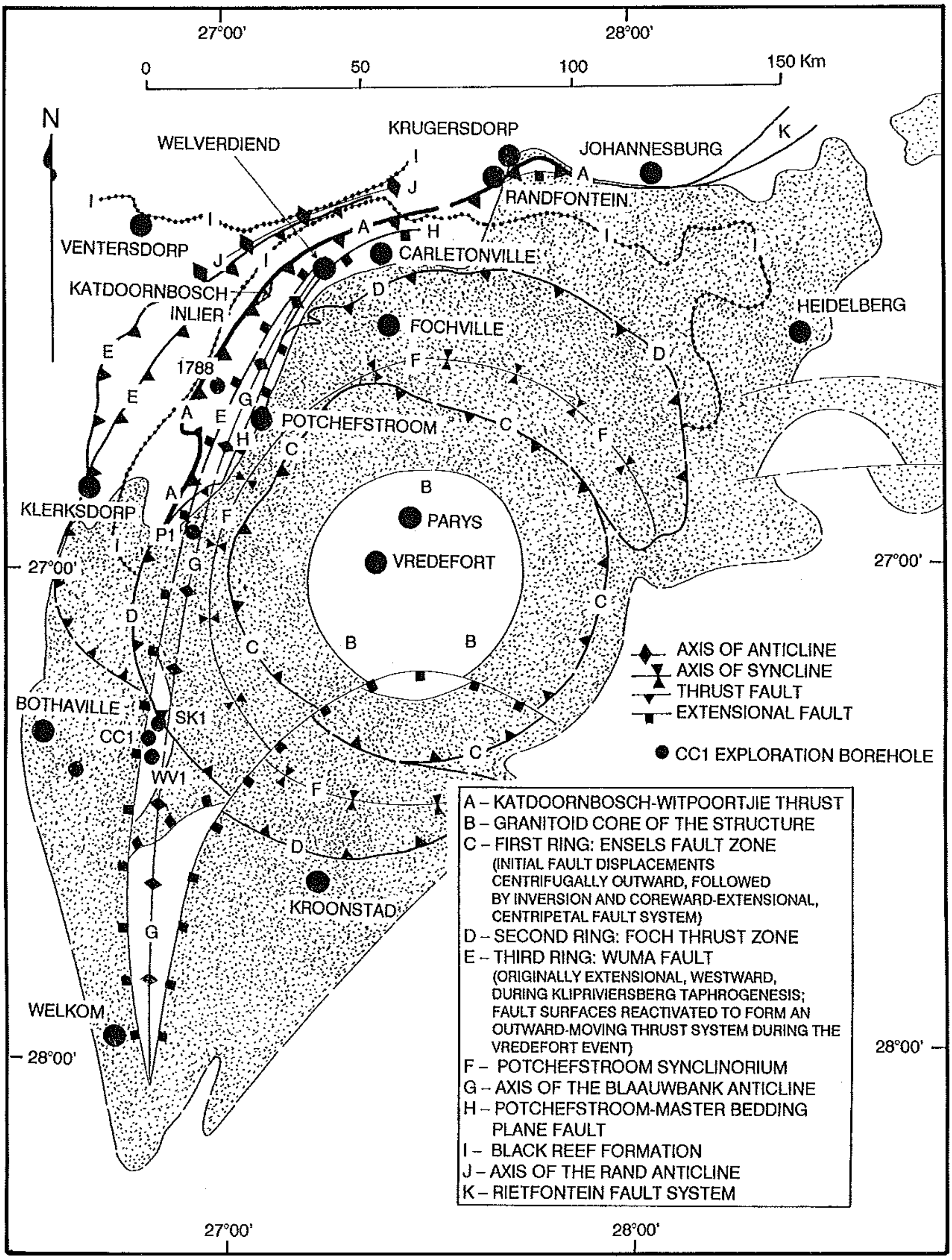


Figure 1. Outcrop and subcrop positions of the main elements comprising the present remnant of the Vredefort Astrobleme, superimposed on the Central Rand Group of the Witwatersrand Supergroup (stippled). The scheme is adapted from Brink et al., (1997). The Katdoornbosch-Witpoortjie Thrust is shown (A) in the northwestern sector of the figure. Note that the southwestern portion of the second ring, as well as a large portion of the ring structure beyond the second ring was removed by erosion to the surface upon which the Karoo Supergroup (not shown) was deposited.

and vibroseis sections. It was stated that the presently seen structure constitutes only the root of the original, pre-erosional astrobleme. The structural remnant consists of two near-concentric rings (Fig. 1), with a third ring that is parallel to the inner two rings and discernible only in the northwest of the structure. The three recognizable rings are outlined by thrust fault zones, while a generation of extensional faulting, formed during a late evolutionary stage, is also evident within the fault zone that forms the inner ring. The presently seen granitoid core of the structure was formed below the final crater. Since its formation, the structure was considerably modified by isostatic uplift and erosion and Karoo sediments now cover its southern half. Outliers of Karoo rocks found on the northern, exposed portion, indicate that these sediments once probably covered the whole of the structure.

In the northwestern sector, the first ring is outlined by the sole of the Ensels Thrust system (Figs. 1 and 2). Detachment of the Ensels Thrust sole took place over the inward-facing limb of a buried anticline, circled by the Potchefstroom Synclinorium. A second anticline formed the ramp below the Foch Thrust imbricate system, which outlines the second ring of the structure. Based on work by McCarthy at al. (1986), the existence of a third ring can be postulated to follow the outline of the Rand Anticline, westward and southward from the Central Rand in a curve towards the area north of Klerksdorp. Recent mapping, following the outlines of the structural blocks mapped by the Geological Survey (1986) revealed the existence and the post-Transvaal age of an eastward-dipping thrust fault system, situated to the north of Klerksdorp. The outline of the sole of this fault, termed the Wuma Fault, is shown in Figure 2. The history of the fault is complicated. Van der Merwe (1994) termed the sector of its outcrop, observed north of Klerksdorp, an "inverted thrust."

Within the Vredefort Structure, outcrops of the Malmani Subgroup occur as two, wide, ring-shaped exposures (Fig. 2). The inner Malmani exposure (IMO) falls within the ring-shaped outline of the Ensels Fault Zone. The outer Malmani outcrop (OMO) ranges from the Foch Thrust Zone outward, up to the Rand Anticline in the north (Fig. 2). North of the Rand Anticline, the chert beds of the Malmani Subgroup do not display the stress release effects, described below, that are seen closer to the impact point in the IMO and OMO.

The outline of the second ring is complicated by interference from an old, north-south striking anticline that displays characteristics of episodic growth under the influence of a recurrent, west-east directed compressional stress field, over a very long period. The anticline was designated the Blaauwbank Anticline (Figs. 1 and 2) by Brink et al. (1999). The outward-directed movement stage is manifested in the Blaaubank Anticline as a final, post-Black Reef age compressional episode, accompanied by thrusting and the further accentuation of the anticlinal fold. After the inversion of the outward-directed stress system associated with this compressional episode (Brink et al., 1999), the Potchefstroom Fault-Master Bedding Plane Fault (PMBF; Fletcher and Gay, 1972; Brink et al., 1999) detached along the eastern limb of the Blaauwbank Anticline. The mechanism of gravity-sliding proposed by Fletcher and Gay (1972) for the formation of the PMBF can be plausibly linked to the existence of the declivity formed during the stage of modification of the transient crater, as shown by Brink et al. (1999).

Chert beds of the Eccles Formation of the Malmani Subgroup, found in a zone in the immediate vicinity of the Foch Thrust surface south of Carletonville and

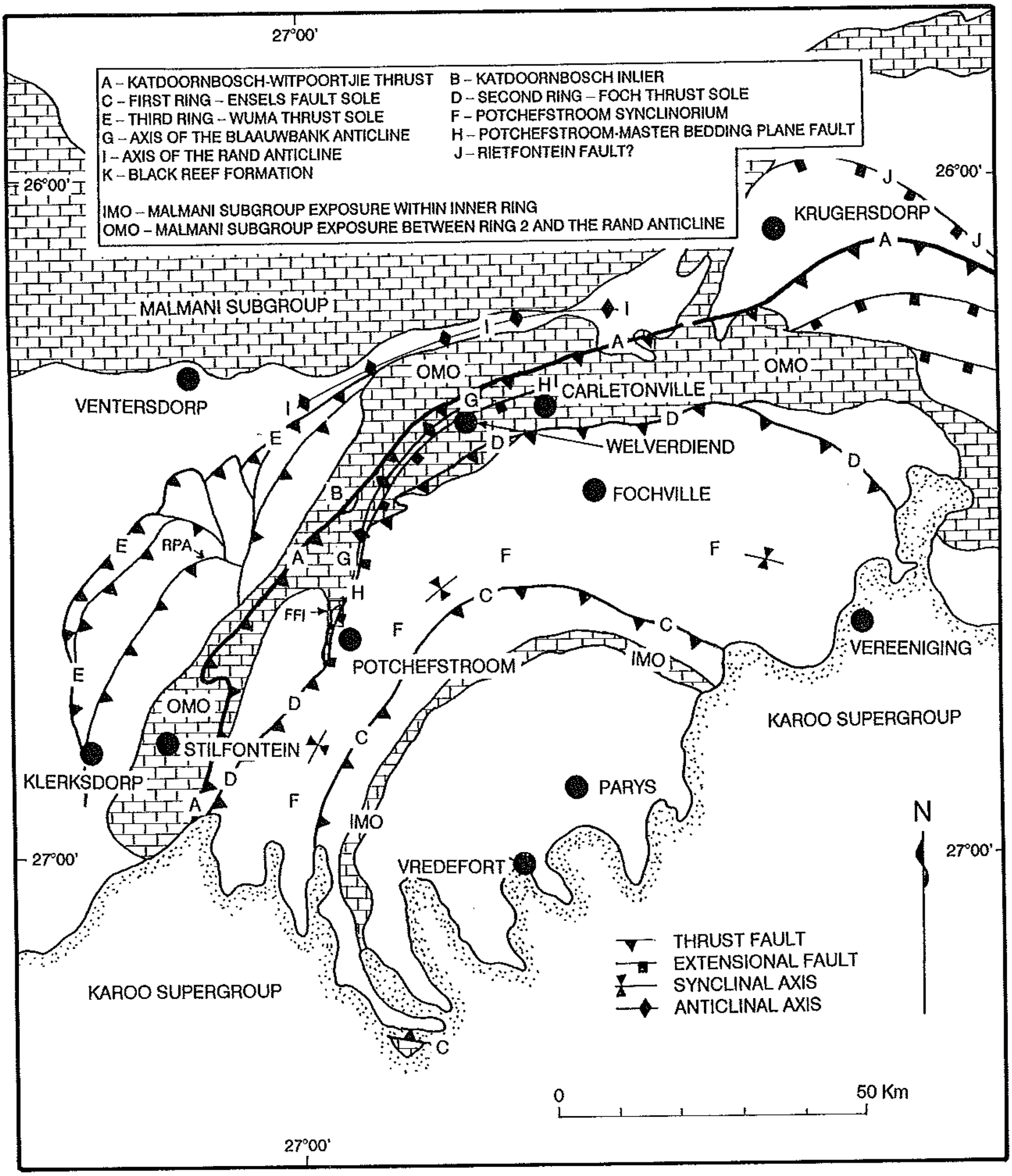


Figure 2. Simplified geological map of the exposed portion of the Vredefort ring basin, showing the distribution of the Malmani Subgroup and structural features mentioned in this paper (modified after Brink et al., 1997).

Welverdiend (Fig. 2) display a peculiar type of brecciation. The brecciation resembles the effects of chocolate-tablet boudinage (Wegman, 1932; Figs. 3 and 4). The breccia was mentioned by De Kock (1964) who termed the zone the "Giant Chert," without recognising the thrust fault, or the nature or cause of the brecciation. De Kock (1964) termed the brecciated zone the "Giant Chert." Engelbrecht et al. (1986) similarly did not recognise the thrust fault, but proposed the inclusion of the brecciated zone into the stratigraphy of the Malmani Subgroup. The brecciated zone is chronologically, spatially and structurally related to the ramp of the Foch Thrust, formed during the Vredefort episode, and cannot be designated a stratigraphic unit. More than 150m of breccia with a matrix of pseudotachylite was found in the thust zone in core from an exploration borehole, drilled by Anglogold Exploration Services near Fochville. During the process of formation of the thrust zone, the primary pseudotachylite breccia was intersected by frictionally generated pseudotachylite associated with the fault plane, and the whole was eventually cut by intrusions of black material consisting mostly of graphitic carbon, emplaced along small fissures. In appearance, the carbon resembles that of the Black Reef shales and thin beds that are often found interbedded in the Malmani dolomite.

Northwest of Potchefstroom (FF1 on Fig. 2; Fig. 5) where the thrust was deflected upward and from its concentric outline by the Blaauwbank Anticline to form a set of imbricate nappes (Brink et al., 1999), the same type of brecciation occurred, but here affecting the Monte Christo Formation. In this occurrence, the breccias were termed "mylonites" by Truter (1936) and "pseudotachylites" by Van der Merwe (1986). These authors did not recognise the west-directed thrusting. Where found on surface, the breccias possess a pseudotachylite-like matrix, consisting of microcrystalline chert, in which the fragments are suspended. The effect is visually very similar to the great pseudotachylitic breccias of the centre of the Vredefort Structure, but the scale is smaller and the fragments are angular. In the OMO, the breccias afford a distinct and obvious criterion for the recognition of trust fault surfaces related to the Vredefort impact event.

All of the chert beds thicker than 1m, exposed within the IMO, display the effects of chocolate-tablet boudinage, irrespective of whether they are found in the proximity of faults. In the OMO, the effects of boudinage are confined to zones in the immediate vicinity of the thrust faults associated with the stage of outward movement, before inversion (Brink et al., in press, 1999). Where only dolomite beds were displaced, the thrust surfaces were often found to be indistinct and difficult to recognise.

A possible reason why chocolate-tablet-type boudinage occurs exclusively in chert and not in dolomite, may be that the fracturing strength of this rock type is exceeded during the expansion to beyond its Hugoniot elastic limit, after the sudden release of hydrostatic stress (Fowles, 1961; Ahrens and Rosenberg, 1968). Before impact, the Malmani Subgroup was subjected to compression by the original confining stress associated with burial underneath at least 4500m of sediments and volcanic beds of the Pretoria Group, thickened by intrusive sills of Bushveld Complex age. Within the ramp zones associated with the anticlinal folding that was created during impact, the compressional stress field was greatly increased during the episode of centrifugally directed stress. Stress release occurred at the moment of thrust fault detachment. Possessing a much higher fracture strength than dolomite (600-800 Mpa,

Figure 3. Chert affected by chocolate-tablet-type boudinage from the Katdoornbosch Fault, southwest of Potchefstroom. Length of the pen is 185mm.

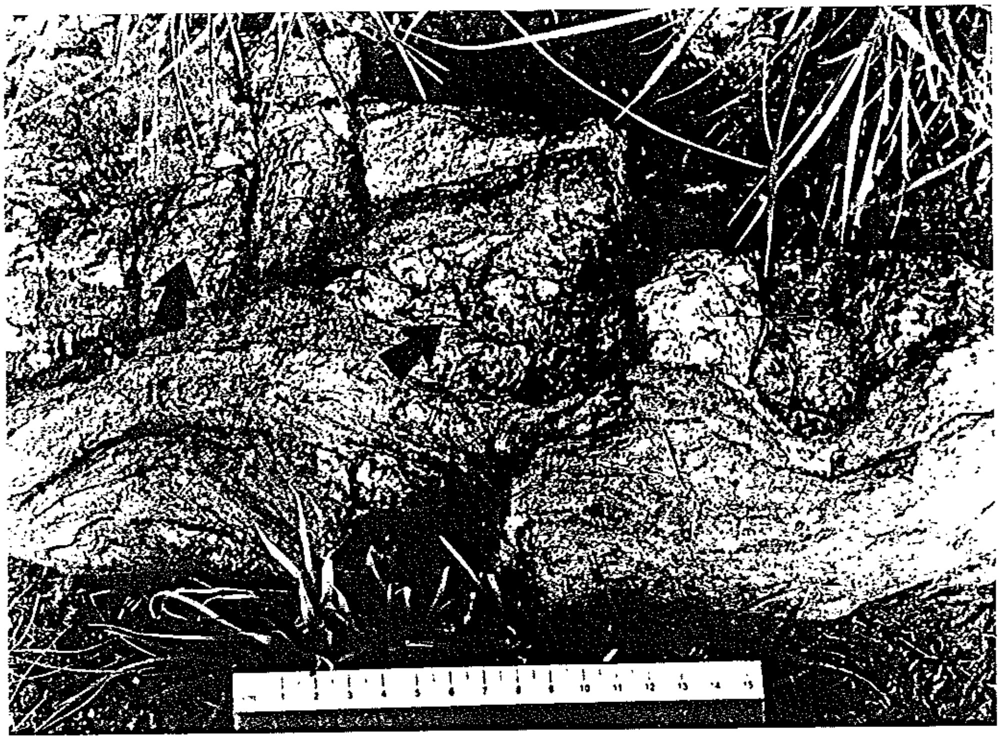


Figure 4. "Smear-banded" pseudotachylite developed on the surface of the Katdoornbosch Fault on Rietfontein 388, southwest of Potchefstroom. Note the inclusions of chert affected by chocolate-tablet-type boudinage (arrowed), formed prior to the fault plane-associated pseudotachylite.

unconfined, for chert, against 260-420 Mpa for dolomite, according to R. More-O'Ferral, Rock Mechanics Engineer, Buffelsfontein Gold Mine, pers. comm. 1997), but not being able to expand elastically, the chert beds "exploded" when their Hugoniot elastic limit was exceeded when expansion was induced by the collapse of the compressional stress field. Dolomite responded by expanding within its elastic limit, without "exploding." Sills of epidiorite, found within the inner ring of overturned West Rand Group rocks, may have behaved in a similar manner (Nel, 1927, Plate VII, p. 93). In field occurrences, these sills are always associated with abundant pseudotachylite, which is not found in the adjacent shale beds. Exposed cross sections of the sills are rare, explaining why the effect of chocolate tablet boudinage has never before been noticed. These effects are conspicuously absent in the occurrences of granophyre that have the morphology of ring dykes observed around the inner periphery of the first ring, indicating a late stage for their emplacement.

The boudinage-formed breccias should not be confused with those that characterise ubiquitously occurring surface mantles, composed of remnants of chert beds, deposited after the removal of the underlying carbonates by corrosion. Nor should they be mistaken for the cherty and dolomitic fault breccias, found along extensional fault surfaces or tensional gashes, as well as the breccia conglomerates of sedimentary origin, of which the Bevet's "conglomerate" bed is an outstanding example. The chert mantles may resemble true breccias, but are of recent origin and were mapped by the Geological Survey (1986) as remnants overlying the Eccles Formation in the area north of Ventersdorp.

KATDOORNBOSCH THRUST – STRUCTURAL GEOLOGY AND THE RECOGNITION OF THRUST FAULTING IN THE MALMANI SUBGROUP

On the farm Katdoornbosch 138, north of Potchefstroom (Fig. 5), and within the OMO, an inlier of granite, bounded in the west by faulting, emerges from below a cover of Ventersdorp sediments and the Black Reef Formation. The inlier was first described by Nel (1935), who explained the structure in terms of a normal fault with a displacement down to the west. Nel based his explanation on the occurrence of similar structures found within the uplifted area associated with the Rand Anticline, southeast of Ventersdorp, where exposures of the Witwatersrand Supergroup and granite display similar displacement relationships. Mapping by the Geological Survey (West Rand, 1: 250 000 Sheet, 1986), does not show the extent of the fault that caused the existence of the Katdoornbosch Inlier. The original mapping of Nel (1934) shows, however, the detailed structural relationships found in the immediate vicinity of the inlier.

The present investigation (Fig. 5) indicates that, in the case of both the Katdoornbosch Fault and those that displace the Witwatersrand successions and the granite southeast of Ventersdorp, the "normal faults throwing down to the west" are in fact thrust fault imbricates with a westward vergence, related to the Wuma Thrust imbricate zone. The Wuma Fault Zone was originally formed as a westward-moving system, during the period of middle Ventersdorp taphrogenesis (Brink et al., 1999). These authors postulated that the westward-moving system was reactivated later, during the first stage of accelerative movement away from the impact site, to display a new, enlarged movement component, still in the same direction. The Wuma Fault

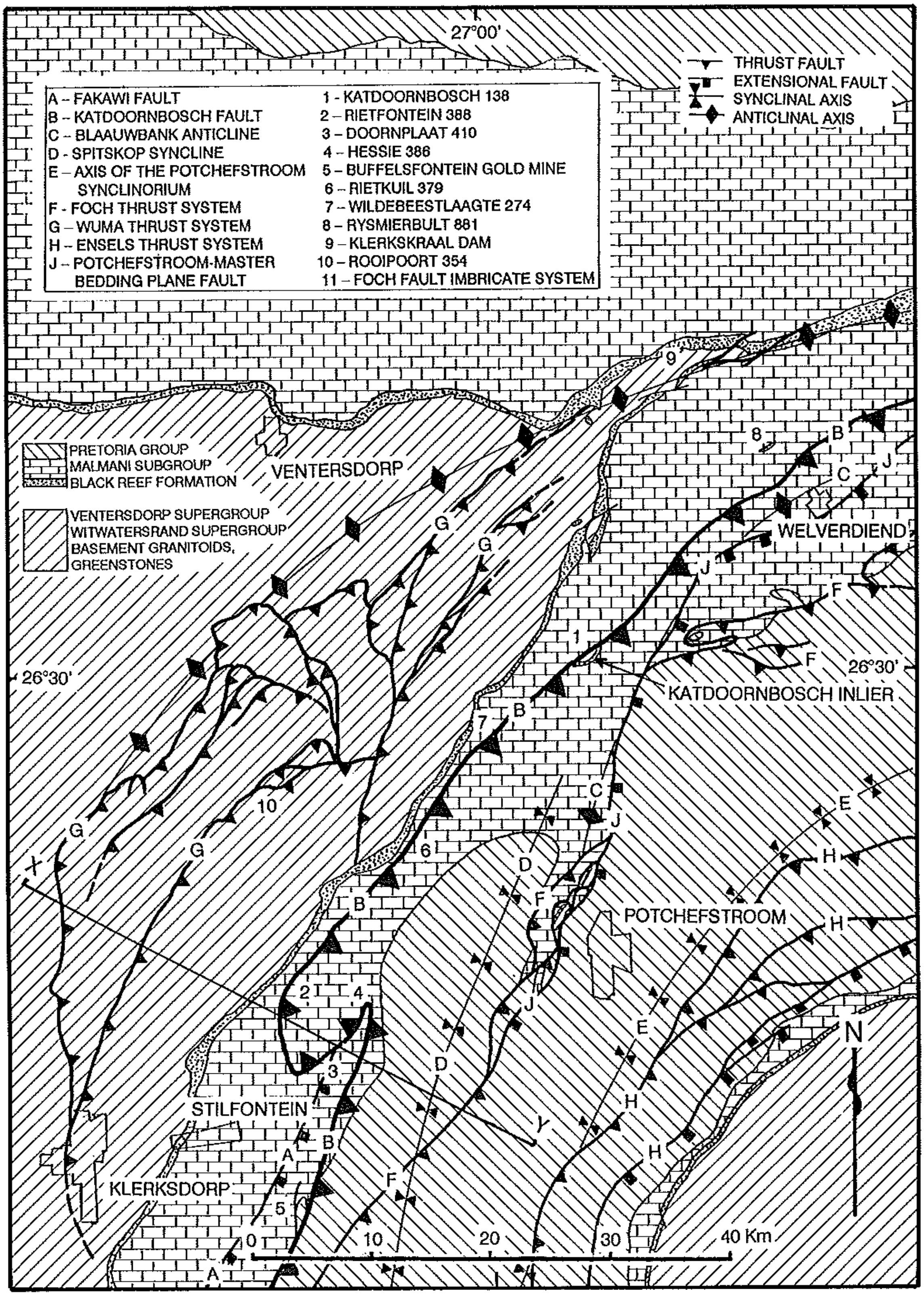


Figure 5. Structural geology of the sector of the Vredefort Astrobleme in which the Katdoornbosch Thrust is found.

Zone now resembles an imbricate thrust system, with the base of the Orange Grove Quartzite thrust over the Allanridge Formation that forms the top of the Ventersdorp Supergroup on Rooipoort 354 (RPA on Fig. 2, approximately 30 km south of Ventersdorp). No inversion of any stress system, as inferred by Van der Merwe (1994), ever took place.

North and south of the inlier, the fault was recognised in the field primarily because it brought the Black Reef to surface. This horizon is overlain by the dolomitic Oaktree Formation of the Malmani Subgroup, which weathers more easily than the overlying cherty formations and is therefore usually characterised by an obvious topographic valley. In places, the outcrop of the Katdoornbosch Fault may be recognised by the occurrence of abundant, banded, cherty pseudotachylite, but also by the occurrence of chert beds fractured by chocolate-tablet-type boudinage, that characterises the thrust zones of Vredefort age in places where chert beds of the Malmani Subgroup were displaced.

Mr. A. Martinson, a geologist-dairy farmer of the farm Beatrix 392 , north of Klerksdorp, found a similar breccia, formed by chocolate-tablet-type boudinage, developed along a north-south striking fault on the farm Rietfontein 388, east of the old Buffelsdoorn Gold Mine. Mapping shows that this fault is situated near the base of the Monte Christo Formation outcrop, in the western limb of the Spitskop Syncline (Fig. 5). Northward, on Rietkuil 379, the fault outcrop becomes difficult to find in the Oaktree Formation, where only dolomite was displaced. In this area, further mapping complications occur where the fault outcrop traverses an artillery range of the Department of Defence, to which access was denied. The outcrop trace had thus to be interpolated. Further to the north, where the fault outcrop crosses the Potchefstroom-Ventersdorp road on Wildebeestlaagte 274, the brecciation and associated pseudotachylite is clearly visible. From here, the fault can be followed to its junction with the fault that brought the Katdoornbosch Inlier to surface (Fig. 5). Around Katdoornbosch 138, the fault was found by tracing the charactristic chert breccia, and also by the occurrence of the topographic valley associated with the Oaktree Formation, which was found to form the roof strata of the fault.

From Katdoornbosch, the fault strikes northeastward, along the western bank of the Wonderfontein Spruit. It occurs along the eastern slope of the hills on the bank of the spruit west of Welverdiend, where spectacular pseudotachylite and brecciation marks its outcrop on Rysmierbult 88 (Fig. 5). Northwest of the fault outcrop and its associated breccia, on the road from Welverdiend to the Klerkskraal Dam, a crescent-shaped klippe of Black Reef Quartzite, underlain by pseudotachylite, demonstrates that the fault is a thrust and also indicates its displacement towards the northwest. The displacement magnitude, indicated by the distance from the fault surface to the furthest side of the klippe, is at least 1.5 km.

Northeast of Rysmierbult, the fault outcrop forms a curve, subparallel to that of the Black Reef found along the southern and eastern limb of the Rand Anticline (Fig. 6). Two kilometres west of Bank Station it crosses a disused tarred road that once connected Bank Station and Rodora. The curve continues towards the Rikasrust smallholdings, soutwest of Randfontein (14 on Fig. 6). Southwest of Rikasrus, Mellor (1917) mapped a peculiar, figure eight-shaped inlier of the Government Subgroup, bounded by Black Reef, on Elandsfontein 277. Closer investigation showed that the inlier consists of two segments of the Government Subgroup, halved by the thrust,

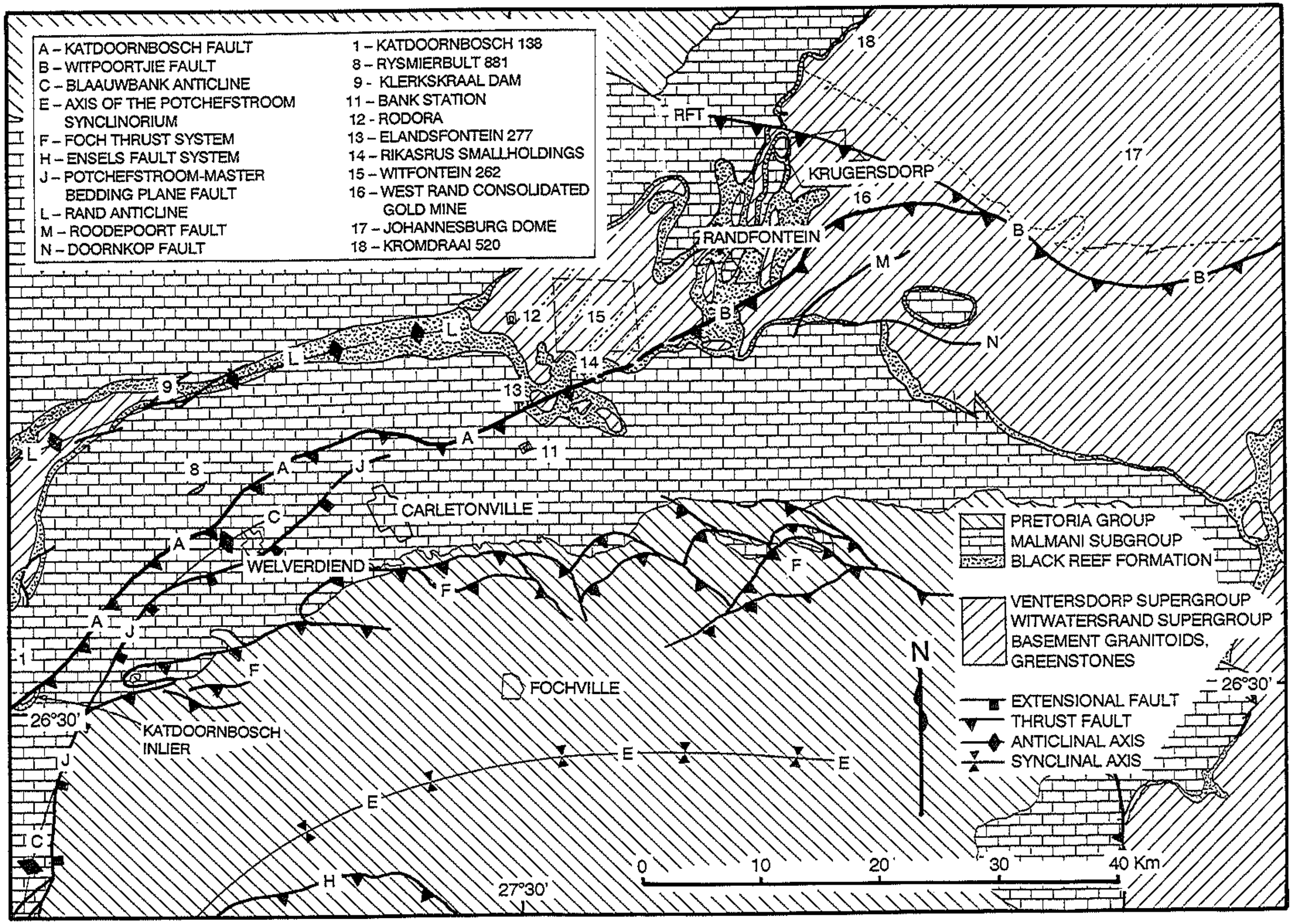


Figure 6. Structural geolgy of the area from Welverdiend to the Johannesburg Dome, intersected by the Katdoornbosch and Witpoortjie Faults.

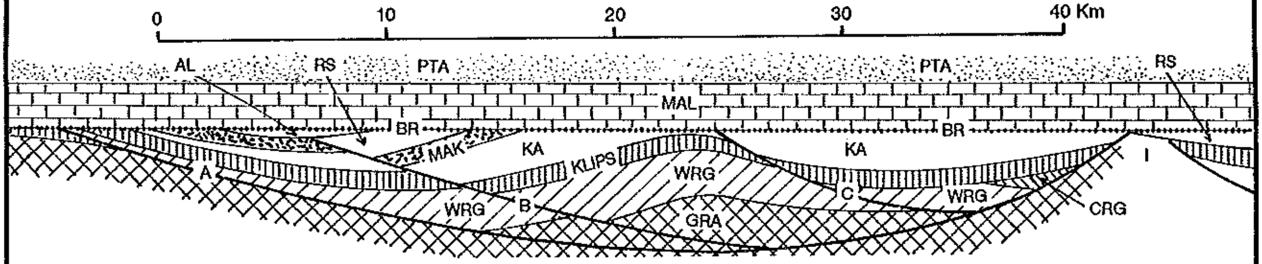
that now possesses an almost west-east strike. From here, intermittent outcrops indicate that the fault can be followed northeastward to an intersection in a drainage ditch along Vleikop road, opposite Plot No. 100 in Rikasrust. Here, the fault intersects the Black Reef, bringing Ventersdorp rocks to surface. The eastward continuation of the thrust from Rikasrus into the area south of Randfontein is unclear, due to the fact that it probably follows the base of the Black Reef into an area covered by agricultural smallholdings. The Black Reef was deposited unconformably on strata belonging to the Hospital Hill and Government Subgroups and it is impossible to ascertain whether the observed stratigraphic hiatus is caused by a fault parallel to the bedding or by a sedimentary unconformity.

A restoration of a structural section through the line X-Y on Figure 5 is given in Figure 7. Although approximately to scale, as derived from Gencor Limited's unpublished "P" series of vibroseis lines of 1987, and various exploration boreholes drilled within the Spitskop Syncline, the section is idealised and generalised to include illustrative features found off the true section line. Amongst these features are the Foch imbricate stack, the extent of which into the section area is only inferred, and the Allanridge Formation (AL) found below the Inner Wuma Thrust (B). It must therefore be accepted as a representative, rather than a true section. An important point is that a paradox exists in that old faults, reacvtivated to form what seems to be a thrust system, produced "compressionally" formed nappes in which contemporaneous "extensional" faults are found. These must be regarded as manifestations of retardation in a system ascribed to acceleration from an impact point, rather than a uniformly horizontally orientated tectonic stress system.

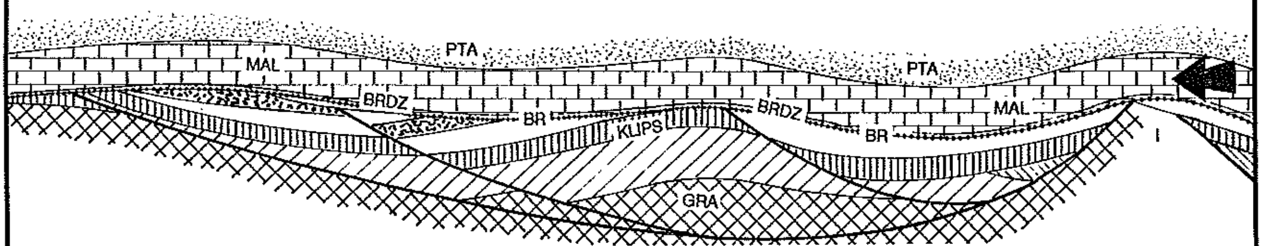
Local retardation also occurred along the floor of the Wuma Fault, where large-scale sigmoidal boudinage, affecting large blocks of the Orange Grove Quartzite found in parts where the overlying nappes were smeared over the fault floor, is found to co-exist with the indications of rapid, "compressional" movement that characterise the zones of both of the Wuma thrusts. These include chaotically rolled, overturned megablocks - blocks stacked together presumably in zones where retardation occurred. In one area, the fine-grained Orange Grove Quartzite, of which all of the grains display authigenic quartz overgrowths, was found to be affected by chocolate-tablet-type boudinage. Highly altered volcanic rocks, probably of Ventersdorp Supergroup origin, display a high degree of chertification and shatter deformation.

WITPOORTJIE FAULT

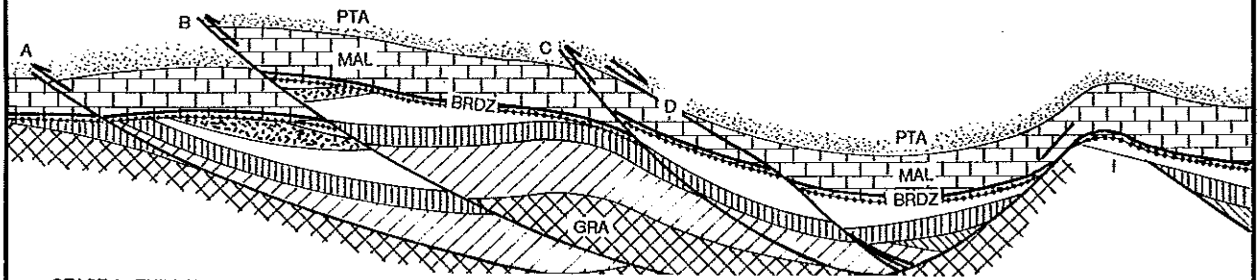
In his mapping of the area around the Central Rand, Mellor (1917) showed a prominent syncline, known as the West Rand Syncline, formed by Witwatersrand strata around Krugersdorp (Fig. 8). Within the syncline, the outcrop of the Main Reef horizon delineates the western and northern boundaries of all the important gold mines of the Krugersdorp-Randfontein area, such as the mine lease areas of Randfontein Estates, West Rand Consolidated and Luipaardsvlei Estates. The outcrop of the Witpoortjie Fault forms the southern and eastern structural boundary of these mines. It possesses a bow-shaped outline, convex to the north. The Main Reef conglomerate beds form the base of the auriferous Central Rand Group, with the



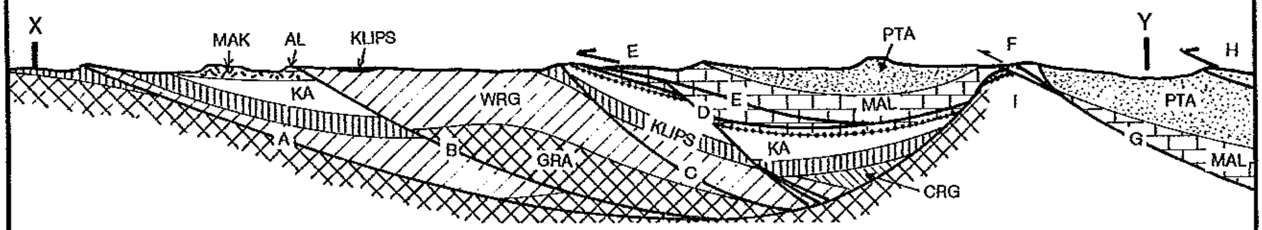
STAGE 1. AT THE TIME OF IMPACT, THE TOTAL TRANSVAAL SUPERGROUP HAS BEEN DEPOSITED. THE BLACK REEF UNCONFORMITY OVERLIES THE VENTERSDORP SUPERGROUP, INCLUDING THE ALLANRIDGE FORMATION (AL). THE EFFECTS OF THE MIDDLE VENTERSDORP AGE EXTENSIONAL TECTONISM ARE EVIDENT AS A SET OF EXTENSIONAL IMBRICATE NAPPES (GIBBS, 1984), FORMED BY THE WEST-MOVING WUMA FAULTS (A AND B) AND THE BUFFELSDOORN FAULT. THE EVOLUTION OF THE BLAAUWBANK ANTICLINE/HORST (I) WAS DESCRIBED BY BRINK ET AL., (IN PRESS, 1999).



STAGE 2. IMMEDIATELY AFTER IMPACT, CRUSTAL MATERIAL IS ACCELERATED AWAY FROM THE IMPACT SITE. IN THIS PART OF THE SYSTEM, INITIAL MOVEMENT IS DIRECTED HORIZONTALLY. UNDULATIONS START DEVELOPING INTO FOLDING AND IN A VERY SHORT TIME, THE FOLDING BECOMES ACCENTUATED AND RUPTURING TAKES PLACE ALONG THE SURFACE KNOWN AS THE BLACK REEF DECOLLEMENT ZONE (BRDZ, FLETCHER AND REIMOLD, 1989).



STAGE 3. THE FAULTS OF VENTERSDORP AGE ARE REACTIVATED. EXTENSIONAL NAPPES NOW BECOME PARTS OF A SYSTEM SIMILAR TO A THRUST IMBRICATE SYSTEM. HOWEVER, FAULTS OF THIS SYSTEM MUST BE TERMED ACCELERATION FAULTS, FORMED BY THE ACCELERATION OF MATERIAL OUTWARD FROM THE IMPACT SITE. WHILE THE LEADING EDGES OF THE NAPPES ARE STILL IN A STATE OF CENTRIFUGAL ACCELERATION, ZONES OF RETARDATION FORM WITHIN THEM, TO PARADOXICALLY CAUSE "EXTENSIONAL" EFFECTS WITHIN THE "COMPRESSIONAL" SYSTEM. PROMINENT AMONGST THESE ARE THE FAKAWI FAULT (D) AND THE NUMEROUS QUARTZ VEINS FOUND IN THE NAPPE AROUND THE FAKAWI.



STAGE 4. MOVEMENT OVER THE "THRUST" SURFACES SLOWS TO A STOP, SUCCESSIVELY FROM THE OUTER FAULT PLANE INWARD. THE PENULTIMATE PLANE OVER WHICH "THRUST" MOVEMENT TAKES PLACE, IS THAT OF THE KATDOORNBOSCH THRUST, WHICH OVERLAPS THE FAKAWI FAULT BOTH IN THE SECTION AND IN THE MAP (GIVEN ON FIGURE 5) ON DOORNPLAAT 410. FINALLY, THE FOCH FAULT SYSTEM FORMS A WESTWARD-MOVING IMBRICATE SET (F) OVER THE BLAAUWBANK ANTICLINE, FOLLOWED BY THE POTCHEFSTROOM FAULT (G), WITH CRATERWARD MOVEMENT RELATED TO THE STAGE OF MODIFICATION OF THE CRATER.

PTA – PRETORIA GROUP	KLIPS - KLIPRIVIERSBERG GROUP	C – BUFFELSDOORN FAULT
MAL – MALMANI SUBGROUP	CRG – CENTRAL RAND GROUP	D - FAKAWI FAULT
BR - BLACK REEF FORMATION	WRG – WEST RAND GROUP	E – KATDOORNBOSCH FAULT
AL - ALLANRIDGE FORMATION	GRA - BASEMENT GRANITOIDS	F – FOCH FAULT IMBRICATE SET
RS - RIETGAT FORMATION	BRDZ – BLACK REEF DECOLLEMENT ZONE	G – POTCHEFSTROOM FAULT
MAK – MAKWASSIE FORMATION	A – OUTER WUMA THRUST	H – ENSELS FAULT
KA - KAMEELDOORNS FORMATION	B – INNER WUMA THRUST	I – BLAAUWBANK ANTICLINE

Figure 7. Restoration of the structural section through line X-Y on Figure 5. Stage 4 shows the present structure.

underlying West Rand Group regarded as being barren. Several of the very recognizable horizons of the West Rand Group are repeated in what is shown in the present mapping to be an extensive imbricate thrust stack composed of imbricates marked "E" in Figure 8.

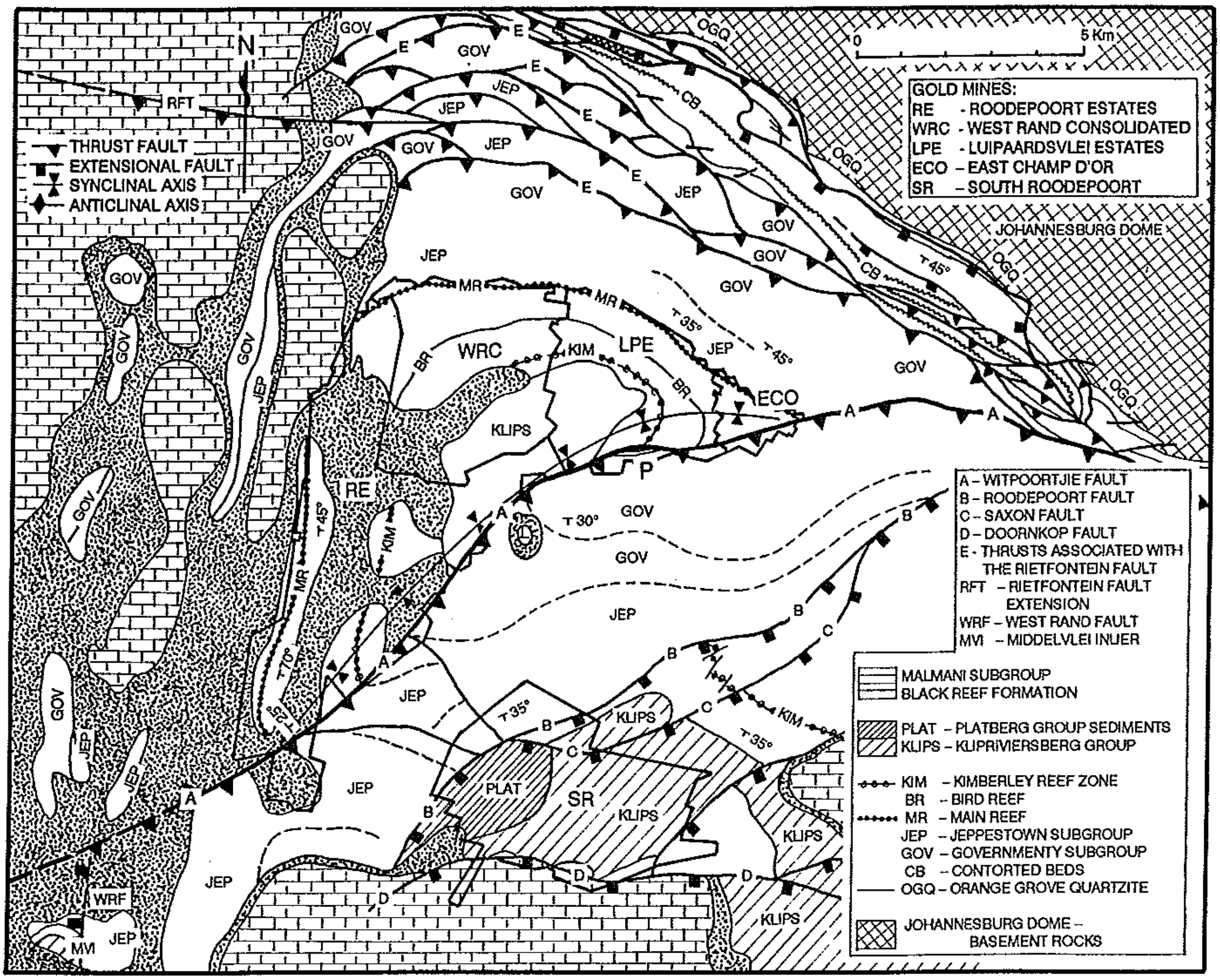


Figure 8. Structural geology of the West Rand Syncline, based on mapping by Mellor (1917), Toens and Griffiths (1964), Tucker and Viljoen (1986) and field work by the present authors.

On surface, West Rand rocks were shown by Mellor (1917) to outcrop south of the Witpoortjie Fault. These consist mainly of the Government and Jeppestown Subgroups (Fig. 8). North of the fault, strata of the Klipriviersberg and Turffontein Subgroup abut against the fault. It was therefore reasonable to interpret the Witpoortjie Fault as a normal fault, with a displacement down to the north and a horst to the south. This interpretation was accepted by later authors such as Toens and Griffiths (1964) and Tucker and Viljoen (1986). Forming the southern boundary of the horst, the Roodepoort and Saxon Faults comprise the main components of a system throwing down to the south. The Central Rand Group reappears in the southern half-graben. Below the horst, no mining has taken place in the area known as the "Witpoortjie Gap" (Fig. 9; Toens and Griffiths, 1964). The Roodepoort Fault dips

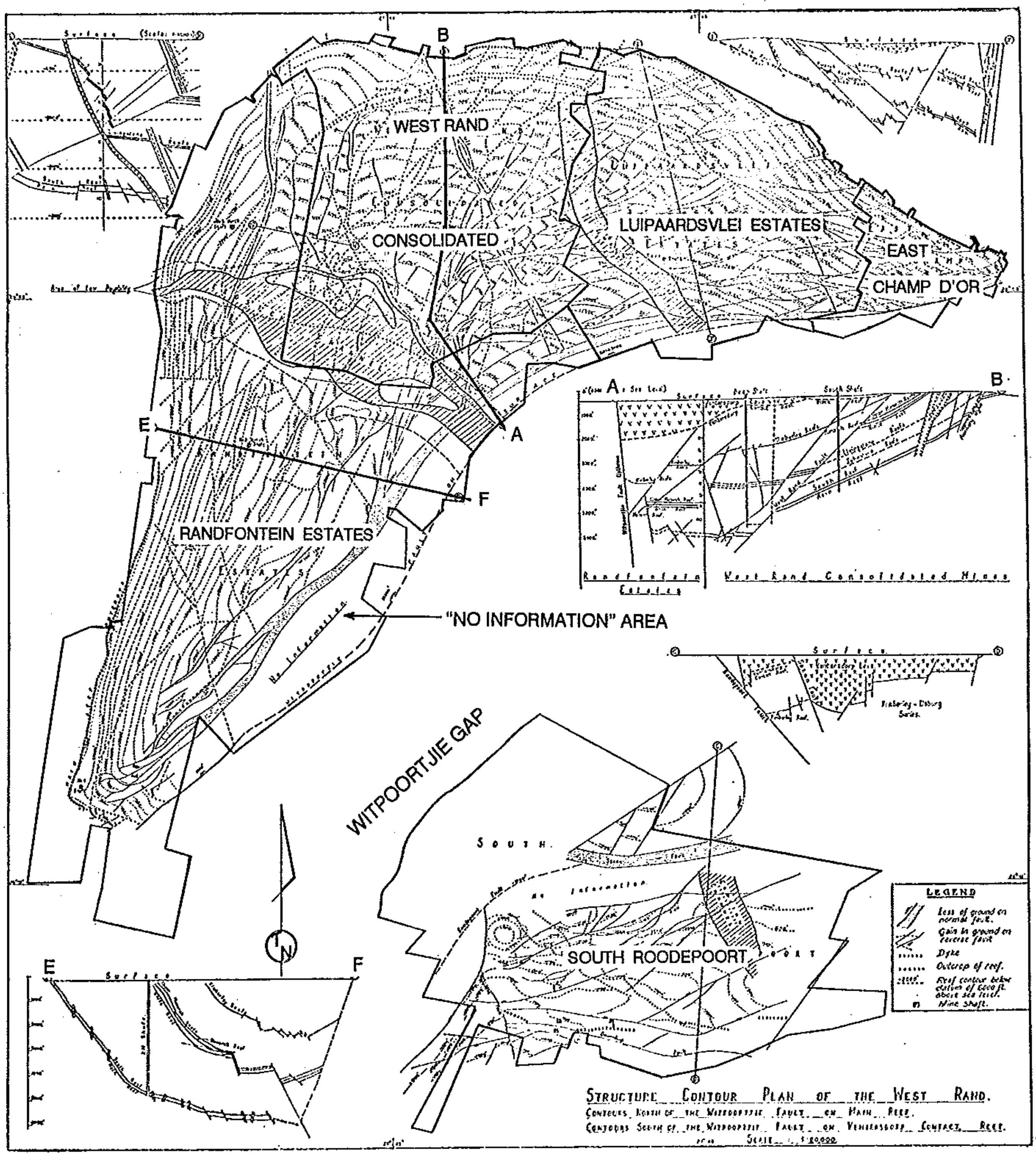


Figure 9. Structural geology of a portion of the Main Reef in the West Rand goldfield, interpreted by Toens and Griffiths, (1964).

towards the south, but follows a convex northward, bow-shaped outline, sympathetic to that of the Witpoortjie Fault. This may have led Toens and Griffiths (1964) to speculate that the outcrop outlines were originally straight, but that a late, post-faulting stage of folding of the West Rand Syncline could have caused the sympathetic bow shapes. It is, however, easily demonstrated that such a late folding event may bend the outcrop line of a north-dipping fault into a north-convex shape, but that the same folding will bend the south-dipping Roodepoort Fault in an opposite sense, to assume a south-convex outline. The north-convex outline of the Roodepoort Fault therefore makes the postulated faulting episode untenable.

Mining in the deep areas of the mines north of the Witpoortjie Fault did not continue after the paper by Toens and Griffiths (1964) was published. In their description of the West Rand Goldfield, Tucker and Viljoen (1986) concentrated on the mines south of the Witpoortjie Gap such as South Roodepoort Main Reef Areas ("South Roodepoort," Fig. 9; mines such as the Cooke Section of Randfontein Estates and Durban Roodepoort Deep are situated outside this figure). Outlines of mined-out areas, such as that of the Main Reef shown in Figure 9, including the area in the southeast of Randfontein Estates Gold Mine marked "no information" by Toens and Griffiths (1964; and Fig. 9, this paper) indicate that mining did not take place up to the fault trace.

In the southern portion of the Kimberley Reefs section of Randfontein Estates, it is possible that mining was terminated along the trace of a smaller fault (the Witpoortjie No. 1 Fault), which is shown (Fig. 9) by Toens and Griffiths (1964) to possess a limited "loss of ground" (horizontal displacement component, or plan view of area in which the reef was eliminated by the fault), as opposed to a total elimination of all the reef to the south of the fault trace by a large fault that would displace the reef to above the present surface erosional truncation. In section A-B (Fig. 9), Toens and Griffiths (1964) showed the inferred fault to be distinct from the Witpoortjie Fault proper, in line with the then current thinking at West Rand Consolidated, namely that the Witpoortjie Fault Zone consists of more than one fault. The fault is shown on the accompanying plan as Witpoortjie Fault No. 1. Section E-F, drawn through Randfontein Estates, does not show more than one fault, and the reef contours are shown to continue around the postulated Witpoortjie Fault No. 1 in the far south of the mine. It is not known whether a similar fault was found in this area of the mine.

No record could be found of any intersection of the Witpoortjie Fault Zone in mining or underground drilling by Randfontein Estates, West Rand Consolidated or Luipaardsvlei Estates Gold Mines. At Randfontein Estates, mining continued in at least one area to a position where, had the fault existed as predicted, the dip would have to be steeper than 80°. Apparently, the cost of exploration drilling, and the cost of winze mining down towards the fault surface caused the managements of the mines involved to lose interest in mining or even prospecting beyond the projected fault trace zone. No surface boreholes were risked into what was expected to be a barren horst area.

Toens and Griffiths (1964) believed that the north-south striking faults, such as the West Rand Fault (WRF, in the southwestern corner of Fig. 8), were formed after the Witpoortjie Fault and its supposed conjugates. An alternative view was held by De Kock (1964), who stated that the Witpoortjie Fault was, in fact, the West Rand Fault, with its strike swinging from southwest to south. Both of these opinions must be regarded as conjectural. The configuration of the two faults shown by Engelbrecht et al. (1986; their Fig. 28), is more acceptable.

The 1: 2 500 000 West Rand Geological Map (S. Afr. Geol. Surv., 1986) shows, if the Witpoortjie Fault is accepted to be a thrust, that the strata of the southern block transgresses, tectonically, over the younger Central Rand Group strata to the north. Eastward, this "transgression" becomes a marked shortening of the footwall strata. Because of urban development, it is now virtually impossible to follow the precise outcrop of the eastern continuation of the fault. Westward, in the area immediately southeast of Randfontein, changes in lithology are observed on the sides of a valley over what must be a displacement zone. By inference, the fault must follow the base of the valley, but no fault plane or outcrop is visible. Trenches for the exploration of the Kimberley Reef Zone at the Azaadville Cemetery, along the road between Krugersdorp and Zuurbekom, revealed synclinal folding of this horizon with an axis sympathetic to that of the expected fault outcrop, but the fault was inferred to be situated further to the southeast.

Similar synclinal folding adjacent to the outcrop of the Witpoortjie Fault was recorded by Toens and Griffiths (1964). The curved, fault-parallel syncline was therefore superimposed across the West Rand Syncline proper. Its close proximity and parallelism to the fault surface indicates a genetic relationship to the fault, and its morphology suggests that it constitutes a floor syncline, below a thrust fault. No roll-over anticline was observed to affect the downthrown block, as may have been expected had the fault been formed in a normal, extensional stress system (Gibbs, 1984). Toens and Griffiths (1964) thought that the fault-parallel syncline pre-dated the formation of the West Rand Syncline and that it was subsequently again deformed during the folding period of the latter syncline. This "later period of folding" was also supposed to have "bent" the outcrop traces of the Witpoortjie and Roodepoort/Saxon fault systems. As explained above, all of the outcrops of these faults are convex-shaped to the north and, because the faults supposedly dip oppositely, they would have been bent in opposite directions, had the same fold been the cause.

The only site where the fault outcrop may be definitely identified, described and measured is near the Randfontein Estates/Luipaardsvlei mines boundary in the southeastern corner of the farm Luipaardsvlei, near the present Kagiso Township. Figure 10 shows a geological map of the fault outcrop of this area. At least two discernable lenses of faulted strata are included within the fault zone. The northernmost lens consists of greenish-white (fuchsitic), fine-grained, trough cross-stratified quartzite. From its superficial appearance, the quartzite may belong to the Hospital Hill Subgroup. The displacement zone separating the Central Rand block to the north from this quartzite consists of highly sheared quartz-sericite, in places more than 1m wide, with a distinct shear zone orientation inclined at 45-50°, dip direction 260°. Dips in the fuchsitic quartzite vary between 65° and 75°, dip direction approximately 340°. The quartzite may have been overturned, but the cross-bedding orientations are not unambiguously recognizable.

The "Hospital Hill" lens is separated from one containing conglomerates resembling those of the Government Subgroup to the south by an indistinct fault surface, the nature of which cannot be discerned. Strata within this second lens dip at 20° to the south. This lens also contains fine-grained quartzite, with sericitic zones and coarser, diamictitic beds. The lithology is similar to the beds that outcrop within

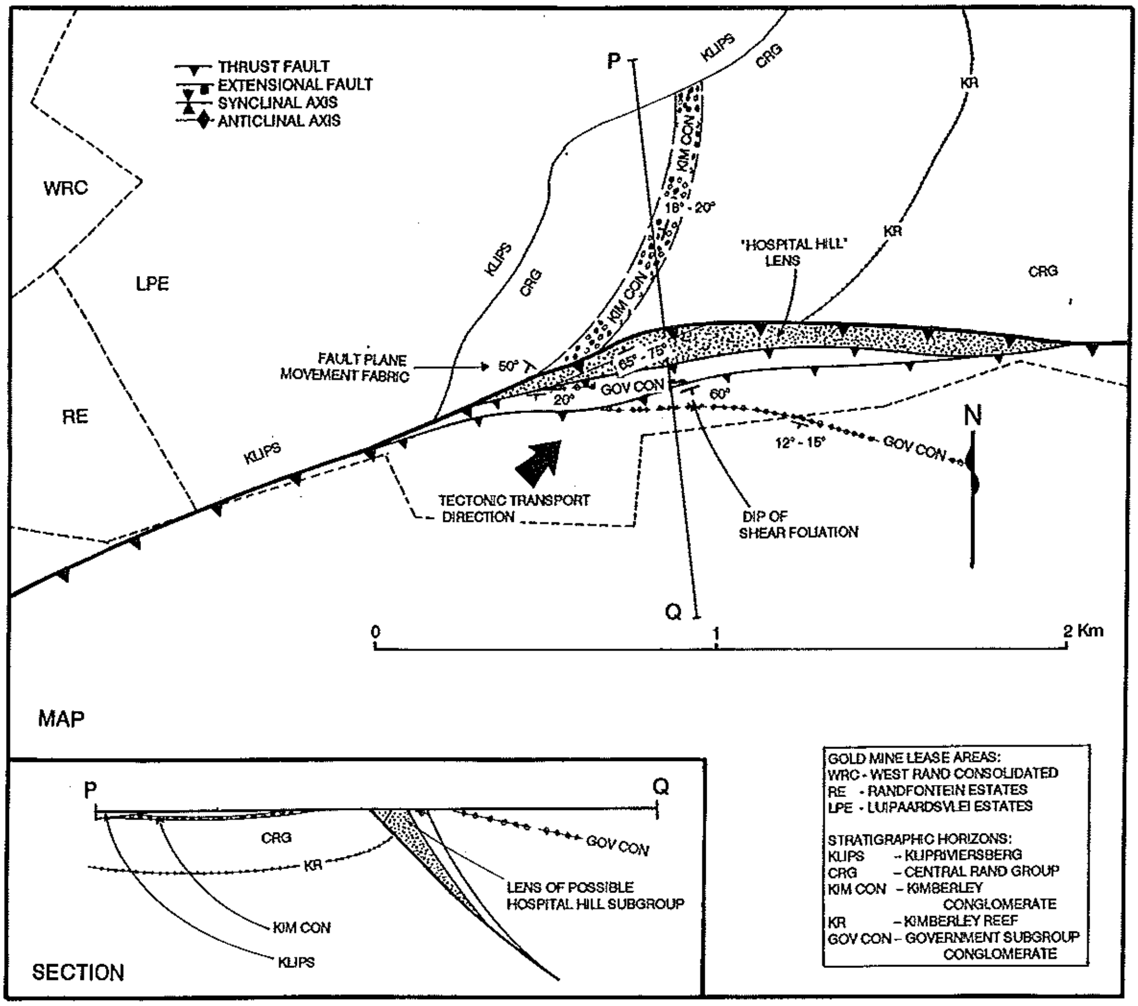


Figure 10. The geology of a portion of the outcrop of the Witpoortjie Fault, near the southern boundary of the Luipaardsvlei Estates Gold Mine lease area. The lens of fuchsitic quartzite, resembling those found in the Hospital Hill Subgroup, is stippled

the main Witpoortjie horst block to the south, ascribed by Mellor (1911) to the Government Subgroup. Near the southernmost fault surface, the quartzite beds on both sides of the fault are charactrised by shear planes displaying fibrous quartz growth. The shear surfaces dip at approximately 60° to the southeast. The quartz growth fabric indicates a movement direction from 240°, moving up over the shear surfaces at an inclination of approximately 25°. The Government Subgroup beds south of the fault zone dip approximately 12-15°, dip direction 195°.

A north-south section through the Witpoortjie Fault described above accompanies the mapping in Figure 10. The syncline north of the fault zone is consistent with a footwall syncline, such as is usually found below thrust fault surfaces. The fault dips to the south, and there is no reason to assume a north-dipping, downthrow fault. All movement indicators, however sparse, indicate thrust movement, up to the northeast. The Witpoortjie Fault must, therefore, be interpreted as a thrust. An implication is that, depending on the dip of the fault, a substantial amount of mineable ground may still exist below the inferred "horst", which now becomes a "nappe."

The ages of the various faults found in and around the West Rand Gold Field are of prime importance to the arguments presented here. The Roodepoot Fault and the Saxon Fault synthetic relationship displaces the Klipriviersberg Group down to the south. A wedge of Platberg Group sediments is found on the downthrown block, and the faults and the blocks displaced by them are truncated to the Black Reef unconformity. The faults are therefore of middle Ventersdorp extensional age. The Doornkop Fault, in the south (D on Fig. 8), displaces the Black Reef Formation. Its displacement direction is southward, towards the centre of the structure, and it may be one of the extensional faults that were formed during the modification of the transient crater.

Based on Mellor's (1917) mapping (Fig. 8), the Witpoortjie Fault is shown to strike westward towards the farm Witfontein 262 (Fig. 6), southwest of Randfontein. Engelbrecht et al. (1986) stated that the Witpoortjie Fault is the same as the fault last seen by Mellor (1917) in the southeastern corner of Witfontein. However, exposures of the bedding and structure on Witfontein are excellent and no fault of the magnitude of the Witpoortjie crosses the farm. In the area south of Witfontein, the structure is presently obscured by the existence of a large number of agricultural holdings. If it can be accepted that a westward extension of the fault, as postulated by Engelbrecht et al. (1986) is correct, the fault can only pass along a line south of Witfontein 262 (i.e. along or near the base of the Black Reef horizon), which brings it to the position of the Katdoornbosch Fault in the Rikasrus smallholdings (Fig. 6), described earlier. Both the faults are thrusts and are the only thrusts known in this area, of post-Black Reef age. Their strikes coincide, and the Witpoortjie Fault and the Katdoornbosch Thrust must, therefore, be regarded as the same.

North of the Main Reef outcrop, the curve around the northern rim of the West Rand Syncline, delineated by Witwatersrand strata, is cut by numerous, generally north-verging, nappes (Fig. 8). A fault displacement that cut the Black Reef Formation along the western boundary of this area was connected by Mellor (1917) eastward to the Rietfontein Fault of the similarly named mine on the East Rand. Beyond its Black Reef intersection the fault was followed, during this study, westward into the Malmani Subgroup for more than 5 km (Fig. 8). In the dolomite, the outcrop of the fault is marked by chert pseudotachylite and chert beds fragmented by chocolate tablet boudinage, indistinguishable in appearance from those of the Foch and the Katdoornbosch thrust zones. On the grounds of their post-Transvaal age, similar orientation in the Vredefort ring system, similar pressure release effects and lithologies, it is proposed that the faults belong to the same Vredefort-related thrust generation.

The westward strike of the western "Rietfontein" Fault follows a west-east portion of the southern bank of the Rietspruit (Geol. Surv. S. Afr., West Rand Map, 1: 250 000, 1986). An excellent outcrop is found to the south of the Tarlton-Oaktree road, approximately 1.5 km from the Tarlton turn-off (RFT, Fig. 8). The strike of the fault may be extended westward from its termination shown in Figures 6 and 8, to join with a similarly orientated and displacing fault, that forms, over a distance of approximately 6 km, the southern boundary of an area overlain by the Pretoria Group. However, the outcrop is covered by soil in the critical juncture zone, preventing any possibility of positive mapping.

North of the Rietfontein Fault, numerous caves are found in the Malmani Subgroup, as noted by Mellor (1917). Amongst these are the anthropologically important Sterkfontein and Kromdraai caves, formed in the highly karst-affected ramp of the Rietfontein Thrust.

CONCLUSIONS

The Katdoornbosch-Witpoortjie Thrust was followed in a continuous line from the area north of Klerksdorp to the West Rand. The continuation of the fault to the east is presently obscured by intensive urbanisation, but there is reason to accept the extent of the faults shown on the Geological Survey's West Rand map (1986) towards their logical limits in the East Rand. In providing an indication of a method for the relative field dating of the Witpoortjie Thrust, a key was found for the relative dating of other faults of similar age and orientation. Examples are the "Rietfontein Fault" and numerous similarly orientated thrust fault imbricates, found to intersect the strata of the Witwatersrand Supergroup below the Jeppestown Subgroup, in the northern portion of the West Rand Syncline ("E" in Fig. 8). A further fault relationship that comes to mind is the set of north-verging thrusts thought by Roering (1984) to be of Ventersdorp age, seen in the Swartkops area. In at least one exposure, a new road cutting at Kromdraai (18, in the north of Fig. 6) at Struben's old Black Reef Mine south of Swartkops, the Black Reef is observed to have ridden northwards on the same fault that caused the foliation of the underlying Ventersdorp sediments. In this cutting, several bedding-parallel fault planes can be seen in the Black Reef Formation, possibly related to the BRDZ of Fletcher and Reimold (1989). It seems that a close look at the chert brecciation associated with thrust faulting that may occur in the area is warranted.

In space and time, the Katdoornbosch-Witpoortjie Thrust (KWT) is one of the ring thrusts, formed beyond the second ring. Because the Foch Thrust imbricate system (F on Fig. 7) was not transported outward after its formation, movement beyond the Foch Trust (or second ring) was terminated by its formation. The KWT was therefore formed before the formation of the second ring. The implication is that it was formed when the great annular ramps of Vredefort were still flat, or in an early stage of their formation. West of Potchefstroom, the KWT was observed in Gencor drilling (e.g. borehole 1782 in the Spitskop Syncline) at 8m above the base of the Black Reef Formation.

The Black Reef itself was intersected by a pseudotachylite zone, associated with the Black Reef Décollement Zone (BRDZ; Fletcher and Reimold, 1989). On surface in this area, the KWT is seen to have detached along a ramp-and-flat surface, with a large overthrust nappe covering the flat portion, remaining after erosion. At the Katdoornbosch Inlier, it displaced granite and the Black Reef to surface, but an element of a flat surface remains in the remnant klippe of Black Reef material found at Rysmierbult 881. Its position on the West Rand indicates that its movement was controlled by the Johannesburg Dome. Relative to the impact area, it is situated beyond and below the Potchefstroom-Master Bedding Plane Fault (PMBF; Brink et al., 1999) and the ramp formed by the Blaauwbank Anticline, that controlled the formation of both the KWT and the PMBF in the west. In the far west, it post-dates the reactivated movement over the old Ventersdorp-age fault surfaces, but broadly follows their morphology.

Apart from the Johannesburg Dome, the pre-existing structural control on the shape of the KWT in the north remains unknown. Underlying the later-formed PMBF, it followed a surface below all of the gold mines of the Central Rand Group of the West Wits Line (Carletonville) and the Central Rand, except for those found in the northern core portion of the West Rand Syncline. A thrust stack with a synthetic, cognate orientational relationship to the KWT is found below these mines (E on Fig. 8), possibly constituting an indication of deep, first stage movement, with the KWT of an immediately later age. All of these ages and stages occurred during the very few first seconds of astrobleme formation. The Doornkop Fault occupies a suitable position to be a component of the last, craterward movement stage of the formation of the Vredefort Structure.

Of interest is the association of thrust faulting and cave formation around the Gatsrand, the area north and west of Potchefstroom, the IMO (Fig. 2) north of Parys, and the area around Sterkfontein and Kromdraai, northwest of the West Rand Syncline. Many of these sites are found in the broken ramp zones, formed during the Vredefort impact event, below the thrust faults. The connection is too obvious to be fortuitous, and the Vredefort Event may ultimately be indirectly responsible for the formation of all of these very important archaelogical sites.

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