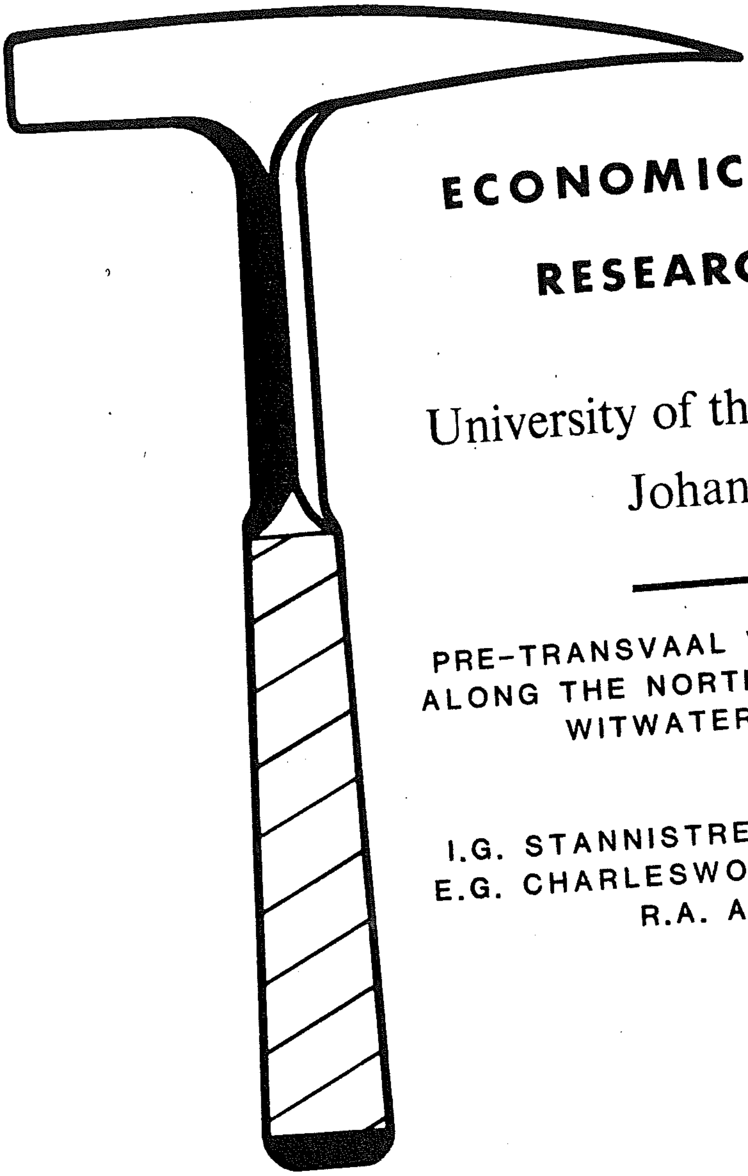

ECONOMIC GEOLOGY RESEARCH UNIT

University of the Witwatersrand
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PRE-TRANSVAAL WRENCH TECTONICS ALONG THE NORTHERN MARGIN OF THE WITWATERSRAND BASIN

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UNIVERSITY OF THE WITWATERSRAND
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by

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ABSTRACT

The pre-Transvaal tectonic history of the northern margin of the Witwatersrand Basin has been re-evaluated in terms of wrench-fault tectonics. Three, major, east-northeast-trending, left-lateral, wrench-fault systems have been recognized: the Sugarbush, the Rietfontein, and the Kromdraai systems. They are characterized by pull-apart basins (e.g. the Bezuidenhout Valley and Kromdraai grabens), narrow slivers of displaced stratigraphy (e.g. Langermanskop, the Rietfontein block) and marginal, convex-upward thrusts. Changes in fault-orientation have resulted in areas of compression passing laterally into areas of extension over short distances. Splays terminate individual fault-systems. Regions of wrench-fault overlap are characterized by fold-domains (e.g. West Rand Syncline, East Rand basin), with folds characteristically trending northwest to southeast. The left-lateral, strike-slip system appears to be of craton-wide scale and probably extends at least as far as the Barberton greenstone belt. The wrench-system appears to have come into existence during Witwatersrand times, but experienced its major movement during middle-Ventersdorp times. The left-lateral, strike-slip system is believed to be related to rifting along the Ventersdorp trough and to right-lateral faulting along the southwestern margin of the Witwatersrand Basin.

These tectonics occurred prior to a post-Transvaal period of folding and thrusting related to the emplacement of the Vredefort dome. The latter is responsible for the penetrative regional cleavage and sub-parallel bedding-faults throughout the area.

The structural model proposed here has implications for the existence of possible outliers of mineralized Upper Witwatersrand stratigraphy.

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PRE-TRANSVAAL WRENCH TECTONICS ALONG THE NORTHERN MARGIN OF THE WITWATERSRAND BASIN

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INTRODUCTION

The Witwatersrand Basin is located at the centre of the Archean Kaapvaal Craton and constitutes one of a succession of intracratonic basins which developed during the Archean and Proterozoic (Brock and Pretorius, 1964; Pretorius, 1979). Placer reefs developed within the Witwatersrand Basin represent the world's major gold-resource, while uranium is an important by-product of mining.

The Witwatersrand Supergroup (Fig.1) consists of the 4 km-thick, lower, West Rand Group, comprising approximately equal thicknesses of shale and quartzite, and the 2 km-thick, upper, Central Rand Group which consists almost entirely of quartzites and includes economically-important conglomerate horizons. Over most of its extent, the Witwatersrand Basin lies unconformably on Archean granite-greenstone terrane, although the western section of the basin is underlain by a small proto-basin, the Dominion Group (Bickle and Eriksson, 1982). In the central basin, the Witwatersrand Supergroup is conformably overlain by the predominantly-volcanic Ventersdorp Supergroup. However, these sequences of rocks become unconformable towards the northwestern margin of the Witwatersrand Basin, particularly in the west, where the major depo-centre of the Ventersdorp Supergroup is developed (Fig. 2). Both the Witwatersrand and Ventersdorp Supergroups are largely obscured beneath the Proterozoic (2 200Ma) Transvaal and Permian Karoo sequences.

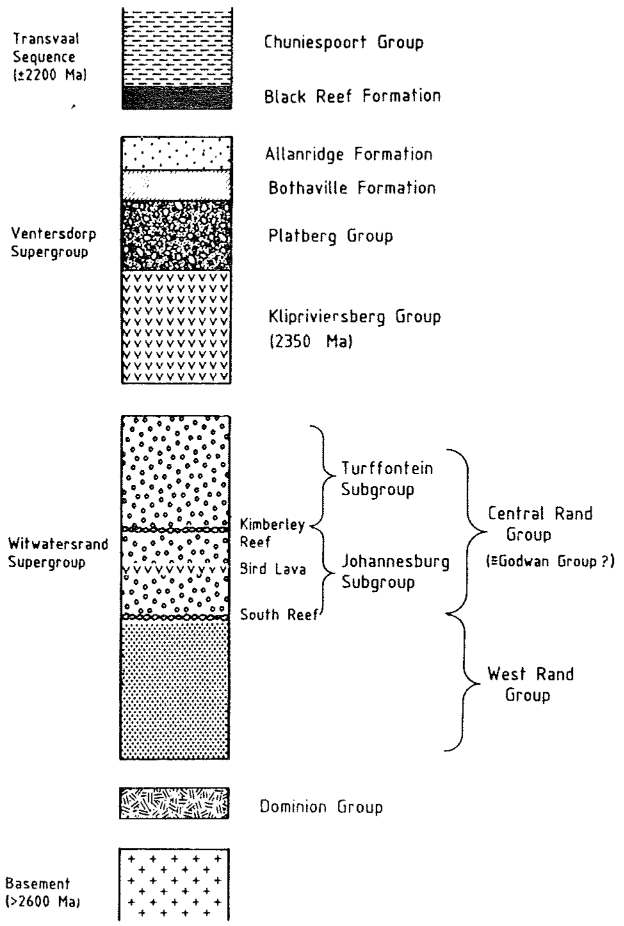


Figure 1 : *Stratigraphic column illustrating the relative positions of the major stratigraphic sequences referred to in the text.*

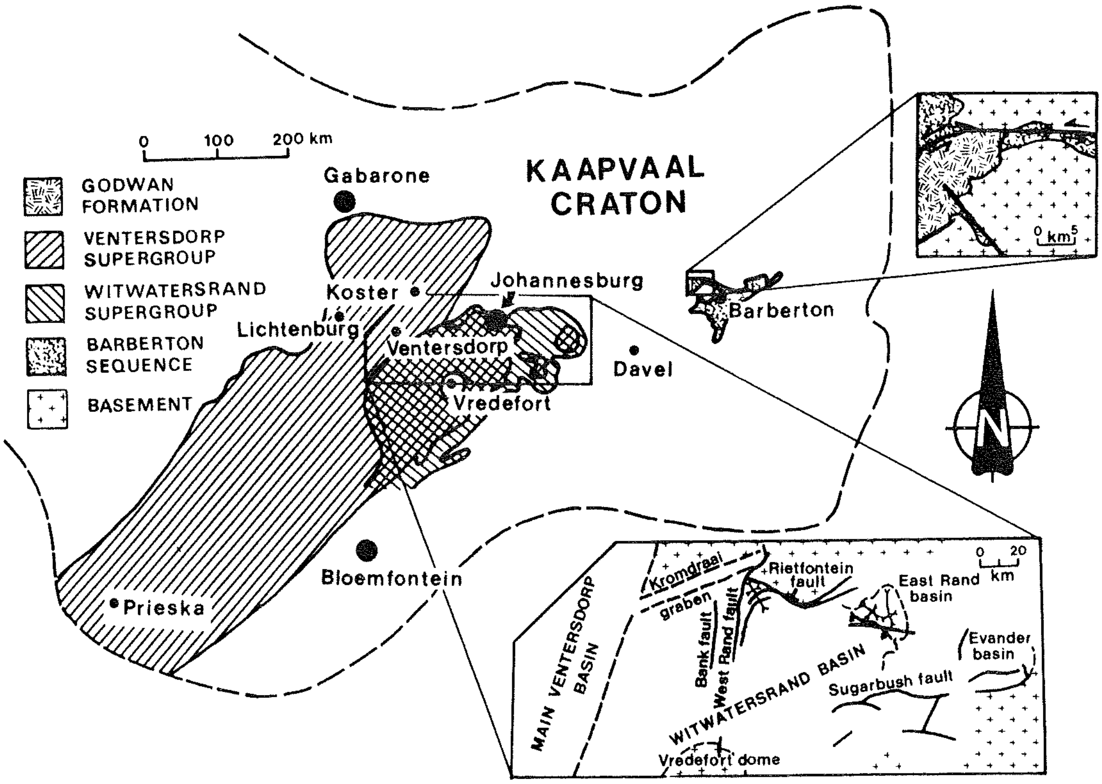


Figure 2 : *Geological setting of Witwatersrand - and Ventersdorp - related rocks on the Kaapvaal Craton.*

The Witwatersrand Supergroup is structurally fragmented, particularly along its northern, western and southeastern margins. Furthermore, the Witwatersrand, Ventersdorp, and Transvaal sequences in the central area of the Witwatersrand Basin were severely disturbed during the emplacement of the Vredefort dome (Manton, 1962; Simpson, 1977). Other post-Transvaal Sequence domes occur flanking the basin, particularly the Johannesburg dome in the north and the Devon dome in the east.

Ideas regarding the tectonic evolution of the Witwatersrand Basin have been dominated by the concept of interfering cross-folds which are considered to manifest themselves as domes interspersed with deep depressions in which Witwatersrand, Ventersdorp, and Transvaal sequences are preserved (Brock and Pretorius, 1964). Detailed basin-edge phenomena, particularly local steepening of dips, have been interpreted in terms of basin-edge subsidence (Brock and Pretorius, 1964; Tweedie, 1984).

Previous models of both marginal subsidence and doming hybridize late-tectonic features with syn- and immediately post-sedimentation deformation of the Witwatersrand and Ventersdorp Supergroups. Bickle and Eriksson (1982) and, more recently, Burke et al. (1985) have reviewed the tectonic history of the western margin of the Witwatersrand Basin, with particular reference to the development of the Ventersdorp trough. The Ventersdorp Supergroup developed in an incipient rift-structure and is characterized by extensional block-faulting, which caused extensive repetition of West Rand Group stratigraphy and which was accompanied by synchronous sedimentation and volcanicity. This tectonic style is in contrast to that along the northern margin of the Witwatersrand Basin where deformation is confined to very narrow zones.

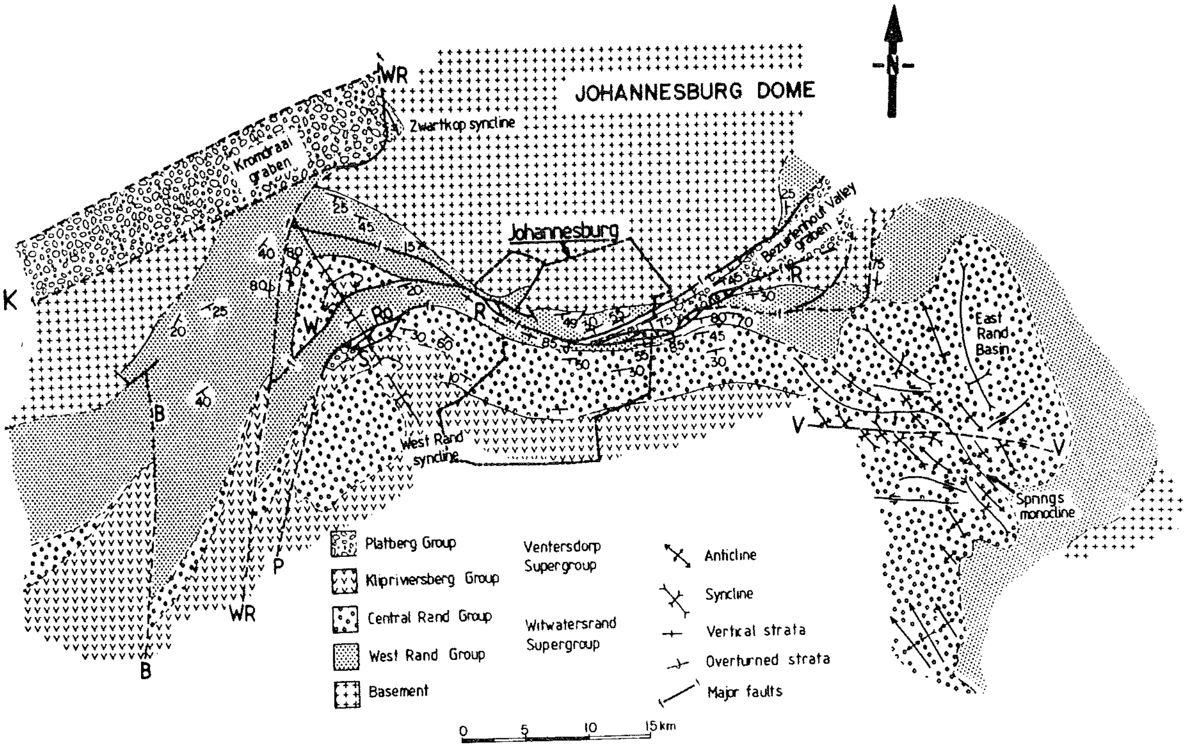
The present study has examined the sequential structural history of the Witwatersrand Basin and has recognized distinct deformational patterns which can be related to two major discrete tectonic events which took place on the craton. The structural style of the northern margin of the Witwatersrand Basin has been studied in detail and its relationship explored to the Ventersdorp trough in the west and to the southwestern margin of the basin.

STRUCTURAL FEATURES ALONG THE NORTHERN SECTION OF THE WITWATERSRAND BASIN

In order to obtain a comprehensive appreciation of the early structural history of the Witwatersrand Supergroup, it is essential to examine the deformation of post-Witwatersrand sequences, so that later events can be characterized. To this end, McCarthy et al. (1985) undertook a regional study of the deformation reflected in the Black Reef Formation at the base of the Transvaal Sequence. They recognized several post-Transvaal deformational events. The most important of these was a period of folding, accompanied by heterogeneous cleavage-development and thrusting. The strikes of folds, cleavages and faults lie tangential to the Vredefort structure and are considered to reflect long-range effects associated with the emplacement of this dome. Dispersion of cleavage-orientation occurred as a result of the later rise of the Johannesburg dome. These events have had varying effects on the underlying Witwatersrand strata. In the ensuing discussion, emphasis will be directed to structures which demonstrably pre-date these younger tectonic events.

Rietfontein Fault-System

The distribution of Witwatersrand rocks in the Johannesburg area is controlled by the major, anastomosing, east-west-trending Rietfontein fault-system, originally described by Mellor (1911a and b; 1913). This fault-system (Fig. 3) is exposed over a strike-length of some 60 km in an erosional window through the Transvaal Sequence, caused by the emplacement of the Johannesburg dome. Certain observed structures are associated with this fault-system: (i) the deep, narrow, fault-bounded, Bezuidenhout Valley graben is developed along the fault; this Ventersdorp-age feature is filled by immature debris-flow deposits which contain rock-fragments unrelated to adjacent rock-assemblages; (ii) narrow, graben - or horst - like slivers are strung along the major faults; (iii) localized east-west-striking thrust-faults, with accompanying overturned dips, are intimately associated with the fault-system; (iv) a northwesterly-striking fold-set occurs across the entire northern portion of the basin; (v) the fault-system passes from regions of apparent extension (duplication of stratigraphy) to areas of apparent compression (elimination of stratigraphy) over short (10 km) strike-distances; and (vi) on its western end, the fault-system undergoes pronounced splaying and changes strike to the southwest, within the core of the major West Rand syncline. These features are discussed in more detail below.



<u>*Figure 3*</u> : *Geological map of the north-central portion of the Witwatersrand Basin. Younger cover has been removed entirely and, in the East Rand Basin, the Ventersdorp rocks have also been removed, to display structure at the base of the Central Rand Group. (B - Bank Fault; WR - West Rand Fault; P - Panvlakte Fault; W - Witpoortjie Fault; Ro - Roodepoort Fault; R - Rietfontein Fault; V - Vogels wrench (tear) - fault). Map compiled from Mellor (1917), Hendriks (1961), Antrobus and Whiteside (1964), de Jager (1964), Toens and Griffiths (1964), McCarthy and Cadle (1984), Stanistreet and McCarthy (1964) and unpublished data.*

(i) <u>*Bezuidenhout Valley Graben*</u>

This structure (Fig. 4) is floored by a normal sequence of Ventersdorp volcanics, identical to those which conformably overlie undisturbed Witwatersrand strata 12 km and more to the south (McCarthy and Cadle, 1984). Overlying the volcanics is an accumulation of debris-flow deposits comprising litharenites and diamictites. The clasts consist almost entirely of Ventersdorp basaltic lavas, while clasts of Witwatersrand derivation are completely absent, despite the fact that the graben is flanked by basement and Witwatersrand sedimentary rocks. In addition, potassic rhyolite clasts, unknown in the surrounding sequences, occur in the graben. The minimum thickness of the sedimentary fill is 2000m to an erosional top and is comparable to the present width of the graben. Dips within the graben are typically of the order of 40°S, in the east, but steepen to 80°S, in the west, accompanied by severe flattening of clasts.

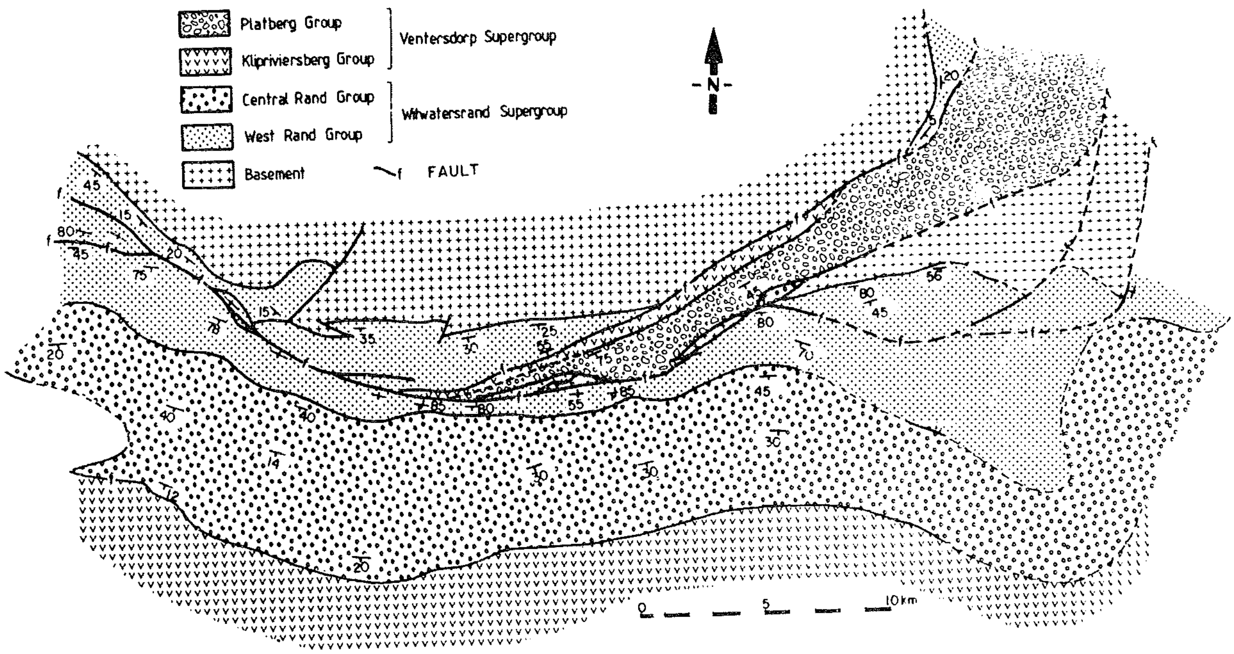


Figure 4 : *Geology of the Bezuidenhout Valley graben and environs, with younger cover removed. Compiled from Mellor (1917), McCarthy et al. (1982) and McCarthy and Cadle (1984).*

Several, long, narrow slivers, with length-to-width ratios of 9 to 1, are developed along the fault-system, particularly the southern margin of the graben (Fig. 4). The slivers expose and juxtapose the entire sequence from the basement through the Witwatersrand Supergroup. Southerly-verging thrusts, bounding these slivers locally overturn strata (McCarthy et al., 1982). In addition, the main fault-zone, in which the slivers are developed, is characterized by vertical-to-overturned dips along its southern flank (Mellor, 1911a and b; McCarthy et al., 1982).

There appears to be duplication of the southerly-dipping West Rand Group strata across the Bezuidenhout Valley graben, suggesting normal faulting. However, the overturned strata flanking the southern-boundary fault of the graben (Rietfontein fault) imply reverse movement.

(ii) West Rand Syncline

To the west of the graben, the Rietfontein fault-system narrows (Fig. 4) and is associated with elimination of strata. Further west, the fault-system widens dramatically within the West Rand syncline (Fig. 3). Movement on major faults within this syncline has resulted in the development of horsts and grabens which are associated with extension along the northwest-trending fold-axis. The faults change strike to a southerly direction along the western limb of this fold and become asymptotic or parallel to a major north-northeasterly-striking fault-system which flanks the western margin of the West Rand syncline.

The fault-system which flanks the West Rand Syncline is complex and involves the West Rand, Bank, and Panvlakte faults (Fig. 3). These faults dip towards the west and duplicate strata. However, they show a reverse sense of movement in that strata close to the faults are overturned and dip westwards (Fig. 3).

Kromdraai Graben

At Zwartkop, to the north of the West Rand syncline, a small outlier of lower Witwatersrand strata takes the form of a southeasterly-plunging syncline, parallel to the West Rand syncline (Fig. 3). Its eastern side is flanked by a sequence of Ventersdorp-age potassic rhyolites and very immature debris-flow fan-diamictites (Hendriks, 1961; Winter, 1976; Stanistreet and McCarthy, 1984). The clasts within these deposits are up to four metres diameter and comprise mainly quartz-arenites, shales, and conglomerates derived from the Witwatersrand Supergroup, even though the graben-like feature is almost entirely flanked by basement lithologies. Although most of this graben is buried beneath younger cover, diamond-drilling (Borchers, 1961) has revealed that it has the form of a long, narrow trough, similar in shape to the Bezuidenhout Valley graben (Fig. 3). It is here named the Kromdraai graben. The eastern contact between this body and the lower Witwatersrand outlier takes the form of an easterly-verging thrust (Hendriks, 1961; Stanistreet and McCarthy, 1984). This fault is interpreted as a northern extension of the West Rand fault-system (Fig. 3).

Although the northern and southern margins of the Kromdraai body are nowhere exposed, it is inferred that they must be bounded by major faults. Partly by analogy with the Bezuidenhout Valley graben and also by virtue of the southern provenance of the sediments within the Kromdraai graben (Stanistreet and McCarthy, in prep.), it is believed that the master-fault lies along the southern margin of this structure. This fault has been termed the Kromdraai fault.

East Rand Basin

East of Johannesburg lies an extension of the Witwatersrand Basin known as the East Rand basin. The boundary between this sub-basin and the main basin takes the form of the northwesterly-trending, southwesterlyfacing, Springs monocline (Whiteside, 1964) (Fig. 3). This monocline appears to have been active during Witwatersrand sedimentation (Antrobus and Whiteside, 1964). The East Rand basin is characterized by the presence of small-scale, en-echelon folds which have a consistent north-westerly orientation (Fig. 5). Closely associated with this folding is a set of strike-slip faults (Ellis, 1943; Cluver, 1957; Whiteside, 1964), the most prominent of which is the Vogels wrench-fault, a westerly-striking, left-lateral, strike-slip fault with a displacement of 1000 metres. Ellis (1943) established that faulting occurred during the period of folding. Detailed mapping in the mines in the central area of the basin, compiled by Antrobus and Whiteside (1964) and, to a lesser extent, by de Jager (1964), has established a detailed chronology for the faults, based on ages relative to dyke-events. If strike-slip faults of comparable age to the Vogels wrench are considered, i.e. pre-Transvaal Sequence in age, a distinct pattern of left - and right-lateral faults emerges (Fig.5). The orientation of pay-shoots and erosion-channels in the gold-uranium-bearing conglomerate horizon in the East Rand basin (Antrobus and Whiteside, 1964; Vos, 1975) parallels the trend of the fold-axes. Furthermore, thickness-variations of stratigraphic units in the vicinity of the gold-uranium-bearing horizon are spatially related to the northwesterly-oriented fold-set (Fig. 6). This implies that the folds had already started to develop during deposition of the gold-uranium-bearing conglomerates.

Sugarbush Fault and Evander Basin

South of the East Rand basin lies the westerly-striking Sugarbush fault (Rogers, 1922; Pretorius, 1964) (Fig. 2). This fault has been interpreted as a normal fault with a downthrow component, to the south, of several kilometres, juxtaposing Ventersdorp and lower Witwatersrand Supergroup rocks (Pretorius, 1964). Diamictites are locally developed adjacent to this fault, on its southern side, apparently overlying mafic Ventersdorp lavas (Rogers, 1922).

Unpublished mapping along the northern side of the Sugarbush fault (Booth, in prep.) indicates a complex fault-system. An array of north-westerly-plunging, short-wavelength folds and northeasterly-striking normal faults is developed in the immediate vicinity of the Sugarbush fault. A sliver of lower Witwatersrand rocks, analogous to those described above, is located along the Sugarbush fault-system, between basement and Ventersdorp rocks. The fault-system disappears beneath Permian cover in the east and does not reappear at the surface. However, exploratory drilling in the east has established the existence of an outlying basin of Witwatersrand rocks, which now hosts the Evander gold-mining complex. The geology of this basin has been described in detail by Tweedie (1981). The southern boundary of the basin is marked by a major, westerly-striking fault. The association between this fault and the Sugarbush fault-system has been considered problematic, as the fault forming the southern boundary of the Evander basin appears to have a northerly downthrow, juxtaposing basement against upper Witwatersrand Supergroup rocks.

The Evander basin contains a northwesterly-plunging fold-set, which is truncated by northeasterly-striking normal faults (Fig. 7), some of which appear to have a left-lateral, strike-slip component (Tweedie, 1981). The eastern boundary of the basin is marked by overturning along a northwesterly-striking axis, with strata dipping towards the east. This structure appears to be associated with westerly-verging thrusts of post - or late - Ventersdorp age.

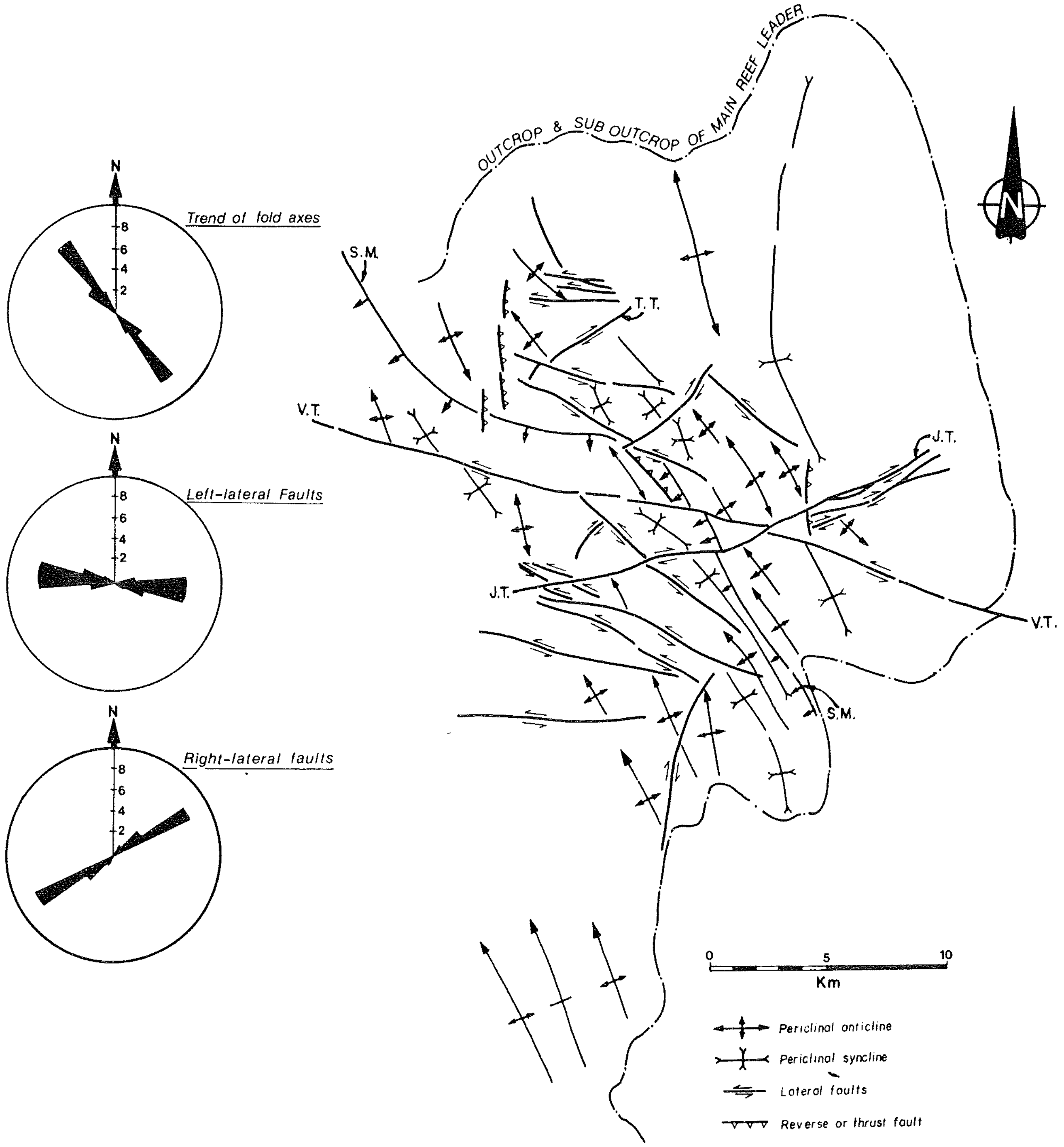


Figure 5 : *The pre-Transvaal structural features of the East Rand basin. Compiled from Cluver (1957), Antrobus and Whiteside (1964), de Jager (1964), and Whiteside (1964). (V.T. - Vogels wrench (tear) - fault; T.T. - Turner's tear-fault; J.T. - Jeffrey's tear-fault; and S.M. - Springs monocline). Orientation of folds and faults is based on the areally-limited study by Antrobus and Whiteside (1964).*

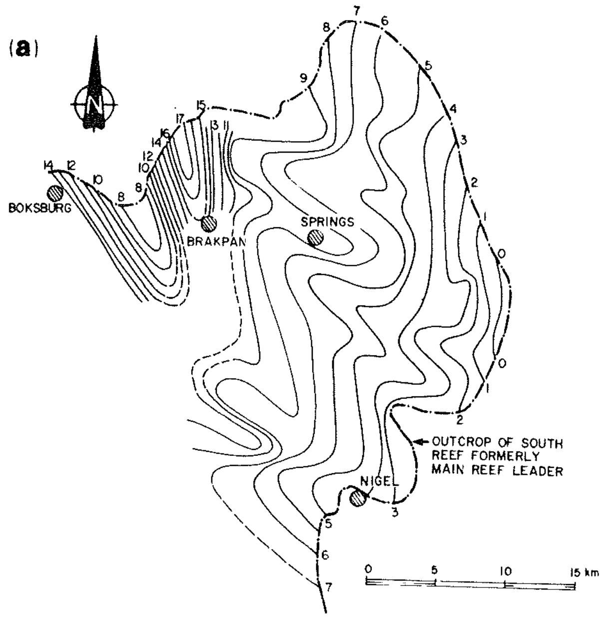


Figure 6a: *Isopachs for the interval between the South Reef (formerly Main Reef Leader) and the Bird Lava (Fig.1) in the East Rand basin (after Cousins, 1965)*

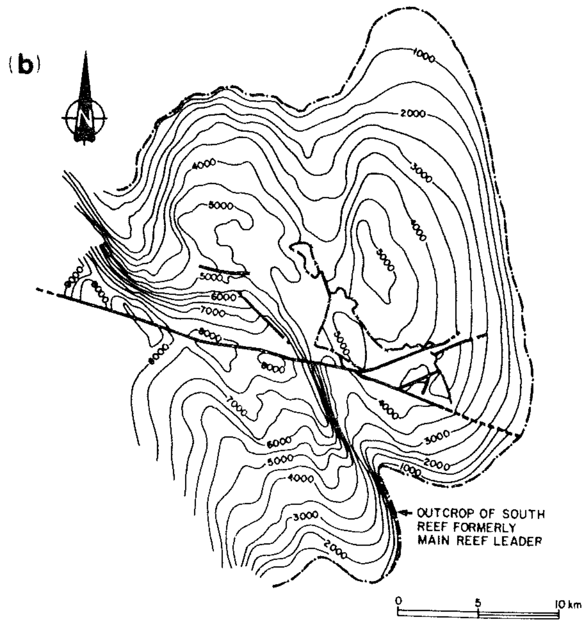


Figure 6b: *Structure-contours of the South Reef (formerly Main Reef Leader) in the East Rand basin (after Whiteside, 1964)*

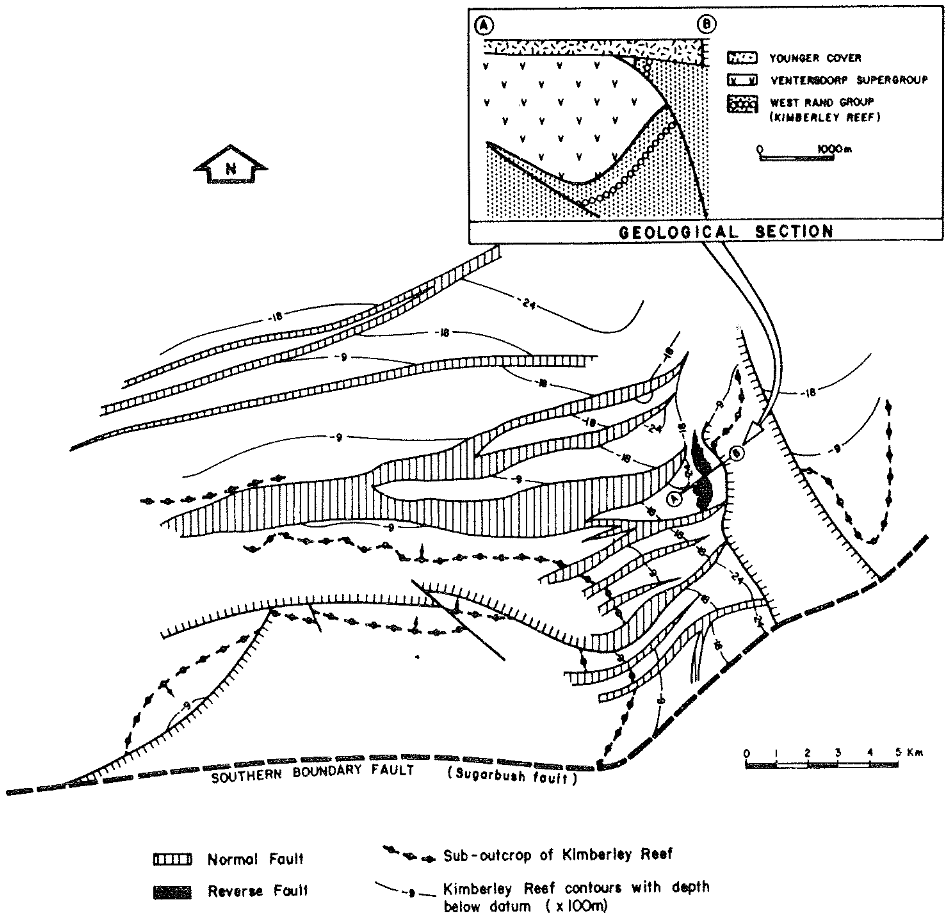


Figure 7 : *Subsurface geology of the Kimberley Reef (West Rand Group) in the southern portion of the Evander Basin (adapted from Tweedie, 1981).*

A STRUCTURAL INTERPRETATION OF THE NORTHERN PORTION OF THE WITWATERSRAND BASIN

The pre-Transvaal deformation of the northern portion of the Witwatersrand Basin, in summary, is characterized by major east-west-striking faults. Associated with these faults are deep grabens which contain accumulations of rapidly-deposited, sedimentary material and which also show evidence of localized acid volcanism. These deposits comprise part of the middle-Ventersdorp Platberg Group (Fig.1). Narrow, fault-bounded slivers are present in the fault-zones. Closely associated with the major faults are northwesterly-striking folds of variable wave-length and northeasterly-striking normal faults, many occupied by Venters-dorp-age dykes. It is believed that the majority of these features could have been produced in a single, prolonged, deformational event, dominated by wrench-faulting. In this context it is perhaps apposite to recall Sylvester's (1984) remarks: "Recognition of wrench faulting is necessarily difficult and complicated by the scale of the faults themselves. To establish wrench faulting requires broad geological knowledge on a regional scale and not a little prescience or audacity to propose that rocks now separated by hundreds of kilometres were once contiguous". In ancient terranes, such as the one under discussion, the problems of recognizing wrench-faults are compounded by deep erosion and younger cover.

The deformational features which may be anticipated in a wrench-system are conveniently portrayed by means of the strain-ellipse for simple shear (Fig.8). Wrench-movement induces both fractures and folds, the development of which may vary within the fault-system (Tchalenko, 1970; Wilcox et al., 1973; Harding, 1985). Folds, when developed, tend to lie along the major axis of the strain-ellipse, making a small angle with the principal-shear direction. These folds may locally be rotated into this direction. Fractures or faults of several types may develop.

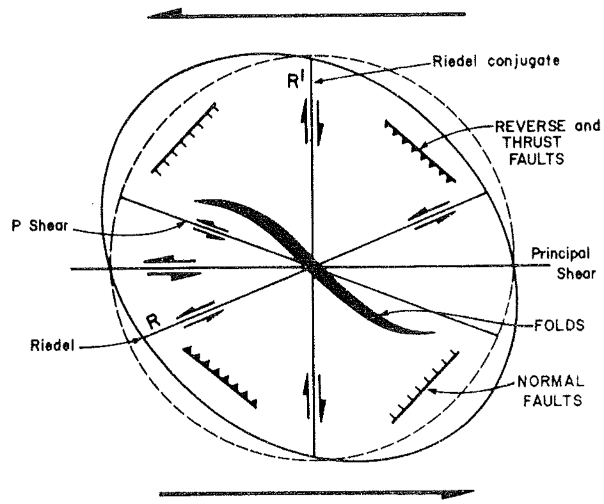


Figure 8 : *Characteristics of the strain-ellipse resulting from left-lateral, strike-slip motion.*

The earliest faults are a conjugate set known as Riedel shears (Tchalenko, 1970; Tchalenko and Ambrayses, 1970) which form at low angles (Riedels, R, Fig.8) and high angles (Riedel conjugates, R', Fig. 8) to the principal-shear direction. The sense of movement on these shears is opposite. Generally, the Riedels are more prominent. As displacement on the wrench-system increases, the Riedels may become linked by a second fracture-set lying close to the principal axis of the strain-ellipse, termed the P shear (Fig. 8) by Tchalenko and Ambrayses (1970). In addition to these, two other fault-sets frequently develop: normal (extensional) faults which lie parallel to the minor axis of the strain-ellipse, and reverse (compressional) faults which parallel the major axis (Fig.8). Faults may hybridize; a Riedel shear may inherit some of the normal component of wrench-deformation (Wilcox et al., 1973). Within wrench-fault-systems, individual faults are frequently distributed in an en-echelon arrangement. Depending on detailed geometry, zones of fault-overlap may be characterized by compressional features (intense folding and thrusting) or by extensional collapse (Crowell, 1974).

This study holds the view that deformation within the northern portion of the basin is controlled by three major, westerly-trending, left-lateral, strike-slip fault-arrays. These are: the Sugarbush, the Rietfontein, and the Kromdraai fault-systems. The best exposed of these is the Rietfontein system and the structural features of this system have been examined in terms of the proposed model (Fig.9)

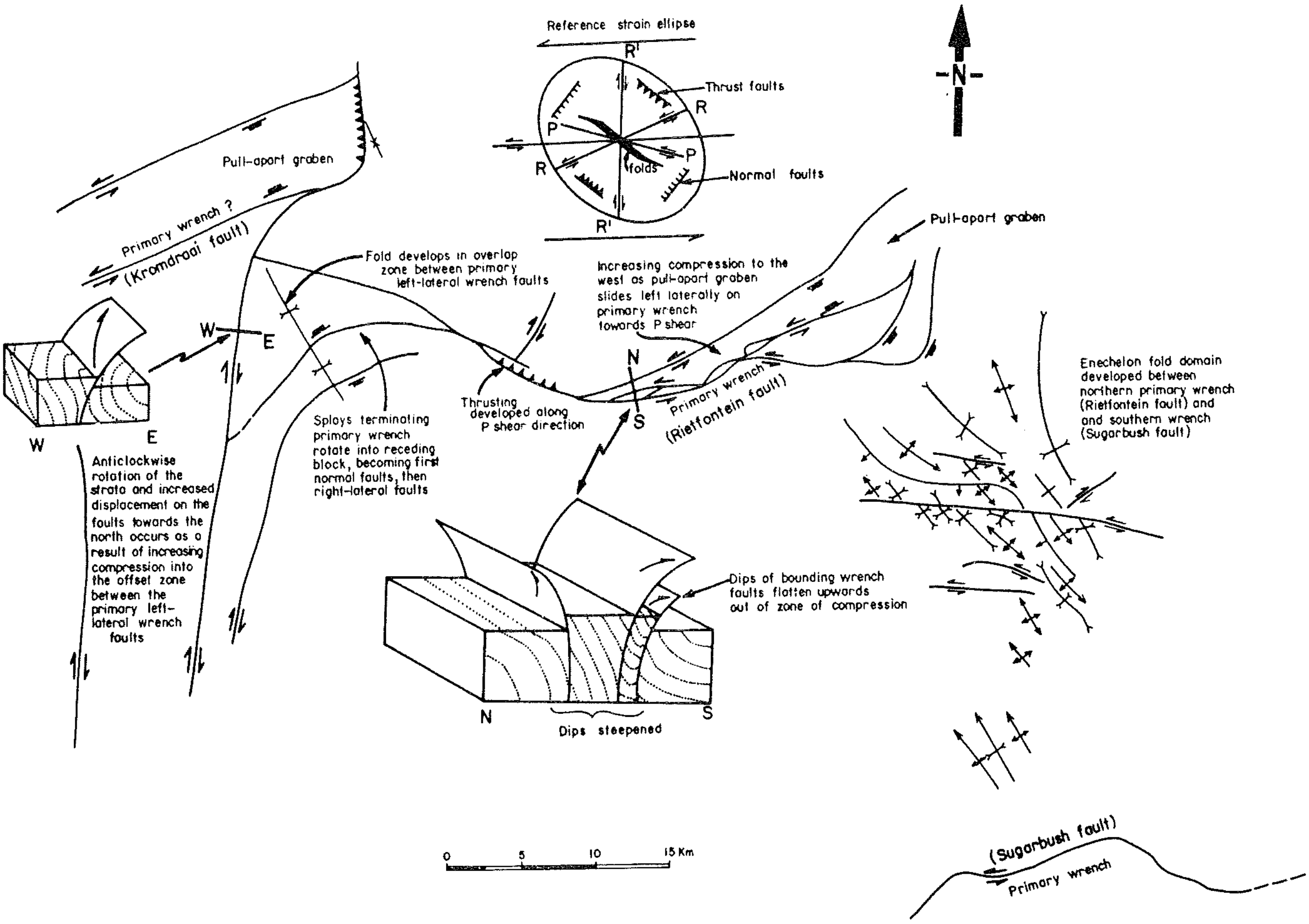


Figure 9 : *A structural interpretation of the north-central portion of the Witwatersrand Basin, with reference to a strain-ellipse resulting from left-lateral, strike-slip motion. Refer to Fig. 2 for geological details.*

The Rietfontein fault-system is characterized by changes in orientation along strike (Fig.9),and this is accompanied by a change in many of the associated features. The northeasterly-striking, wedge-shaped, Bezuidenhout Valley graben (Figs. 3, 9) is interpreted as a pull-apart basin (fault-wedge basin), developed on the main fault-system. In spite of its narrowness, this graben contains in excess of two kilometres of rapidly-deposited sediment, derived from a provenance-area containing only Ventersdorp Supergroup lavas. The superimposition of coarse, proximal diamictites on distal debris-flow accumulations implies periods of intermittent, rapid subsidence, indicative of fault-control on sedimentation. Modern-day analogues of such narrow basins are developed along the Anatolian wrench-system and have been described by Hempton and Dunne (1984). The thickness of fill in the Bezuidenhout Valley graben (2 km) is compatible with the length of the basin (30 km), as deduced from the work of Hempton and Dunne (1984), whose analysis would predict a fill of 2,7 km, although it must be borne in mind that the shape of the graben has been modified by progressive, and younger, deformation. Potassic, acid volcanics are associated with pull-apart basins (Hempton and Dunne, 1984), which would explain the presence of such clasts in the diamictite which fills the Bezuidenhout Valley graben.

In the east, dips within the graben are moderate (45°S), but steepen westwards to high angles (80°S), accompanied by flattening of clasts. This is interpreted as the result of left-lateral translation of the sediment-filled graben into a zone of compression created by a change in strike of the southern-boundary fault from west-southwest to west-northwest (Fig. 9). This change in strike of the southern-boundary (Rietfontein) fault has also resulted in a zone of overthrusting immediately west of the western termination of the graben (Figs. 3, 9).

The dips of the faults bounding the graben appear to flatten upwards (Fig. 9); dips of adjacent Witwatersrand strata steepen towards the graben on its northern flank and are overturned on its southern flank (Figs. 3, 9), reminiscent of the 'palm tree' style of faulting described by Sylvester and Smith (1976) along the San Andreas fault-system or the 'flower structures' of Harding (1985). The slivers developed along the Rietfontein fault may be highly compressed segments in the branched fault-array, similar to those described by Sylvester and Smith (1976) in the Mecca Hills of southern California.

In the west, the Rietfontein fault splays and several subsidiary faults are developed, all of which curve towards the south (Figs. 3, 9). Here, with strike essentially northeast, the faults are extensional (normal faults), bounding a series of horsts and grabens and consistent with the strain-ellipse (Fig. 9). The curvature of these terminal splays towards the south, i.e. into the receding block, conforms with a left-lateral wrench-system (Freund, 1974). A similar phenomenon occurs at the eastern end of the Rietfontein fault-system, where splaying of the fault also takes place, but curvature in this instance is towards the north.

The western termination of the Rietfontein fault-system is marked by the development of a prominent fold, the West Rand Syncline (Fig. 3). The postulated Kromdraai fault, which is regarded as one of the major wrench-faults on the northern edge of the basin, appears to originate in the region north of the syncline (Fig. 9). The association of these two faults with the syncline is no coincidence: the offset between the Rietfontein and Kromdraai faults (Fig. 9) represents a major compressive stepover in which relative movement of the adjacent blocks has been accommodated by folding (see Crowell, 1974).

Bounding the western margin of the West Rand syncline is the West Rand fault, a right-lateral, northerly-trending, curvilinear fault. In terms of the strain-ellipse (Fig. 9), the West Rand fault and associated Bank fault represent a conjugate right-lateral array to the major left-lateral system, perhaps analogous (although a mirror image of) the San Andreas-Garlock faults (Crowell, 1974). The West Rand fault has a thrust component, which overturns the western margin of the West Rand Syncline. This is interpreted as a consequence of the compressive nature of the stepover between the Kromdraai and Rietfontein faults. These faults may have existed as a single fault-line prior to being offset by the West Rand fault, in which case only the later phases of movement have been taken up in the West Rand syncline.

Details of the geology associated with the Kromdraai fault-array are vague, because this fault-system is largely obscured by younger cover. Like the Rietfontein fault-array, however, this system is characterized by the presence of a long, narrow, graben-like feature, apparently identical in shape and orientation to the Bezuidenhout Valley graben, but twice the size. The Kromdraai graben also contains an accumulation of immature sediments, as well as acid volcanics (Stanistreet and McCarthy, 1984). In this case, however, Witwatersrand Supergroup strata dominated the provenance-area of the sediments.

The absence of suitable reference-points and the limited exposure make it impossible to determine the total movement on the Rietfontein-Kromdraai fault-system. However, lower Witwatersrand Supergroup (West Rand Group) rocks are known to exist in the Koster area (Fig. 2) (Watchorn, 1981). Furthermore, aeromagnetic anomalies very suggestive of the West Rand Group, are developed west of Lichtenburg (Fig. 2). The occurrence of West Rand Group strata in these areas could well be accounted for by substantial left-lateral movement along the Rietfontein-Kromdraai fault-system.

The East Rand basin (Figs. 3, 9) probably also reflects compression due to fault-stepover, in this case between the Rietfontein and Sugarbush fault-systems. A field of en-echelon, northwesterly-striking folds is developed here (Antrobus and Whiteside, 1964; Whiteside, 1964; de Jager, 1964), cut by northeasterly-striking, right-lateral and westerly-striking, left-lateral faults (Fig. 5). Reference to the strain-ellipse indicates that the orientation of these folds and faults is compatible with the regional left-lateral fault-system proposed here (Fig. 8).

Pay-shoots in the gold-uranium-bearing conglomerates of the Witwatersrand Supergroup, as well as syn-depositional warps in the East Rand basin (Fig. 6), have the same orientation as the later fold-set. It appears that the folds were initiated during sedimentation, and, therefore, it is inferred that the left-lateral tectonic regime has a long history, spanning at least the development of the upper Witwatersrand and Ventersdorp Supergroups, although the major movement appears to have taken place in middle-

Ventersdorp times.

The left-lateral nature of the Sugarbush fault-system is more obvious, by virtue of a seventy-kilometre displacement of the contact between the Witwatersrand and the Ventersdorp rocks (Borchers, 1964; Fig. 10). The major fault which marks the southern boundary of the Evander basin is probably the easterly continuation of the Sugarbush fault-system, although this interpretation has not been considered seriously before, because the Sugarbush was regarded as a normal fault (Rogers, 1922; Pretorius, 1964; Tweedie, 1981). In terms of the model proposed here, a displaced portion of the Evander goldfield is predicted to exist to the east, and this may coincide with a prominent northwesterly-striking magnetic anomaly south of Davel, some sixty kilometres east of Evander (Fig. 2).

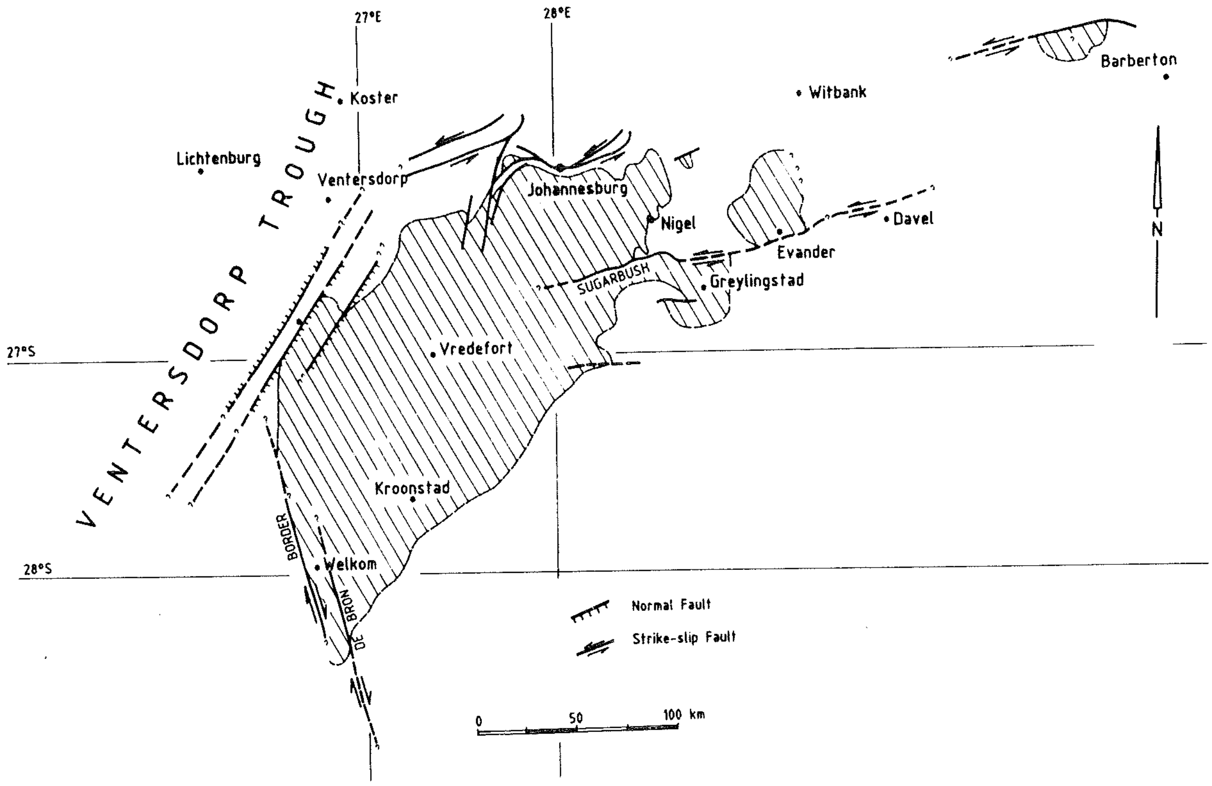


Figure 10 : *Map showing relationships of the presently-known Central Rand Group basins (shaded) to the major fault-systems described in the text.*

Northwesterly-plunging folds of variable wavelength occur in the Evander goldfield, especially on Winkelhaak and Leslie gold mines. This orientation coincides with the regional fold-orientation. The folds are cut by northeasterly-striking normal faults (Fig. 7), again compatible with the stress-field associated with a left-lateral shear-couple (Fig. 8). The southeastern margin of the Evander basin is characterized by thrusting along a northwesterly-trending fault system (Fig. 7), accompanied by overturning of strata towards the west, analogous in many ways to the West Rand fault-system and in accordance with the strain-ellipse. During upper Witwatersrand times, it is likely that the Evander basin was separated from the East Rand basin by northwest-trending anticlinal arches (the Sundra and Winterhoek anticlines of Button, 1968). These anticlines appear to form an integral part of the fold-system associated with the wrench-couple which operated along the northern portion of the Witwatersrand Basin.

REGIONAL ASPECTS OF THE PROPOSED TECTONIC MODEL

In each of the areas considered, alternative structural interpretations are possible (Mellor, 1911 a and b; Rogers, 1922; Cluver, 1957; Brock and Pretorius, 1964). However, there is a uniformity in tectonic style across the entire northern portion of the basin. This has been interpreted in terms of a major, left-lateral, strike-slip fault-system which operated along the present northern margin of the Witwatersrand Basin and may have come into existence during upper Witwatersrand times and continued to mid-Ventersdorp times, when major fragmentation occurred. Although this study is based on the central, northwest, and south Rand areas, the structures recognized appear to form part of a craton-wide tectonic framework.

The full extent of the proposed strike-slip system is not known, due to younger cover. However, developed beneath a Transvaal-Sequence cover towards the eastern margin of the craton is a sequence of volcanics and sedimentary rocks (Godwan Group) which is faulted against basement rocks, including those of the Barberton greenstone belt (Fig. 2) (Visser et al., 1956). These volcanics yield a Pb age of 2326 $\pm$ 65 my, which is indistinguishable from the age of the Ventersdorp volcanics (Armstrong, 1985). The bounding fault is pre-Transvaal in age, has palm-tree and other strike-slip characteristics, and has the same sense of oblique, left-lateral slip as the faults described above from the Witwatersrand Basin (Myers, in prep.) and as those described from the Jamestown schist belt by Anhaeusser (1971, 1972). Anhaeusser (1971, 1972) recognized these left-lateral faults as the last major deformation in this area. The present study suggests that the fault bounding the northern margin of the Godwan Group represents an eastward extension of the left-lateral wrench-system proposed here. If this is correct, the cratonic proportions of the wrench-system would be confirmed.

The main movement on the wrench-system along the northern portion of the Witwatersrand Basin occurred during Ventersdorp times and can probably be related to the development of the main Ventersdorp Basin. The axis of Ventersdorp Supergroup deposition lies along the western margin of the Witwatersrand Basin (Fig. 2) and is dominated by extensional faulting. Erosional windows through the Ventersdorp sequence indicate that Witwatersrand Supergroup rocks have been repeatedly duplicated by faulting, over a zone at least 90 km wide (Nel, 1927). An analysis by Burke et al. (1985) suggests these structures represent half-graben features associated with crustal thinning in a major rift-event.

The southwestern margin of the Witwatersrand Basin is apparently defined by a major linear structure (the Border Fault) which is parallel to several, well-documented, north-northwest-striking, right-lateral, oblique-slip faults (Dell, 1982; Minter et al., 1985). The deformation associated with the Border structure - folding, overturning of strata, thrusting (Olivier, 1965) - suggests that it is probably also an oblique-slip fault. The Border structure was clearly active during Witwatersrand sedimentation (Olivier, 1965) and shows evidence of right-lateral, strike-slip motion during early- and middle-Ventersdorp times. It appears, therefore, that a right-lateral, strike-slip system was operative along the southwestern margin of the Witwatersrand Basin at the same time as the Ventersdorp trough was developing and the left-lateral system along the northern portion of the basin was operative. The regional disposition of these various structures in relation to the presently-known extent of the Central Rand Group basin is shown in Figure 10. The geometry of these structures suggests a regional conjugate-fracture system (Callow and Myers, in prep.), possibly formed in response to a northeast-southwest compression imposed on the craton.

Burke et al. (1985) suggested that the Ventersdorp trough formed in response to the collision of the Zimbabwean and Kaapvaal cratons. The conjugate-fracture system shown in Figure 10 may well relate to this event.

CONCLUSION

A major, en-echelon, strike-slip fault-system has been recognized along the northern edge of the Witwatersrand Basin. This sytem is characterized by pull-apart-type basins containing immature, debris-flow deposits. Diverging thrusts and narrow wedges are associated with the faults. Prominent northwesterly-striking fold-sets are developed across the basin, especially in the West and East Rand areas, which represent fold-domains formed as a result of offset in the major wrench-system. There is an association between this westerly-trending fault-system, the northeasterly-trending Ventersdorp trough, and the north-northwesterly-trending southwestern margin of the Witwatersrand Basin. The Ventersdorp trough is characterized by early northeasterly-striking normal faults, reflecting regional extension. The north-northwest-striking faults which define the presently-known southwestern margin of the Witwatersrand Basin appear to represent a conjugate-fracture set to that on the northern margin.

The recognition of strike-slip tectonics introduces a new predictive capability into the geology of the Witwatersrand Basin. On a macroscopic scale, it implies the existence of displaced portions of Witwatersrand stratigraphy lying external to the main basin. On a mesoscopic scale, it provides a framework for understanding sedimentation and structure on individual mining properties. Syn-sedimentary folding associated with early wrench-movement along the northern margin implies that pay-shoots will have a general southeasterly orientation across this portion of the basin. Similar controls may apply elsewhere in the basin. The nature of the displacement of these pay-shoots by subsequent, pre-Transvaal, wrench-associated faults may also be predictable.

On the basis of the tectonic model presented here, several areas appear to be highly prospective for gold-uranium mineralization. These are: the area between Lichtenburg and Koster, where portions of the up-dip extension of the West Wits Line may pe preserved; the Davel area where the southern portion of the Evander Basin may be preserved; and the Kromdraai and Bezuidenhout Valley grabens which may locally contain upper Witwatersrand strata at depth. The possibility exists that slivers of Central Rand Group strata are preserved along the Kromdraai fault, analogous to that on the Rietfontein fault, on which the Rietfontein Consolidated Gold mine operated (Mellor, 1911a and b; Engelbrecht, 1957). There is also the possibility that smaller, isolated basins may lie along the southerly extension of the Border structure, analogous to the Evander basin, as well as in the wrench-fault system to the east of Evander.

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