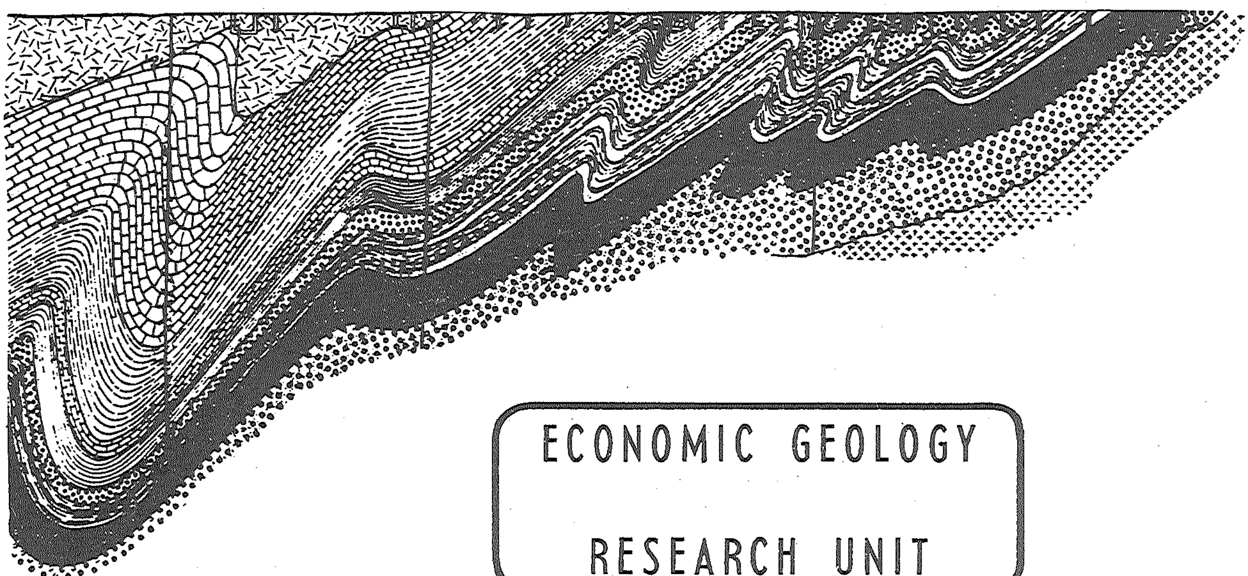
UNIVERSITY OF THE WITWATERSRAND

JOHANNESBURG



ECONOMIC GEOLOGY

RESEARCH UNIT

INFORMATION CIRCULAR No. 48

THE TECTONICS OF THE WEST RAND SYNCLINE : A FIELD STUDY OF BRITTLE FAILURE IN THE WITWATERSRAND BASIN

C. ROERING

UNIVERSITY OF THE WITWATERSRAND
JOHANNESBURG

THE TECTONICS OF THE WEST RAND SYNCLINE : A FIELD STUDY OF BRITTLE FAILURE IN THE WITWATERSRAND BASIN

by

C. ROERING
(Research Fellow, Economic Geology Research Unit)

ECONOMIC GEOLOGY RESEARCH UNIT
INFORMATION CIRCULAR No. 48
August, 1968

THE TECTONICS OF THE WEST RAND SYNCLINE : A FIELD STUDY OF BRITTLE FAILURE IN THE WITWATERSRAND BASIN

ABSTRACT

Structural geological techniques have been applied in the interpretation of the tectonic development of rocks belonging to the Lower Division of the Witwatersrand System in the West Rand Syncline.

The major events were : a period of strike faulting with reversed movements; formation of the syncline due to a north-south compression wedging the Witwatersrand System in between two granite massifs; and reactivation of the reverse faults, as wrench faults, by the north-south stress, to give rise to various types of second-order fractures. The geometry of second-order fractures adjacent to wrench faults, established in this area, differs markedly from the pattern suggested by Moody and Hill (1965), but reveals a high degree of similarity to those proposed by Chinnery (1966) for fracture phenomena in elastic media.

* *

THE TECTONICS OF THE WEST RAND SYNCLINE : A FIELD STUDY OF BRITTLE FAILURE IN THE WITWATERSRAND BASIN

CONTENTS

* *

THE TECTONICS OF THE WEST RAND SYNCLINE : A FIELD STUDY OF BRITTLE FAILURE IN THE WITWATERSRAND BASIN

INTRODUCTION

A. LOCATION OF WEST RAND SYNCLINE

The area mapped lies between Johannesburg in the east, Krugersdorp in the centre, and Bank in the southwest. Two separate map areas are described in this paper — the Tarlton—Bank area in the west and the Krugersdorp—Florida Hills area in the east (Figure 1). The reason for a subdivision into two distinct areas is that there is a natural break in the continuity of exposure of rocks belonging to the Lower Division of the Witwatersrand System. Each area represents one of the limbs of the West Rand Syncline, the axial-plane trace of which has a northwest trend. The exposed portions of rocks belonging to the Lower Division of the Witwatersrand System in the areas mapped are shown in Figure 1, as is the broadly arcuate structure of the West Rand Syncline. Approximately 80 square miles of surface outcrop were mapped. The eastern area consists of the southeastern portion of the West Rand Goldfield and the western portion of the Central Rand Goldfield, while the western area contains the southwestern segment of the West Rand Goldfield and the eastern section of the West Wits Line Goldfield.

B. GENERAL GEOLOGY

The Witwatersrand System is subdivided according to the succession exposed in the Johannesburg area, which is regarded as the type-locality. A type-section for this Central Rand area is given in Table 1.

		Series	Thickness
Witwatersrand System	Upper Division	Kimberley-Elsburg Series	6,100 ft.
		Main-Bird Series	3,330 ft.
	Lower Division	Jeppestown Series	3,700 ft.
		Government Reef Series	6,300 ft.
		Hospital Hill Series	4,900 ft.

Table 1 : Stratigraphic Succession of the Witwatersrand System in the Central Rand Area (after Pretorius, 1964).

The Witwatersrand System is built up essentially of sediments in which quartzites, conglomerates, and shales predominate. Mellor (1921) suggested that the Lower Division can be distinguished from the Upper Division by the presence of a larger number of shale and ferruginous horizons, a relatively subordinate development of conglomerates, and the presence of numerous quartzite bands less than 300 feet in thickness. Fuller (1958) found that, in the East Rand, the Orange Grove and Hospital Hill quartzites correspond to true ortho-quartzites, while the quartzites of the Government Reef and Jeppestown Series are sub-greywackes. In general, there is a progressive coarsening in the grain-size of arenaceous members of the Lower Division from the base upwards. Coarsening persists into the Upper Division, with the development of thicker and more numerous conglomerate bands, containing larger pebbles (Pretorius, 1964).

Since the present paper deals exclusively with the Lower Division, details of this assemblage only are given in Table 2.

Series	Horizon	Thickness (ft.)
Jeppestown Series 3,700 ft.	Shales	450
	Quartzite	200
	Shales	350
	Quartzite	150
	Shales	200
	Quartzite	350
	Shales	450
	Quartzite	450
	Shales	350
	Quartzite	200
	Shales	550
Government Reef Series 6,300 ft.	Upper Government Quartzites	480
	Shales	110
	Quartzites	500
	Government Reef	1
	Government Reef Shales	450
	Lower Government Quartzites	300
	Shales	480
	Coronation Quartzite	600
	Coronation Reef	3
	Coronation (West Rand) Shales	600
	Lower Coronation Quartzite	825
	Shales	100
	Quartzite	300
	Shales	100
	Promise Quartzites	800
	Promise Reef	1
	Quartzite	250
	Shale	400
Hospital Hill Series 4,900 ft.	Quartzites	300
	Shales	100
	Quartzites	450
	Shales	400
	Hospital Hill Quartzites	600
	Hospital Hill Shales and Contorted Bed	700
	Speckled Bed	5
	Red Shales	750
	Ripple-marked Quartzites	25
	Water Tower Slates	800
	Quartzites	220
	Shales	150
	Orange Grove Quartzites	400

Table 2 : Detailed Stratigraphic Succession of the Lower Division of the Witwatersrand System in the Central Rand Area (after Pretorius, 1964).

C. PREVIOUS WORK

A great volume of literature exists on the Witwatersrand System, but very few attempts have been directed towards determining the significance and genesis of structural geological features. The more notable contributions in the latter respect have been by Brock (1950, 1954, 1961), and Brock and Pretorius (1964a, 1964b), on a regional scale, and by Threader (1963) and Olivier (1965), on the scale of individual gold mines.

Regarding structural investigation of the West Rand Syncline, several important contributions have been made. The first comprehensive account was given by Mellor (1913), after having completed an exceptionally thorough map of the area. His prime objective was the delineation of the overall synclinal nature of the structure, and the location of major faults, e.g. Witpoortjie, Saxon, Rietfontein, West Rand, etc. He also established the presence of folding in the Government Reef horizon to the north of Krugersdorp. In 1917, Mellor described the synclinal structure of the Witwatersrand System in and around the Krugersdorp area. He suggested that the outcrop shape of the Lower Witwatersrand rocks was related to the immediately adjacent granite outcrops. The syncline was thus "projected between" two large masses of granite. Great emphasis was again given to the large faults.

Pegg (1950) dealt essentially with the Upper Division in the West Rand Syncline. The data were gathered from underground workings. A sequence of events was described by him as beginning with the deposition of the Witwatersrand sediments. This was followed by a period of deformation in which the West Rand Syncline was formed. Later deformation gave rise to the Witpoortjie and associated faults. Although a systematic pattern of faults was shown to cover the whole area, no rigorous attempt was made to analyse the data.

Brock and Pretorius (1964a) referred to the West Rand Syncline as the "West Rand Triangle". It was suggested that this was an "angular depression of an early age between two massifs", and that it belonged to one of their primary features of basining, i.e. a "transgressive overlap which is in fact a subsidiary basin". The same authors (Brock and Pretorius, 1964b) developed a genetic model for basin-type deposition, as revealed by the Witwatersrand. The structure of the Witwatersrand Basin, was, to a large extent, determined by a grid pattern derived from the intersection of axial-plane trace lines of major folds giving rise to culminations and depressions arranged in a systematic manner. The major trend was east-northeast, while the dominant transverse trend was northwest. Folding was considered to be a result of movement of blocks, generally fault-bounded, which occur within, or on the margins of, the basin. This fault pattern was probably related to the grid pattern of folding described above. An intimate relationship between folding and faulting was suggested by these authors.

Toens and Griffiths (1964) studied the Upper Division of the Witwatersrand System in the West Rand Syncline, and proposed the following sequence of tectonic events:

- (i) gentle folding of strata resulting in two synclines which have a direction of plunge at right angles to each other, i.e. refolding of an existing syncline;
- (ii) accentuation of folding caused by increased pressure from the west, resulting in a certain amount of reverse faulting;
- (iii) formation of Witpoortjie and associated faults;
- (iv) accentuation of pre-existing folding due to compression from the east; bending of the Witpoortjie fault; and
- (v) development of faults at right-angles to faults of Witpoortjie age.

The Witpoortjie fault which is referred to frequently is the curved fault shown in Figure 1, occurring to the east of Randfontein and to the south of Krugersdorp.

D. OBJECTIVES OF THE PRESENT INVESTIGATION

Over a period of nine years, between 1960 and 1968, the Economic Geology Research Unit of the University of the Witwatersrand has been involved in a program of geological studies and detailed mapping of both intercratonic geosynclinal and intracratonic basin environments in the Kaapvaal crustal fragment of South Africa. Structural analysis incorporating the use of minor structures has been particularly successful in unravelling geological and tectonic problems in the geosynclinal environments, especially where metamorphic rocks have been developed. In contrast, minor structures are not developed to a similar extent in the cratonic environment. In general, penetrative structures, such as lineations and cleavage, have not formed in such areas, so that other diagnostic structures have to be sought which can be used to decipher the deformational history. Fractures, of various types, are by far the most common type of structure found in cratonic basin areas, being the predominant response to applied stresses.

Unfortunately, the analysis of fracture patterns is fraught with difficulty because:

(i) the generation of fractures in rock, particularly on a geological scale, is not fully understood;

(ii) no objective criteria exist for the classification of each fracture encountered; (it is extremely difficult to define exactly the nature and movement direction, if any, by mere inspection of a fracture in the field);

(iii) classification of fractures on geometric similarity alone is non-definitive; (several genetically different fractures can have the same orientation); and

(iv) in many instances, the fracture itself cannot be observed, only indirectly inferred from systematic displacement of rock units; (such data are two-dimensional).

The present investigation is an attempt to analyse the tectonics of a cratonic basin area, using only information that can be gathered in the field. The most important parameters that could be measured were bedding plane orientations, fractures, and cleavages in some shale horizons. Since the abundant fractures must give some clue to the deformational history of the area, these received particular attention. The work was thus largely directed towards the analysis of fracture patterns, particular attention being paid to the nature of secondary fractures associated with primary faults.

The field study was started in March, 1966, and completed in February, 1968. Several thousand structural geological observations were made. Mapping was carried out on a scale of 1:12,000, and the geological data transferred on to a base map of the same scale. The final geological maps were also prepared on the same scale, but, because of their large size, only generalizations and portions of these maps are presented in this paper.

STRATIGRAPHY OF THE LOWER DIVISION OF THE WITWATERSRAND SYSTEM IN THE WEST RAND SYNCLINE

The stratigraphic succession determined during the course of mapping the area is essentially the same as that described by Mellor (1917). Because of the difficulty of distinguishing between the various quartzite horizons, no attempt has been made to depict the boundaries of the major stratigraphic units on the maps of Figures 2 and 3. The type-section of the stratigraphic column in the Krugersdorp—Florida Hills area is shown in

Figure 4. The difference between the classification employed in Figure 4 and that given in Table 2 is that the Hospital Hill Quartzites have not been identified in the sequence of dominantly arenaceous members below the Government Reef conglomerate.

Referring to Figure 4, the following succession has been determined in the field:

A — A dominantly arenaceous sequence made up of at least four major quartzite bands. Thickness : 410 feet. Referred to as the Orange Grove Quartzites. Some of the quartzites are exceptionally pure, consisting almost entirely of silica. The first shale band is also characteristic, having a typical bluish-black colour, and often revealing a good cleavage.

B — This is essentially an argillaceous member, with several distinctive markers. Total thickness : 3,700 feet. A great deal of confusion exists as to what these beds should be called, largely because of the difference in terminology and classification used by Mellor (1913, 1917). The following names have been used for various parts of B: Parktown Beds, Red Shales, Water Tower Slates, Hospital Hill Slates. Further confusion is caused by the occurrence of slates in broad zones adjacent to faults, irrespective of the stratigraphic position of the particular shale band. As a whole these rocks weather to reddish shales which, at certain localities, are well cleaved. Certain characteristic markers are present in this dominantly argillaceous sequence, viz.:

B1 — The Orange Grove Quartzites do not end abruptly upwards. There is a gradual transition to shale through an alternating sequence of thinly-bedded quartzites and shales, the quartzites becoming less numerous and diminishing in thickness. A cycle of arenaceous sedimentation thus gives way to one of argillaceous sedimentation over a zone of transition.

B2 — This band of dark-brown to black ferruginous shale generally forms a conspicuous outcrop that serves as a useful marker in field mapping. Thickness : 10-20 feet. Referred to as the Magnetic Marker in the Water Tower Slates, the latter term having been used by Mellor (1913) to classify the succession between the Orange Grove Quartzites and the Ripple-Marked Quartzite. Adjacent to the Magnetic Marker, beds of fine-grained ferruginous quartzite and brownish-black shale are present.

B3 — At several localities, a quartzite band 3-5 feet thick occurs just above the Magnetic Marker.

B4 — A hard quartzite band, up to 20 feet in thickness, forms a persistent outcrop. Mellor (1913, 1917) referred to this as the Ripple-Marked Quartzite, as it often reveals this structure.

B5 —Another quartzite band, some 5 feet in thickness, forms fairly persistent outcrops. Called the Speckled Bed by Mellor (1917), due to a somewhat mottled texture.

B6 — A quartzite band often exposed on the erosional scarp of the next marker, B7. It is 3-5 feet in thickness.

B7 — This is one of the most conspicuous markers in the dominantly argillaceous sequence. It consists of banded ferruginous chert which is frequently highly contorted, and thus called the Contorted Bed by Mellor (1921). Its thickness cannot be accurately obtained because of folding. The folded zone is approximately 20-30 feet wide. The banded ferruginous chert is associated with massive black ferruginous shales and fine-grained ferruginous quartzites.

In the shales immediately below the overlying group of quartzites is a magnetic shale band 10-20 feet thick. It is not always exposed, and thus does not serve as a useful marker. Often, pitted solution cavities, 1-5 inches in diameter, characterize this rock. This magnetic shale band occurs 100-200 feet below the overlying massive quartzite horizon.

C — The uppermost group of rocks in the stratigraphic column relevant to this paper extends from the argillaceous group B to the Government Reef Conglomerate. This group of rocks has a thickness of approximately 4,000 feet, and consists of an alternation of shales (often cleaved in places) and quartzites which locally are gritty and contain pebble bands. This dominantly arenaceous sequence was split by Mellor (1913) into the lower three major quartzite bands, included in the Hospital Hill Series, and the upper sediments belonging to the Government Reef Series. This breakdown does not appear acceptable in that the entire group of dominantly arenaceous sediments belongs to a new cycle of sedimentation following after the deposition of the dominantly argillaceous sequence below.

Several other horizons, not shown in Figure 4 are of importance. Black ferruginous shale bands are among these. One such horizon occurs in the shale band immediately above the second quartzite band above the base. Another occurs in the shales above the fourth quartzite band, while yet a third is present in the shales immediately below the Government Reef. All these horizons are strongly magnetic.

A significant horizon, occurring in this dominantly arenaceous group, is a tilloid band which is 50-200 feet in thickness. It has been found at two different localities only in the map areas, and its exact stratigraphic position cannot be fixed because of complex faulting at the one loaclity and poor outcrop at the other. A tentative stratigraphic position for the tilloid band is within the shale sequence above the fourth or fifth quartzite above the base. The tilloid has a reddish-weathering quartzitic matrix in which occur widely disseminated rounded pebbles of varying size. Large fragments of quartzite, up to several feet in size, occur in this matrix, giving the horizon its conspicuous character. Erosion channels within the tilloid are filled with cleaner reworked matrix material, and show a higher concentration of pebbles. Another type of reworking is associated with a concentration of pebbles, resulting in a poorly-developed conglomerate band. Such a rock-type may be of significance when considering the genesis of rocks belonging to the Witwatersrand System. It could have been the parent-rock of conglomerates, quartzites, and shales which differentiated out in the depository upon in situ reworking of the tilloid material. In order to avoid any controversy, the non-genetic term "tilloid" has been used in this paper.

STRUCTURAL GEOLOGY

In the course of mapping, it soon became evident that fracturing was the most significant mode of failure of the rocks. The word "fracture" is used here to embrace any distinct surface of loss of cohesion in the rock-pile. It includes both faulted surfaces, along which there has been undoubted displacement, and tensional breaks, along which there has been no movement. The reason for introducing this particular meaning to the term is that it is often not possible in the field to examine a fracture and state exactly what type it is.

The various structural geological parameters that could be measured fairly consistently over both map areas were bedding planes and fracture surfaces. Cleavage, although developed, is confined to the Krugersdorp—Florida Hills area. In order to simplify the description of the structural geology, the two map areas have been subdivided into sub-areas (Figures 2 and 3). The basis of the subdivision has been somewhat subjective, attempts being made to delineate smaller areas which display a particular structural geological feature, such as a fault, a particular family of faults, or a fold.

A. BEDDING PLANE DATA

(a) Tarlton-Bank Area

In Sub-area 1, a large right-lateral fault occurs (Figure 2). As the fault is approached, the bedding planes are distinctly rotated. From a normal average strike of 045° (true bearing) and dip of 25°-30° to the southeast, the beds swing around and parallel the fault which strikes at 135°. This systematic rotation of bedding planes, as the fault is approached, is shown in Figure 5. Here the pi-pole plot of the bedding plane poles defines a fold, the axis of which plunges to the east (083°) at 20°. The great circle containing the bedding plane poles has an azimuth direction of 173°, and dips at 70° to the west. This is a first example of the intimate relationship between folding and faulting in the investigated areas.

Sub-area 2 is characterized by the presence of at least two major open folds, one of which is shown in Figure 6. The axial-plane trace of these folds trends at 120°, while the fault of Sub-area 1 had a trend of 135°. The bedding plane pole plots for Sub-area 2 show a cluster of points with a weak scatter in a north-south direction (Figure 5). If a great circle is fitted to these data, it has an azimuth of 183°, and a dip of 70° to the west. These combined data show similar characteristics to Sub-area 1, and suggest that the same stresses produced the geometrical similarity. Sub-area 1 may have failed by fracturing and folding, while Sub-area 2 was folded only.

Sub-areas 3, 4, and 6 show virtually identical characteristics, as regard bedding plane orientations (Figure 5). The average bedding plane orientation determined in these areas is : strike 035°, dip 35° to the southeast. This can be taken as the average regional orientation for the Tarlton-Bank area.

A synclinal structure is indicated by the outcrop pattern of Sub-area 5 (Figure 2). The folding is clearly related to a fault that trends at 065°, and which displays a distinct left-lateral component in plan. The bedding plane data (Figure 5) for this sub-area show rotation on to a small circle, which means that the fold has a conical shape and plunges towards the east. A conical shape such as this can be caused by unequal, or differential, displacements along a wrench fault.

Distinct signs of folding can be detected in Sub-area 7 (Figure 2). Furthermore, the lowermost succession of Witwatersrand rocks is repeated by faulting, the fault plane itself having been folded with the sediments. The bedding plane data for this area are shown in Figure 5, and define a fold with an axis plunging to the south (204°) at an angle of 15°. The great circle for this fold has an orientation of : strike 114°, dip 75° to the north. Folds with this geometry have not been found in any of the other sub-areas, indicating that the stresses required to produce these folds must have been decidedly restricted in their distribution.

Bedding plane plots from Sub-area 8 are few, but suggest that the area is somewhat inhomogeneous with respect to fold types (Figure 5). A possible reason for this complexity of bedding plane orientation is the presence of a zone of intensive faulting in the northwestern part of the sub-area.

(b) Krugersdorp-Florida Hills Area

As can be seen from the plot of bedding plane poles, Sub-area 9 is homogeneous with respect to bedding plane orientations (Figure 7). The single maximum of the diagram indicates that bedding planes have a uniform orientation of : strike 115°, dip 30° to the southwest. In the detailed map of Sub-area 9 (Figure 8), a fold can be seen to occur in the northernmost arenaceous group, i.e. the Orange Grove Quartzites. This fold is related to a fault that has a strike of 127° and forms the southern limit of the fold. As the fault is approached, the beds change their orientation and the strike swings around to a north-south direction. The fold axis plunges to the northwest at a flattish angle, once again illustrating the intimate relationship of folding and faulting.

The detailed geology of Sub-area 10 is best seen in Figure 8. In spite of complex faulting, distinct folds can be identified next to the prominent northwest-trending fault in the central part of the sub-area. It will be shown later that the folding did not result from drag on a left-lateral wrench fault, but that faulting took place after the development of the fold. Figure 7 gives an indication of the nature of these folds. A distinct pi-pole girdle defines folds plunging to the southwest (210°) at a steep angle of 74°. Several other bedding planes near the centre of the diagram are similar to the population observed in Sub-area 9. In general, however, it is apparent, from a comparison of the bedding plane data from Sub-areas 9 and 10, that the bedding planes of Sub-area 10 have a steeper orientation. In spite of the folding, the poles of these beds lie closer to the periphery of the stereographic projection (Figure 7). The change in orientation is due to the presence of a fault trending at 120°, that separates the two sub-areas. This is one of the fundamental fault trends of the Krugersdorp-Florida Hills area. From this particular example, it can be seen that bedding plane data can be useful in defining the presence of fundamental faults in a basin-type structural environment.

There is a distinct open fold in Sub-area 11 (Figures 3 and 7). The plot of the bedding plane poles reveals a single maximum defining an average bedding orientation of : strike 106°, dip 20° to the south (Figure 7). These data also differ from those of previous sub-areas, and, here again, major faults separate this group of virtually homogeneous bedding plane orientations from groups of other areas (Figure 3). Because the fold which occurs in this area is open, there is very little angular spread of the bedding poles, when plotted on a stereographic projection. However, fitting a great circle to this restricted data defines a horizontal fold axis that strikes at 103°. This approximate direction is given because it differs from the regional fault-fold trend of the Krugersdorp-Florida Hills area by approximately 20°. The folding may, therefore, be related to the major fault separating Sub-area 10 from those sub-areas to the north. The bedding plane data are not sufficiently precise to prove or disprove this relationship.

The pi-pole plot of the bedding planes in Sub-area 12 gives a marked concentration of points about which there is considerable scatter (Figure 7). From these data, the average orientation of bedding planes is : strike 114°, dip 15° to the south. As shown in Figure 8, there are several fold closures in the area, but the folding is not systematic. This is indicated by the bedding plane poles which do not clearly define any particular great circle. Various fold axis orientations were measured in the field, but there are too few data, widely dispersed over the stereogram, to permit interpretation. However, it can be concluded that cross-folding is present in the area.

The bedding plane data from Sub-area 13 are somewhat scattered, but two distinct trends may be present, viz. a great circle trending in a northwesterly direction, parallel to that defined in Sub-area 10, and a north-northeast-trending great circle (Figure 7).

Approximate positions of great circles which fit these two trends are : strike 013°, dip 76° east; and strike 143°, dip 15° north, respectively. These orientations are similar to those obtained for Sub-areas 10 and 11, which were, respectively : strike 013°, dip vertical, and strike 120°, dip 16° north. With the open type of folding found in the area, it was not possible to obtain a better correlation. The confinement of the bedding plane poles to the outer portion of the stereographic projection again clearly indicates steeper dips than those obtained for Sub-areas 9, 11, and 12. Although no fault could be identified in the field between Sub-areas 12 and 13, the difference between bedding plane orientations in these two areas indicates a break. Furthermore, the Contorted Bed in Sub-area 13 points to faulting having taken place. The projection of the fault zone trending at 120° from Sub-areas 9 and 10 into Sub-area 13 would satisfy the data. Within this sub-area, several minor folds are developed which have a fairly consistent axial planar trend, viz. strike 030°, dip 69° to the east-southeast. This attitude does not compare with any of the other trends determined so far. It does, however, indicate a compressive σ_1 in the 120° direction, which is parallel to the major fault trend described above.

Sub-area 14 shows a remarkably uniform orientation of bedding planes, in spite of the fact that several large faults are present (Figures 3 and 7). The average orientation of the bedding is : strike 118°, dip 68° to the southwest. There may be a tendency for the beds to be rotated into folds which have geometrical characteristics similar to those developed in Sub-area 10. This is suggested by the spread of pi-poles on a great circle having the same orientation as that of Sub-area 10.

Plots of the bedding plane poles for Sub-area 15 define a single maximum, with a weak spread on a great circle which has a northeast trend (Figure 7). The average orientation of the bedding is : strike 116°, dip 45° to the southwest. The great circle, which fits the weak northeast scatter of points, has a strike of 035° and is vertical. The only noticeable folding in this sub-area is immediately next to the curved fault marking the lower southeastern boundary of Sub-area 15. In the southeastern part of the area, near the outcrop of the Contorted Bed, is a small fault-bounded syncline of rocks belonging to the upper, dominantly arenaceous, group of sediments. Shale horizons, immediately adjacent to the westward continuation of the first-mentioned fault, also show distinct signs of folding. These observations again confirm the intimate relationship of folding and faulting. From the combined bedding plane data of Sub-areas 14 and 15, it is apparent that faulting separates two domains of differing bedding plane orientation. Both areas are rather homogeneous with respect to bedding plane orientations, but the northern area has a flatter dip than the area to the south of the postulated fault.

Sub-area 16 shows a fairly uniform orientation of bedding planes, the average being : strike 133°, dip 50° to the southwest (Figures 3 and 7).

The bedding plane poles from Sub-area 17 show a wide scatter (Figure 7). A maximum defines a common orientation of : strike 126°, dip 60° to the southwest. The departure of points from this average orientation, giving rise to the scatter of Figure 7, is due to two factors, viz. strong folding of sediments immediately adjacent to the faults, and the presence of several large regional faults, plus smaller faults which divide the area into smaller units having differing orientations (Figures 3 and 9).

In the southwestern part of Sub-area 18, there are distinct indications of folding (Figure 10). This is revealed by the flat orientations of bedding planes, and by the change in strike of the Government Reef Conglomerate. Intensive faulting complicates the picture. However, the plot of the bedding plane data is surprisingly systematic, the poles being distributed fairly well on a great circle (Figure 7). The pi-pole plot defines a fold axis which plunges to the west-northwest (308°) at an angle of 15°. The great circle has a strike of 38° and a dip of 75° towards the east-southeast. Indications of similarly oriented fold trends have been found in Sub-areas 10, 11, 13, and 15. It is important to note that this fold trend is parallel to a postulated major fault trend, separating areas to the north, with flatter dips, from areas to the south, with steeper dips. The maximum of the pi-pole plot defines the average orientation of beds occurring in the northern part of the sub-area, which are unaffected by the folding. This average is : strike 130°, dip 56° to the south-west (Figures 7 and 10).

Figure 3 shows that Sub-area 19 is located more or less in the hinge zone of a fold. Faulting could, therefore, be expected to be rather complex. Examination of the bedding plane data reveals considerable scatter, pointing to considerable variation in the orientation of these planes (Figure 7). The average orientation is : strike 118°, dip 35° towards the south, confirming that there is still a tendency for shallower dips in the lowest part of the succession.

Sub-area 20 was chosen on the assumption that it might show the most complete rotation of bedding planes, since it is the best exposed portion of the West Rand Syncline. The bedding plane data are complex, due to the presence of other folds, such as the closed synclinal structure of Government Reef in Figure 11, occurring immediately west of Munsieville Location. The fact that the area is strongly faulted adds to the complexity of the bedding plane data. Figure 7 shows how complex the data really area. The first point to be noted is that a maximum of the pi-pole plot defines an average orientation that is flatter for this group of rocks than for any of the other sub-areas. The synclinal structure found in the Government Reef can explain this. The maximum of pi-pole plots defines an average orientation of : strike east-west, dip 30° to the south. Two great circles can be fitted to pi-pole plots, one having a north-northeast trend (strike 015°, dip vertical) and the other a west-northwest trend (strike 113°, dip 60° to the north). The former defines a fold axis which is horizontal and trends at 105°, which is parallel to the large fault responsible for the repetition of the Government Reef in this sub-area (Figures 3 and 10). This fault, which has an upthrow to the south, provides further evidence of the intimate relationship between folding and faulting, the synclinal structure to the north of the fault being directly related to the fault movement. The latter great circle defines the fold axis of the West Rand Syncline, that plunges to the south-southwest (203°) at 30°. The wide scatter of points about the great circle defining this fold axis is caused by complex faulting and later folds which deform the western limb of the fold, and which appear to belong to a conjugate set of folds.

(c) Significance of the Bedding Plane Data

The data have so far shown that a very intimate relationship exists between faulting and folding. Not only do folds form adjacent to faults, but the strikes of the fold axes are generally parallel to those of the faults. Since these structures are strike faults (or only slightly transgressive to the bedding) and since the movements on the faults are essentially of a reverse nature, it might be expected that the downthrown block would be deformed into a synclinal structure, close to the fault plane. This requires the downthrown block to have bedding planes oriented in such a way that they dip into the fault plane. At least two good examples affirm this relationship, viz. the fault trending at 120° in the eastern part, and the 105°-trending fault in the western part of the Krugersdorp-Florida Hills area. With respect to the former fault, several minor folds were found in Sub-area 13 which pointed to a major compressive stress oriented in the direction of strike of the fault. This conclusion is supported by the geometry of conjugate folds occurring in the fault zone (see below).

In other respects, bedding plane data have not been of particular use in the analysis of folds. This is largely a result of the shape of the type of fold developed in this area. The generally open folds are not amenable to satisfactory treatment on a stereographic projection. It has been shown, however, that bedding plane orientations can assist in determining the presence of faults, because the fault planes frequently separate domains in which the average attitude of the bedding planes differs. In the domains themselves, there can be a high degree of consistency in orientation.

Since the present work has been directed towards a study of the West Rand Syncline as a whole, Figure 12 was constructed to contain all the bedding plane maxima from the various sub-areas that do not reveal complex folding. From the outcrop pattern of the West Rand Syncline in Figure 1, it could be anticipated that the combined bedding plane data from the two map areas would simply define the macro-fold geometry. Figure 12 shows that a simple, coherent, synclinal structure is not, in fact, present. The maxima for the Krugersdorp-Florida Hills area fall on a great circle, while the maxima for the Tarlton-Bank area form a small cluster, which does not lie on this great circle. In other words, the Tarlton-Bank limb does not belong to the fold pattern developed in the Krugersdorp-Florida Hills area. This is a result of two factors:

(i) A major fault separates the two areas. This fault was identified by Mellor (1913), and named the West Rand Fault (Figure 1); and

(ii) The great circle that fits the bedding plane maxima for the Krugersdorp-Florida Hills area defines a horizontal fold axis which strikes at 117°. As pointed out above, this direction is virtually the same as that of a fundamental fault direction, viz. 120°. All that the regional bedding plane data reveal is a very strong parallel geometrical relationship between the axis of regional folding and the strike of a fundamental fault.

The geometry of the West Rand Syncline is thus not uniquely indicated by Figure 12. A rough estimate of the fold axis trend of the Syncline was determined as having a plunge of 30° to the south-southwest (203°). This compares fairly favourably with the orientation of the fold axis determined by Steyn (1963), from bedding plane measurements made underground on rocks belonging to the Upper Division of the Witwatersrand System. He established that the fold axis plunged to the south (186°) at 22°. The absolute angular difference between the two sets of data, as determined from the stereonet, is 18° which is not unacceptably large. Both sets of data give a good indication as to the geometrical attitude of the fold axis of this syncline.

B. CLEAVAGE DATA

(a) Cleavage Related to Faults

Possibly, the most spectacular development of cleavage in a fault zone is found in Sub-area 10. The northwest-trending fault, adjacent to which there are distinct signs of folding, has developed in it an excellent cleavage, as well as minor folds. Details of some of these structures are shown in Figure 13. The cleavage affects the quartzites, as well as the shales. Outside of the fault zone, a cleavage may be present in the shales. The width of the fault zone is 200-400 feet. The cleavage has an east-west orientation, and the fault itself strikes at 133°. The cleavage is steeply dipping.

Adjacent to the fault marking the lower boundary of Sub-area 15, cleavage is strongly developed in the shales. This cleavage again has an east-west orientation (Figure 3). Further away from the fault, the strong cleavage is no longer developed.

Near the southern edge of Sub-area 19, where the Contorted Bed shows fracturing by east-west faults, well-developed cleavages occur in the shales. These cleavages also have an east-west trend, and dip fairly steeply towards the south. It is not known whether these cleavages are shear fabrics parallel to the fault planes, or whether they are related to a regional stress pattern (Figure 10).

(b) Other Cleavages

Throughout the Krugersdorp-Florida Hills area, cleavage is developed in certain of the shale horizons, particularly in those occurring in the dominantly arenaceous sequence of Sub-area 14. No significant cleavages were found in the Tarlton-Bank area, but this may be due to the very poor exposure of shale in the area. A stereographic plot of all the cleavage plane poles from the Krugersdorp-Florida Hills area is shown in Figure 14. The cleavage has a fairly constant orientation over the whole area. In Sub-area 20, where there is a distinct change in strike of the bedding plane orientation of the western limb, as compared with the eastern limb of the fold, the cleavage still has an east-west trend. In other words, it has not been folded with the bedding planes, and was superimposed on the already bent synclinal structure. The single maximum of Figure 14 suggests the same conclusion.

The cleavage pole plot defines an average orientation of : strike 099°, dip 69° to the south. The major compressive stress producing this cleavage would have been oriented at right-angles to this plane, i.e. it would have had an azimuth of 189° and a plunge of 21° to the north. These data are almost identical to those reported by the author from a study of en-echelon crack arrays in the same area (Roering, 1967). An azimuthal value of 183° was obtained from that study for the orientation of the principal compressive stress. The analysis was based on two-dimensional data only. If the data from the two investigations are combined, it is clear that a north-south stress was dominantly active in the area. Furthermore, this stress was superimposed on the already buckled synclinal West Rand structure.

The previous interpretation by Roering (1967) that this stress could be related to second-order principal stresses, as described by Moody and Hill (1956), adjacent to wrench faults would now appear to be incorrect. Detailed work on the faulting (see below) shows that the Moody-Hill wrench fault pattern cannot be applied to the area. This means that some other mechanism of stress distribution has to be sought.

The maximum of the cleavage plane poles has been plotted in Figure 12, together with the bedding plane maxima. Since the cleavage pole does not lie on the great circle derived from the bedding plane maxima for the Krugersdorp-Florida Hills area, it cannot be related to this folding. Also, since the fold axis that was established for the West Rand Syncline as plunging to the south-southwest at 20° cannot lie near the average cleavage plane trace, the cleavage is not related to the period of folding which produced the West Rand Syncline.

C. CONJUGATE FOLD DATA

Conjugate folding is very strongly developed immediately adjacent to the 120°-trending fault that separates Sub-areas 9 and 10 (Figure 8). Data from this fault zone are consistent in that the monoclinally-shaped folds, representing one of the set of conjugate shear planes, have essentially the same orientation, and show the same relative direction of movement. Plots of the poles of the two sets of axial planes from these conjugate folds are presented in Figure 15. The orientation of the principal stress system which produced these folds is also shown in this figure, where σ_1 lies in the 121° direction and is virtually horizontal, plunging to the west-northwest at 6°. This direction is the same as the strike of the fault, viz. 120°. In other words, σ_1 lies in the plane of the fault, and is virtually horizontal. Had there been readjusted stresses of second-order type, as described by Moody and Hill (1956), σ_1 would then have made an angle of 75° with the fault plane. This means that either the Moody-Hill wrench fault pattern is incorrect, or that it is not applicable to this particular area.

Occurring over the whole of the Krugersdorp-Florida Hills area, are numerous left-lateral monoclinal-shaped folds. These folds are distinct from the conjugate folds described above, although they appear to be related to a stress field of similar orientation. Data from these folds are recorded in Table 3, where E. and W. refer to the direction of dip of the axial plane.

Strike	Dip	Strike	Dip
160°	70°E	163°	71°E
172°	90°	165°	72°E
010°	87°W	164°	90°
010°	90°	158°	90°
165°	90°	006°	90°
010°	81°W	000°	85°E
002°	88°W	169°	78°E
155°	90°	015°	78°W
010°	90°	177°	68°W
178°	76°W	160°	75°E
173°	90°	003°	90°
172°	90°		
167°	52°E	Mean strike : 174°	
010°	79°W	Standard deviation : 12°	

Table 3 : Orientation of Axial Planes of Left-lateral Monoclinal-shaped Folds from the Krugersdorp-Florida Hills Area.

Since these data are identical with those of the left-lateral set of folds found in the fault zone, this would tend to indicate a regional stress similar to that of Figure 15.

The orientation of the stress field is related to the orientation of the fault in Sub-areas 9 and 10. Therefore, if this stress is regional, then it must be the product of a regional fault, or zone of faults, that trend in the 120° direction. Such a fault zone has already been postulated to accommodate the bedding plane data. The relationship of this stress field to the fault zone is one of the most important criteria used in the interpretation of the tectonics of the area.

D. INJECTIVE SHALE DATA

At a number of localities in the Krugersdorp-Florida Hills area, transverse shale "dykes" penetrate quartzite horizons. These have been observed in both the lower and upper arenaceous groups of Figures 2 and 3. The injective shales cut through quartzite bands which are at least 100 feet thick. A very complex fabric is often present in the shales. A "cleavage", commonly parallel to the walls of the "dyke", is frequently developed, and this follows the shapes of minor irregularities in the side-walls. The "cleavage" is thus similar to flow-lines of extruded viscous material. Individual "cleavage" planes are well slicken-sided, where one unit has moved past another. Quartz veining may sometimes accompany these injective shales. In general, the thickness of these "dykes" varies from 6 inches to 10 feet.

Unfortunately, this phenomenon has been observed at six different localities only in the area, and it cannot be said whether there is a particular tendency for these structures to occur in any specific section of the West Rand Syncline.

These "dyke" structures appear to represent a macro-boudinage type of phenomenon. The competent quartzites must have been extended more or less in the plane of the bedding, before fracturing. Then, in a plane normal to this, the ductile shales flowed into the fractured zone. At some time in the evolution of the area the rocks must have been subjected to tensile stresses, acting in the plane of the bedding.

E. MACRO-FRACTURE DATA

(a) Conjugate Pairs of Fractures

Within both map areas, there occur good examples of two simultaneously-developed conjugate fractures that displace the rocks systematically on either side of each fault (Figures 2, 3, 6, 8, and 9). In the Tarlton-Bank area, such structures are more common in Sub-areas 3 and 4. In the latter, it is apparent that the orientation of σ_1, producing the conjugate faults, is aligned parallel to the strike of the bedding. The Krugersdorp-Florida Hills area reveals at least four such structures, one in each of Sub-areas 15 and 17, and two in Sub-area 19. On a broad scale, it can be seen that σ_1 for all these conjugated structures lies virtually parallel to the bedding. This is particularly apparent in Sub-area 19, where there is a definite change in the strike of the bedding of the Orange Grove Quartzites, and also a change in the strike of the conjugate faults.

Concerning the origin of the conjugate faults, all that is known is that the stresses which produced them are oriented approximately parallel to the strike of the bedding in both mapped areas. This does not imply that stress was transmitted to the competent members of the stratigraphic succession during a period of buckling. The conjugate faults are, themselves, steeply-dipping. This means that the line of intersection of the faults (i.e. the intermediate principal stress direction) must also be steeply-dipping. Since some of the areas where these conjugated faults occur, e.g. Sub-area 4 of the Tarlton-Bank area, have shallow dips, the intermediate principal stress is independent of the attitude of the bedding. Therefore, the stresses could not have been transmitted by the competent layers. The occurrence of conjugated faults in both areas indicates that the whole of the outer limb of the West Rand Syncline was subjected to compression, and must have been shortened. It appears unlikely that the syncline is a simple fold structure, caused by buckling of more competent strata, since, under these conditions, tensional phenomena would be present in the Orange Grove Quartzites in the hinge zone of the fold. Tensional phenomena are indicated by the injective shales, but these structures are certainly not confined to the hinge of the fold.

Apart from the evidence of compression in the outer arc of the fold, the conjugate faults provide only limited information about the genesis of the fold structure, as the argument can be advanced that they were formed prior to the folding.

(b) Other Types of Fractures in the Tarlton-Bank Area

When the azimuths of fractures from the Tarlton-Bank area are plotted on a rose diagram, five distinct maxima are evident (Figure 16). Proceeding in a clockwise direction, these occur at azimuths of 005°, 044°, 072°, 122°, and 145°. The 072° and 122° maxima occur in a spread, which may be due to one or more separate populations being present.

During the course of mapping, certain horizontal displacements could be determined on some of the macro-fractures. This direction of movement need not necessarily be the true component, and might represent only an apparent movement in plan. However, in examining this component for various fracture orientations, it was found that fractures of approximately the same orientation show the same component of horizontal movement (Figure 2). The nature of the displacement associated with the different geometrical groups of fractures is given in Table 4.

Orientation	Apparent Horizontal Displacement
005°	Right-lateral
044°	Left-lateral
072°	Left-lateral
122°	Left-lateral
145°	Right-lateral

Table 4 : Orientation of Major Fracture Groups and the Apparent Direction of Horizontal Displacement in the Tarlton-Bank Area.

(c) Other Types of Fractures in the Krugersdorp-Florida Hills Area

1. Eastern Section (Sub-areas 9-15)

The frequency distribution of fractures in the eastern section shows numerous peaks (Figure 17). This is due to a larger number of observations and a smaller class interval (5° instead of 10°) than have been employed in other sections. The main peaks have been identified in Table 5.

Of significance in this section is the fault separating Sub-areas 9 and 10, which strikes at 120°. As pointed out previously, this fault gave rise to numerous conjugate folds immediately adjacent to it. The conjugate folds have their axial planes (planes of a shear couple) oriented at 073° and 172°. The former is right-lateral, while the latter is left-lateral. These orientations and direction of movement correspond with the large east-west-trending faults of Sub-areas 9 and 11, as well as with the north-south-trending faults of Sub-areas 11 and 12 (Figures 3 and 8). Thus, there are established faults with the same symmetry and the same sense of movement as the conjugate fold axial planes. The stress field producing the conjugate folds could also have produced several large faults similar to those depicted in Figures 3 and 7, in which case the second-order effects on the 120°-fault must have extended for a distance of at least 3,000 feet away from the fault plane. This is not considered excessive when the magnitude of some of the conjugate folds is examined. Two such large folds occur in Sub-area 10 (Figure 8). In the central part of this sub-area, immediately to the south of the Magnetic Marker, a fold occurs which appears to be related to differential movement on a northwest-trending fault. The axial plane and geometry of this fold suggest that it is identical to that of the north-south conjugate set shown in Figure 15. The diagonal northwest fault is probably related to the same stress which produced the fold, but post-dates the folding.

Orientation	Apparent Horizontal Displacement
004°	Left-lateral
017°	Probably left-lateral
044°	?
059°	?
084°	Right-lateral
097°	Probably right-lateral
109°	Right-lateral
132°	Right-lateral
163°	Left-lateral

Table 5 : Orientation of Major Fracture Groups and Apparent Horizontal Displacement in the Eastern Section of the Krugersdorp-Florida Hills Area.

In the eastern part of Sub-area 10, a broad quartzite band shows two distinct inflexions on its northern boundary. These inflexions are, in fact, large folds which have a right-lateral component of horizontal movement. The shales immediately to the east of the inflexions have an abundant development of minor folds which trend in the same direction as the larger fold in the quartzite. The axial planes of these minor folds are oriented east-west and have a vertical dip. Again, they can be related to the one group of conjugate folds found immediately adjacent to the fault trending in the 120° direction. The effects of the stress system, deduced in Figure 15, thus extend for a considerable distance from the major fault, giving rise to both large folds and faults up to a distance of at least 3,000 feet from the primary fault.

Another important genetic feature, related to the 120°-trending fault separating Sub-areas 9 and 10, is revealed at its northwestern extremity near the Contorted Bed. The fault cannot be followed westwards; it gives way to a series of east-west trending faults which, in some cases, have a right-lateral displacement. Furthermore, several thrust faults, having the same east-west trend, indicate that compression occurred at the fault extremity. The thrust faults show that the compressive force acted from the east, so that the eastern side was pushed on to, and over, the western side. This faulting is developed at the apparent tip of the 120°-fault, where stresses might have been built up to an appreciable magnitude, to give rise to second-order faults.

It was suggested, in the section dealing with the bedding plane data, that there is a zone of faulting, or a fault, that separates the northern, more flatly-dipping strata from the southern, more steeply-dipping strata. Such a fault would have its strike almost parallel to the strike of the bedding planes, and would be a reverse fault with an upthrow on the south. The fault separating Sub-areas 9 and 10, when projected westwards, can be followed, with interruptions, as far as, and into, Sub-area 17 (Figure 3). Parallel faults may separate the Contorted Bed outcrops of Sub-area 15 (Figure 3). Sub-areas 9 and 10 have provided evidence of a period of movement on the 120°-fault which required almost horizontal stresses, i.e. wrench fault movement. Faults of this type may, therefore, have a complex evolution, at one stage being essentially reverse faults, and at a later stage, subjected to horizontal stresses, behaving as wrench faults. An alternative explanation is that faults with the same geometry may have different origins. However, it would seem advisable to take recognition of the geometrical orientations of pre-existing fractures, and then consider how they behaved under superimposed stresses, i.e. to take recognition of the control of anisotropy on fault movements. Parallel faults of different origin (if they could form at all in the same restricted area) could be expected to behave in almost identical manner when subjected to a later stress field.

2. Central Section (Sub-areas 16-19)

The frequency distribution plot of fractures from this section reveals five distinct maxima (Figure 17). These are recorded in Table 6, together with their apparent horizontal displacements.

Orientation	Apparent Horizontal Displacement
008°	?
049°	?
084°	Right-lateral
104°	Right-lateral
126°	Right-lateral

Table 6 : Orientation of Major Fracture Groups and Apparent Horizontal Displacement in the Central Section of the Krugersdorp-Florida Hills Area.

Several conspicuous fracture arrangements can be seen in Sub-area 16 (Figure 3). Here, strike faults which have an orientation of 120°, and which have a right-lateral apparent horizontal displacement, are associated with east-west-trending right-lateral faults. This situation is similar to that in the eastern section, described above, and appears to be fundamental in the generation of fractures in the area. Several large faults occur in the southern part of Sub-area 17 (Figure 3). One of these, called the Rietfontein Fault by Mellor (1913), persists into Sub-area 20. These faults are oriented at 105°. At their eastern extremities, they join the 120°-trending faults. As was shown in the section dealing with the bedding plane data, these faults have a reverse movement, with an upthrow to the south.

The most striking feature of this central section is the systematic development of east-west fractures in Sub-area 18 (Figures 3 and 10). It is significant that these fractures lie on the line of continuation of the 120°-fault that can be traced from Sub-area 9 into Sub-area 17. The east-west fractures at the end of a large regional fracture (or zone of fractures) can be compared to the pattern of east-west fractures terminating the 120°-fault in Sub-area 10.

Within this central section, a dominant set of fractures in the 050° direction starts to become significant in Sub-area 18 (Figure 3). It is not possible to define the apparent nature of these faults, from the available data occurring in this section.

3. Western Section (Sub-areas 19 and 20)

In this section, there are five distinct trends of fractures, some of which have been discussed above (Figure 17 and Table 7).

Orientation	Apparent Horizontal Displacement
008°	?
038°	Right-lateral
057°	?
075°	Right-lateral
138°	?

Table 7 : Orientation of Major Fracture Groups and Apparent Horizontal Displacement in the Western Section of the Krugersdorp-Florida Hills Area.

Of importance in this section is the persistence of the east-west trend which is systematically developed in Sub-area 18, and the strong development of trends at 038° and 138°. The 038° trend appears to have a right-lateral component, as determined in Sub-area 19, where both the Orange Grove Quartzite and the Magnetic Marker show definite horizontal displacements (Figure 3). The Contorted Bed, to the north of Sub-area 18. has the same right-lateral sense of displacement on faults oriented in the 038° direction (Figures 3 and 10). The outcrop pattern of the Contorted Bed, near its western extremity in, and north of, Sub-area 20, suggests that the east-west fractures also have a right-lateral component (Figure 11), confirming information gathered from the other sections.

For the fractures oriented in the 138° direction, no systematic data are available to clearly indicate the nature of these faults and the displacement they have produced.

(d) Comparison of Fractures in the Two Mapped Areas

In order to obtain an idea of the correlation between the fracture systems occurring in the Tarlton-Bank Area and the Krugersdorp-Florida Hills Area, an attempt was made to determine discrete fracture trends for the region as a whole. The following procedure was adopted. Firstly, the modes were calculated for each maximum on the various azimuth frequency diagrams. It was not possible to objectively define each discrete population, so that the data used for calculating the modes were obtained by visual inspection of Figures 16 and 17. The class-group containing the maximum plus one class-group on either side, were used for determining the mode. If the maximum was spread over two or three class-groups, then a number of class-groups of equal magnitude was chosen on either side of the maximum to calculate the mode. The standard deviation about this mode was also determined in each case. The combined data for the West Rand Syncline, as a whole, are recorded in Table 8.

Krugersdorp-Florida Hills Area			Tarlton-Bank Area
Eastern Section	Central Section	Western Section	
004° (000°-007°)	008° (000°-015°)	008° (359°-017°)	005° (352°-018°)
017° (014°-020°)			
044° (040°-048°)	049° (042°-056°)	038° (032°-043°)	044° (039°-048°)
059° (055°-062°)		057° (050°-065°)	
084° (074°-095°)	084° (076°-091°)	075° (068°-082°)	072° (063°-082°)
097° (093°-100°)			
109° (105°-112°)	104° (097°-110°)		
132° (129°-136°)	126° (119°-133°)	138° (118°-157°)	122° (107°-137°)
163° (152°-173°)			

Table 8 : Modal Direction of Various Major Fracture Trends and the Scatter of One Standard Deviation about the Mode, for Different Areas of the West Rand Syncline (Standard Deviation in Brackets)

Examination of Table 8 shows a reasonable amount of correspondence between the orientation of the fractures for the different sections, and, of more importance, between the Tarlton-Bank Area and the Krugersdorp-Florida Hills Area. However, the degree of overlap is not immediately apparent, and Figure 18 has been constructed as a graphical representation of the data. Such a diagram may be of some use in defining discrete geometric populations of fracture data from areas similar to that described in this paper. It can be seen from Figure 18 that there are more maxima, with relatively smaller standard deviations, present in the eastern section of the Krugersdorp-Florida Hills Area. As pointed out earlier in the paper, this is due to there being more data available for the area, permitting a smaller class interval to be used for the frequency diagrams (Figure 17). In the other sections, where there are less data, two or more populations may be included in what appears to be a single maximum. This is apparently what has happened in the case of the fractures that have been classified as belonging to the 010° category (Figure 18). In this particular group, two distinct families of fractures are present in the eastern section of the Krugersdorp-Florida Hills Area. In the other sections, there is apparently only one group of fractures within this class. A similar interference occurs around the 40°-60° group of fractures. Since the data in the diagram (Figure 18) were selected indiscriminantly, the merging and splitting of data are to be expected. In an attempt to put some system into the data, horizontal lines have been drawn through the various blocks incorporating the modes and the standard deviation spreads. The horizontal lines have been chosen so as to pass through as many blocks as possible, i.e. they are orientations common to the various maxima of fracture frequencies in the different sections. These horizontal lines are considered to give an indication of discrete fracture trends common to the whole West Rand Syncline (Figure 18).

It can be seen that certain fracture orientations occur in both limbs of the regional fold. This would suggest that the fractures are independent of the synclinal structure, and were superimposed on the folded strata. If this were the case, then the sense of movement on the various fractures should be the same. However, this is not so, since the direction of movement on fractures having a similar orientation in the Tarlton-Bank Area as in the Krugersdorp-Florida Hills Area is often not the same for the two areas (see Table 9).

Krugersdorp-Florida Hills Area			Tarlton-Bank Area
Eastern Section	Central Section	Western Section	
004° L.L.	008°	008°	005° R.L.
017°			
044°	049°	038° R.L.	044° L.L.
059°		057°	
084° R.L.	084° R.L.	075° R.L.	072° L.L.
097°			
108° R.L.	104° R.L.		
132° R.L.	126° R.L.	138°	121° L.L.
163° L.L.			145° R.L.

Table 9 : Comparison of the Apparent Sense of Movement of Major Fracture Groups in the Tarlton-Bank Area and the Krugersdorp-Florida Hills Area (R.L. = right-lateral movement; L.L. = left-lateral movement)

Table 9 illustrates the danger of any classification of fractures which is based on geometry alone. Strike directions, in themselves, are not definitive in an analysis of fractures, because similarly oriented fractures may not, in fact, be related at all.

Regarding the area investigated in this paper, it can be seen from Table 9 that the fracture patterns of the two larger map areas, although having a high degree of geometrical correlation, cannot be compared directly on a genetical basis. If the fractures were not superimposed on an already deformed syncline, then the alternative might be that the fracture pattern, or a portion of the pattern, at least, may have been rotated by the folding. The problem then becomes one of establishing if any constant angular relationship between the fractures of the Tarlton-Bank Area also holds for the data from the Krugersdorp-Florida Hills Area (Table 10).

Tarlton-Bank Area	Angular Difference	Krugersdorp-Florida Hills Area
005° R.L.	76°	081° R.L.
122° L.L.	75°	017° L.L.
145° R.L.	79°	044° R.L.
072° L.L.	91°	163° L.L.
044° L.L.	86°	130° R.L.
Mean Angular Difference	81°	
Standard Deviation	6°	

Table 10 : Angular Difference in Transforming Fracture Directions from the Tarlton-Bank Area to Corresponding Directions in the Krugersdorp-Florida Hills Area.

The values for the Krugersdorp-Florida Hills area are the best average strike values of fractures for the eastern limb of the West Rand Syncline. These have been taken from Table 5 and Figure 18. The angle by which the Tarlton-Bank fractures have to be rotated to conform with the Krugersdorp-Florida Hills fractures varies between 75° and 91°. The mean angle that would have to be applied is 81°, in a clockwise direction. This angle is the same as the difference in strike of the bedding planes of the two straight limbs of the West Rand Syncline (117° for the Krugersdorp-Florida Hills area, as obtained from the generalized data of Figure 11, and 035° for the Tarlton-Bank area). The correspondence of the data, when treated in this manner, is more convincing than the relationship shown in Table 9 and Figure 18. The only anomalous correlation in Table 10 is the fracture group oriented in the 044° direction in the Tarlton-Bank Area, which has a left-lateral component, while the 130° trend of the Krugersdorp-Florida Hills area has a right-lateral component. For all other directions, the data correspond well.

The orientations of 044° and 130° in the two mapped areas are significant, because in each area the respective trend is that which lies closest to the orientations of the bedding planes and the regional strike faults, which latter, in the case of the Krugersdorp-Florida Hills area, are of fundamental importance. It has been pointed out that such faults in the Krugersdorp-Florida Hills area may represent reverse faults which were subjected to later wrench movements. If a period of reverse faulting preceded the folding, then a later north-south oriented stress could have produced, on the bent fault plane, a left-lateral movement on the Tarlton-Bank limb, and a right-lateral movement on the Krugersdorp-Florida Hills limb. Stresses with this orientation have definitely affected the West Rand Syncline.

Collectively, the analysis of fractures in the West Rand Syncline indicates that at least some of the fracture trends can be correlated between one limb of the syncline and the other, by means of a consistent 80° angular relationship, which can be correlated with the difference in strike of the bedding planes in the two limbs of the fold. The problem that arises is whether all the fractures were rotated by the folding, or whether only some major structural breaks were rotated, and these subsequently acted upon by a regional stress which produced second-order fractures geometrically linked to the first-order structures. If, in the latter case, the data were unfolded, the good correspondence between directions of movement and orientations of fractures, indicated in Table 10, could be obtained. This assumes that the second-order fractures are a result of a readjusted stress field, with the second-order major compressive stress lying in the plane of the fault, and having an almost horizontal attitude. The problem of which mechanism could have affected the area depends upon the timing of the various events within the area, and on the genesis of the fracture patterns.

F. GEOMETRICAL RELATIONSHIPS OF GENETICALLY RELATED FAULTS

An essential aspect of any investigation such as this is the setting up of certain geometrical criteria on fault development, which will assist in the interpretation of the classification of faults. Since, as has been shown above, geometrical classification, alone, of faults is not very useful, it becomes necessary to know something about the genesis of the faults. Several notable contributions have been made in the study of faulting (Moody and Hill, 1956; Chinnery, 1961, 1965, 1966). Extensive literature exists on rock mechanics, but very few of the investigations have dealt with fracture types that have been measured in the field.

Certain data from the Krugersdorp-Florida Hills Area permit the establishment of a working model for fracturing in this type of environment. Environment is such an important factor in determining the geological nature of rocks undergoing deformation that the model described here is not necessarily applicable to other areas. Very little is known about the variations in the confining pressure, the temperature, the magnitude of the applied stresses, and the strain rates of the rocks undergoing deformation in different environments.

The fault providing the most evidence of secondary fracturing is the one separating Sub-areas 9 and 10. Where this fault ends, it is replaced by a series of fairly systematically oriented fractures. The major fault has a 120° trend, while the fractures at the tip have an east-west orientation, and often reveal a right-lateral component of movement. Several thrust faults, also belonging to the group of east-west fractures, indicate that compression close to the tip of the major fracture was directed from the east towards the west. Since the east-west fractures are slightly offset to the south of the major 120° fracture, it would appear that the major fault is of a right-lateral type. That movements were essentially horizontal is confirmed by the conjugate folds within, and immediately adjacent to, the major fault. Furthermore, it is significant that the orientation of the major principal compressive stress axis was essentially horizontal and in the plane of the fault. Using this information, it is possible to relate several of the larger east-west and north-south faults to the effect of this stress adjacent to the 120°-trending fault.

The fault which trends at 135° and has strong folds associated with it in Sub-area 10 is a left-lateral fault. It appears to link up with the major 120°-trending fault (Figure 8). That this fault has a left-lateral movement can be confirmed by numerous smaller folds occurring adjacent to it. On the northern side of the fault, these folds close towards the west, while on the southern side they close towards the east. The limbs adjacent to the fault are often oriented parallel to the fault plane. The symmetry of this fault is similar to that proposed by Chinnery (1966) for the orientation of second-order faults (Figure 19). The east-west fractures near the tip of the 120°-trending fault are also similar in type, orientation, and movement to those suggested by Chinnery (1965) (Figure 19).

All the features that can be collectively related to a wrench fault are shown diagrammatically in Figure 20. It is quite clear that this pattern does not conform to that postulated by Moody and Hill (1956). They proposed that second-order fractures would be caused by a resolved second-order major compressive stress oriented at an angle of approximately 75° to the master shear. The misconceptions in their reasoning have been pointed out by Chinnery (1966) who demonstrated that Moody and Hill (1956) had treated a tensor quantity as if it were a vector. Chinnery (1966) suggested that the second-order compressive stress axis may be oriented at varying angles to the master shear, being dependent upon the coefficient of sliding friction on the fault plane. If there were no friction, then the major compressive stress axis would be parallel to the fault plane. In the area investigated, a coefficient of friction of zero appears to have been unlikely, as it is considered that the stress which produced the wrench movements was probably related to the north-south-directed stress that was responsible for the cleavage which penetrates the whole Krugersdorp-Florida Hills area. This would mean that the entire area was under compression, as a result of this force, and it is unlikely that the fault oriented in the 120° direction would have remained open. An alternative explanation may be given, using the information in an earlier paper of Chinnery (1961), in which he presented a diagram showing the resultant horizontal displacement of ground adjacent to a wrench fault (Figure 21). The movement next to the fault tends to parallel the fault. Since these movements must ultimately represent the direction of a principal compressive stress, they could produce the conjugate folds and associated faults adjacent to the 120° master fault.

From all the points mentioned so far, it appears that a great many of the features suggested by Chinnery (1961, 1965, 1966) are applicable to the present investigation, and, because his work was based on an elastic model, some of the deformation of the Krugersdorp-Florida Hills area must have been brittle.

Another point to be considered is the extent to which faults of the 120° trend are developed in the Krugersdorp-Florida Hills area. Figure 22 is a generalized map of fractures in this area. On the west-northwest projection of the 120°-fault of Sub-areas 9 and 10, a line of faults can be followed far towards the west. This trend is complicated by the 105°-

trending faults which appear to merge with the major fault. The 120°-trend master fault also gives way to a highly systematic set of east-west-trending faults. These cut across the line of the master fault, and are not confined to the south side of the fault, as in Sub-area 10. It has been pointed out in earlier sections of the paper that the repetition of the Contorted Bed in various localities could be due to the presence of faults having a trend parallel to the strike of the formations. Furthermore, the regional fold structure of the area is on an axis which strikes in the 120° direction, and, because the folding, as a rule, has been produced by faulting, the presence of faults trending in this direction can be inferred. The location of such faults would be near the Contorted Bed outcrops, and the systematic east-west fractures of Sub-area 18 would then be on the southern side of the master fault.

Finally, concerning the nature of fractures in the Krugersdorp-Florida Hills area, Figure 23 is a plot of poles to fracture planes, where these could be measured in three dimensions in the field. All the faults are clearly steeply-dipping, which shows that they are of the normal, reverse, or wrench fault type. Flat thrust faults are not common in the area. The maxima determined from Figure 23 are –

Strike	Dip
065°	88° south
085°	80° south
108°	73° south

These strike directions compare well with the data given in Table 9.

THE DEFORMATIONAL HISTORY OF THE WEST RAND SYNCLINE

An interpretation of the nature and significance of the faults, folds, and other structural phenomena observed in the West Rand Syncline has led to the following postulated sequence of events in this part of the Witwatersrand Basin :

1 – Deposition of sediments belonging to the Witwatersrand System.

2 – Formation of extensive strike faults which, in the Krugersdorp-Florida Hills area, were reverse faults with an upthrow to the south, giving rise to a repetition of strata. These strike faults were responsible for the development of folds, particularly in the block of ground to the north of the fault which, in places, was deformed into a synclinal structure. The axes of the fold structures are essentially parallel to the strike of the faults, and have a flat orientation. In areas to the south of those investigated, the Witpoortjie Fault and associated faults, as well as related folds, are possibly linked to this period. The folded synclinal structure of the Upper Witwatersrand strata, lying immediately next to the Witpoortjie Fault, is a particularly fine example of folding developed as a result of faulting.

3 – Bending of strata and faults to form the large arcuate structure of the West Rand Syncline. There are no obvious indications of a simple buckling process of the strata to form the fold. The only signs of stresses which may be related to a folding process are the conjugated faults which indicate compression in the plane of the bedding, but, since the intermediate stress axis does not lie in this plane,

it cannot be related to a stress system which was taken up by the competent strata during a period of buckling. The only really consistent indicator of a regional stress is the cleavage, which suggests a north-south compression. It is possible that, prior to the development of the cleavage, which itself is superimposed on the bent syncline, the same compressive force may have forced the Witwatersrand sediments in between the granite massifs now marking the rim of the syncline.

4 - Formation of the cleavage by the same north-south stress, after folding.

5 - Continuation of the stress which reactivated the rotated strike faults. These faults now appear as wrench faults, with a right-lateral movement in the Krugersdorp-Florida Hills area, and a left-lateral movement in the Tarlton-Bank area.

6 - Associated with this period of wrench faulting was the development of second-order stresses, oriented so that the maximum compressive stress lay in the plane of the fault. This readjusted compressive stress gave rise to various second-order fractures (Figure 20). That these second-order fault movements post-date the cleavage can be confirmed on an outcrop in Sub-area 10 where, on a small scale, these faults clearly deform the cleavage.

7 - In the core of the fold, right-lateral faults, trending at 138°, resulted from an east-west compression.

8 - Formation of large reverse faults, trending in a 105° direction, that are found in Sub-area 20. These faults are clearly post-West Rand Syncline formation in age, as they show no indications of folding.

9 - Long after the deposition of the Black Reef, a fundamental fault formed to the west of the Orange Grove Quartzite exposures in the Tarlton-Bank area. In Sub-areas 7 and 8, there are fold and fault styles which differ markedly from any of the established trends. This distinctive style of deformation appears to be related to the major fault west of the Tarlton-Bank area. This fault is known as the Bank Fault and has a northwest trend.

* *

LIST OF REFERENCES CITED

Brock, B.B. 1950 The Vredefort Ring.
Trans., Geol. Soc. S. Afr., 53, p.131-157.

Brock, B.B. 1954 A View of Faulting in the Orange Free State.
Optima, 4, p. 5-17.

Brock, B.B. 1961 The Structural Environment and Borehole Geology of Western Deep Levels Limited.
Trans., Geol. Soc. S. Afr., 64, p. 163-192.

Brock, B.B., and D.A. Pretorius — 1964a — An Introduction to the Stratigraphy and Structure of the Rand Goldfield.
in S.H. Haughton, ed. - "The Geology of Some Ore Deposits of Southern Africa", Geol. Soc. S. Afr., 1, p. 25-62.

Brock, B.B., and D.A. Pretorius — 1964b — Rand Basin Sedimentation and Tectonics.
in S.H. Haughton, ed. - "The Geology of Some Ore Deposits in Southern Africa", Geol. Soc. S. Afr., 1, p. 549-599.

Chinnery, M.A. — 1961 — The Deformation of Ground Around Surface Faults.
Bull., Seism. Soc. Amer., 51, p. 355-372.

Chinnery, M.A. — 1965 — The Vertical Displacements Associated with Transcurrent Faulting.
J. Geophys. Res., 70, p. 4627-4631.

Chinnery, M.A. — 1966 — Secondary Faulting.
Can. J. Earth Sci., 3, p. 163-189.

Fuller, A.O. — 1958 — A Contribution to the Petrology of the Witwatersrand System.
Trans., Geol. Soc. S. Afr., 61, p. 19-45.

Mellor, E.T. — 1913 — Structural Features of the Western Witwatersrand.
Trans., Geol. Soc. S. Afr., 16, p. 1-32.

Mellor, E.T. — 1917 — The Geology of the Witwatersrand : Explanation of the Geological Map of the Witwatersrand Gold Field.
S. Afr. Geol. Surv., Pretoria, 42 pp.

Mellor, E.T. — 1921 — The Geology of the Country Surrounding Johannesburg : Explanation of Sheet 52 (Johannesburg).
S. Afr. Geol. Surv., Pretoria, 46 pp.

Moody, J.D., and M.J. Hill — 1956 — Wrench-fault Tectonics.
Bull., Geol. Soc. Amer., 67, p. 1207-1246.

Olivier, H.J. — 1965 — The Tectonics of the Upper Division of the Witwatersrand System in the Loraine Area of the Orange Free State Goldfield.
Trans., Geol. Soc. S. Afr., 68, p. 143-175.

Pegg, C.W. — 1950 — A Contribution to the Geology of the West Rand Area.
Trans., Geol. Soc. S. Afr., 53, p. 209-224.

Pretorius, D.A. — 1964 — The Geology of the Central Rand Goldfield.
in S.H. Haughton, ed. - "The Geology of Some Ore Deposits in Southern Africa", Geol. Soc. S. Afr., 1, p. 63-108.

Steyn, L.S. — 1963 — The Sedimentology and Gold Distribution Pattern of the Livingstone Reefs on the West Rand.
Unpub. M.Sc. Thesis, Univ. of the Witwatersrand, Johannesburg, 126 pp.

Roering, C. 1967 The Geometrical Significance of Natural En-Echelon Crack-Arrays.
Inform. Circ. No. 34, Econ. Geol. Res. Unit, Univ. of the Witwatersrand, Johannesburg, 11 pp.

Threader, V.M. 1963 A Study of Fracture Patterns in the Orange Free State Gold Field of South Africa.
Trans., Geol. Soc. S. Afr., 66, p. 93-108.

Toens, P.D., and G.H. Griffiths 1964 The Geology of the West Rand.
in S.H. Haughton, ed. - "The Geology of Some Ore Deposits in Southern Africa", Geol. Soc. S. Afr., I, p. 283-322.

* *

KEY TO FIGURES

Figure 10 : Detailed geology of Sub-area 18 and adjacent areas. Same key as for Figure 8. Government Reef Conglomerate represented by circles. (see Figure 3 for location).

Figure 11 : Detailed geology of portion of Sub-area 20. Key identical to that used for the previous figures, except that the triangles in this area refer to a tilloid band. (see Figure 3 for location).

Figure 12 : Composite plot of bedding plane maxima from individual sub-areas of the West Rand Syncline. Stereographic projection of various bedding plane maxima from Figures 5 and 7, and of cleavage maxima from Figure 14.

Figure 13 : Detail of cleavage in relation to folds in a fault zone. Similar-type folds are associated with the cleavage developed in the fault zone, while differential left-lateral movement, which is parallel to that of the fault itself, is portrayed in smaller, drag-type folds. The dotted zones are massive quartzite bands which are relatively unaffected by the cleavage.

Figure 14 : Stereographic projection of poles to the cleavage planes occurring in the Krugersdorp-Florida Hills area. 127 observations.

Figure 15 : Stereographic projection of axial planes of conjugate folds and constructed principal stress axes, adjacent to the major fault in Sub-area 10.

Figure 16 : Frequency distribution of macro-fracture azimuths in the Tarlton-Bank area. 138 observations.

Figure 17 : Frequency distribution of macro-fracture azimuths in the Krugersdorp-Florida Hills area. 466 observations.

Figure 18 : Diagram representing a spread of one standard deviation about the calculated mode of individual peaks occurring in Figures 16 and 17. The Y-axis represents the strike directions of the faults. Separate sections are portrayed by the blocks. The fine-dots are the eastern, the vertical lines the central, and the large dots the western sections of the Krugersdorp-Florida Hills area. The open blocks refer to the Tarlton-Bank area. Horizontal lines have been drawn through the areas so as to pass through as many blocks as possible. These horizontal lines are taken to represent discrete orientations of fractures common to the entire West Rand Syncline.

Figure 19 : Trajectories showing the direction of maximum shear stress at each point on the ground surface, after faulting has occurred. The heavy line represents the master fault. This diagram has been constructed for a condition of pure shear. (from Chinnery, 1966).

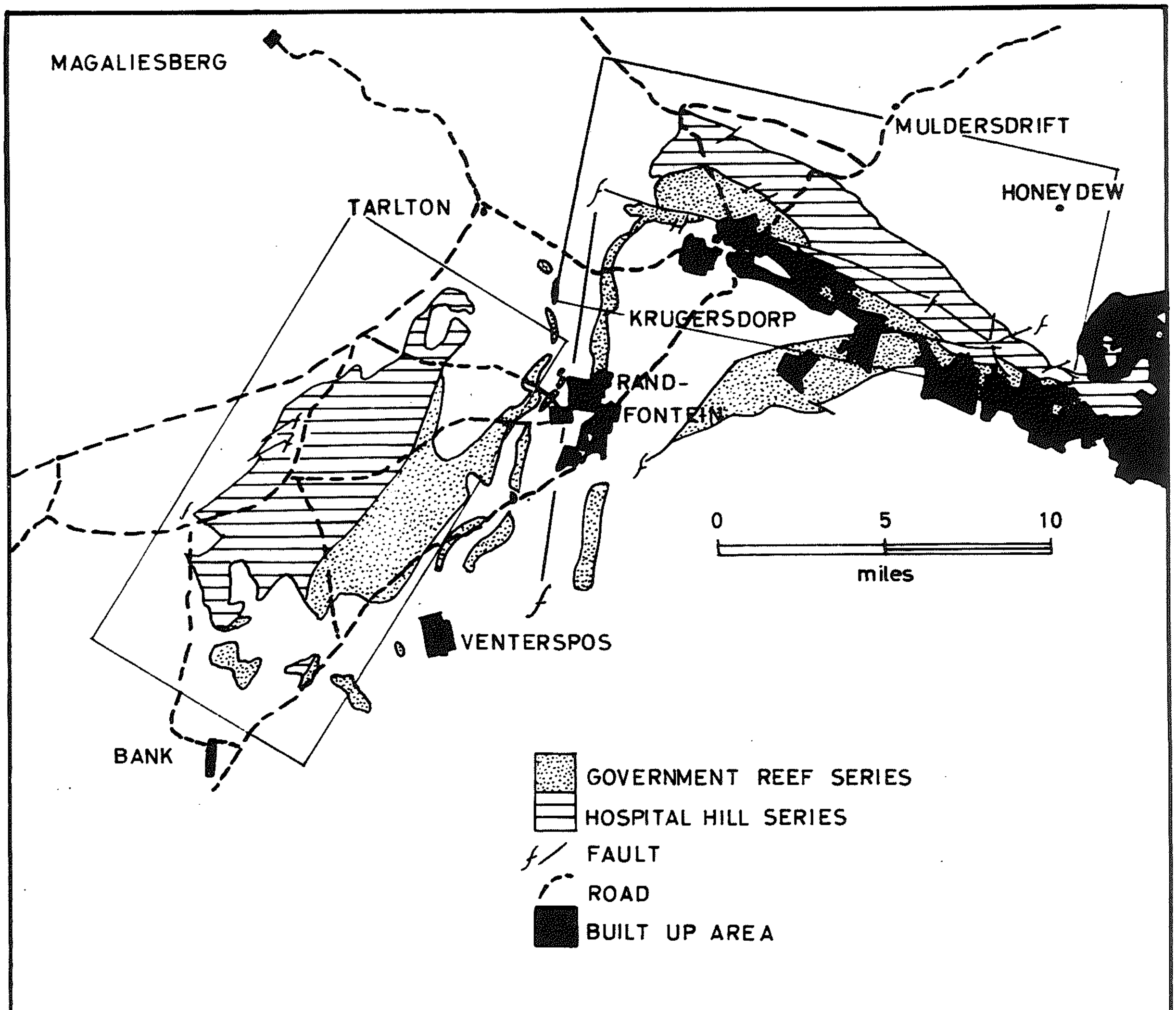
Figure 20 : Generalised diagram showing the orientation of secondary fractures and conjugate folds associated with wrench faults in the Krugersdorp-Florida Hills area.

Figure 21 : Resultant horizontal displacement of ground adjacent to a wrench fault. Contour values are in units of $10^{-3}U$, where U represents the total relative displacement of the two sides of the fault. Above: depth of fault is 1/20 of the surface length. Below: depth of the fault is equal to the surface length. This diagram has been constructed for a condition of uniaxial compression. (from Chinnery, 1961).

Figure 22 : A generalised map showing the major faults of the Krugersdorp-Florida Hills area. The heavy lines refer to the 120°-trending faults. Other fractures are represented by thinner lines. The roads shown in Figure 3 are portrayed in this figure by dashed lines.

Figure 23 : Equal-area projection of poles to fault planes in the Krugersdorp-Florida Hills area.

* *



LOCATION OF MAPPED AREA IN RELATION TO THE WEST RAND SYNCLINE OF THE WITWATERSRAND SYSTEM

FIG.1

GENERALISED STRUCTURAL GEOLOGICAL MAP OF THE TARLTON-BANK AREA

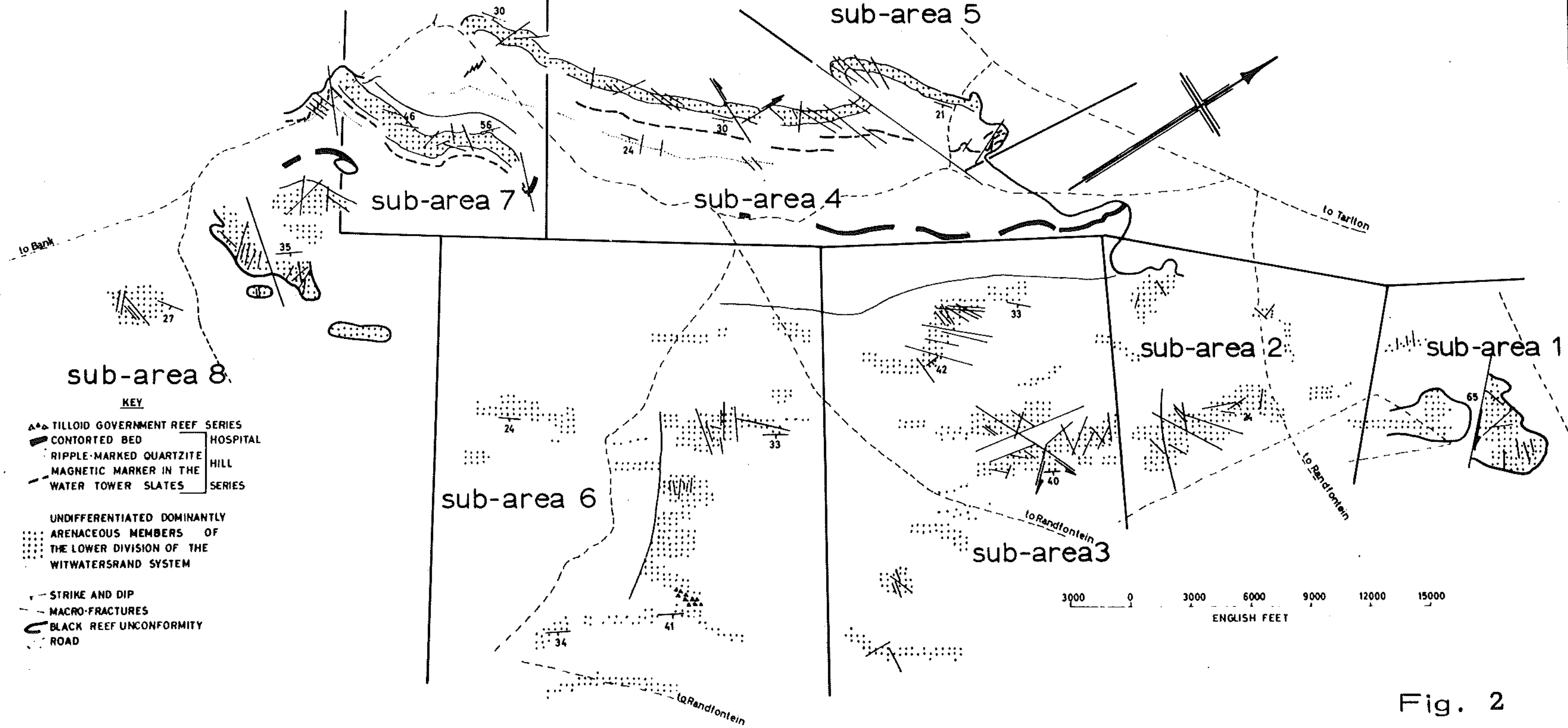


Fig. 2

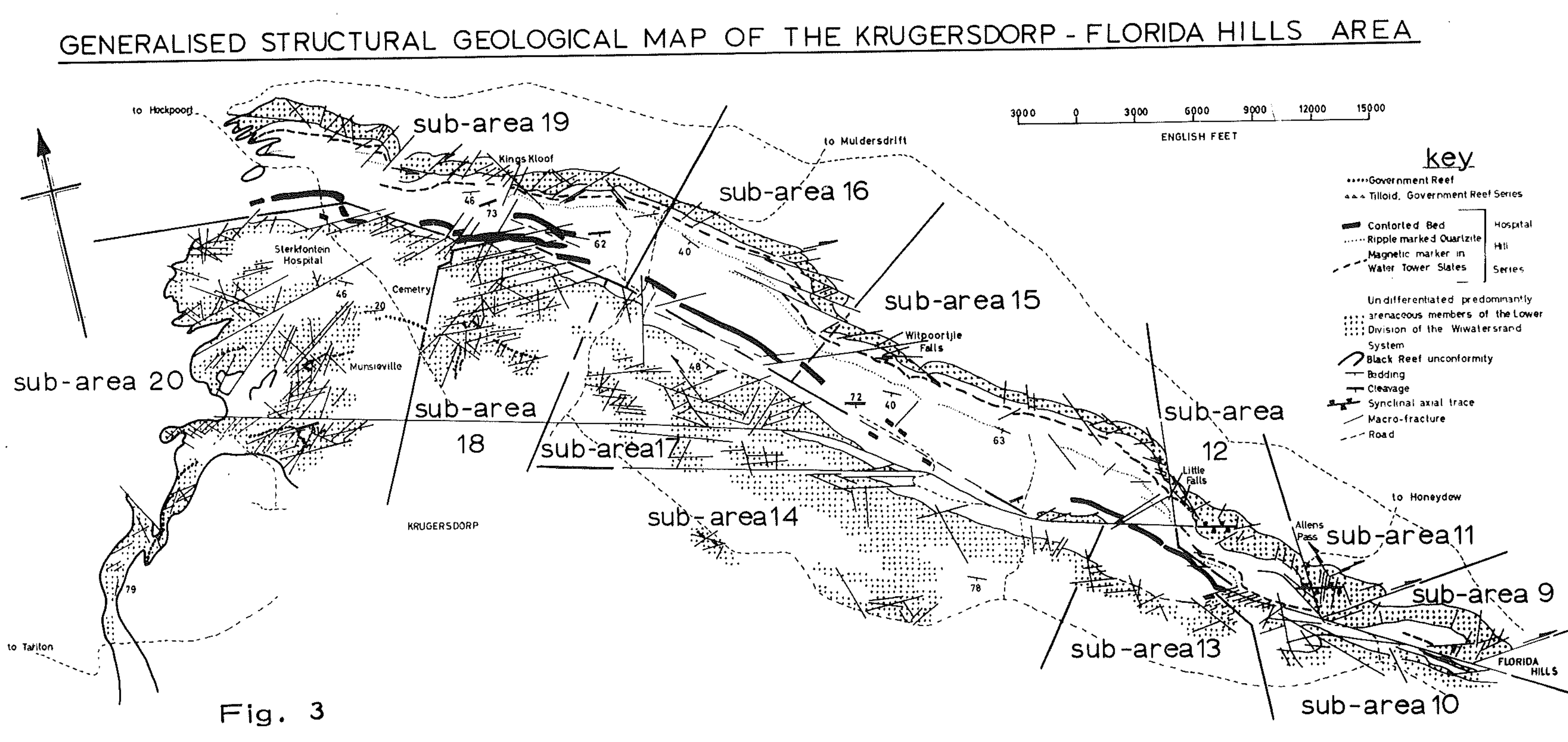
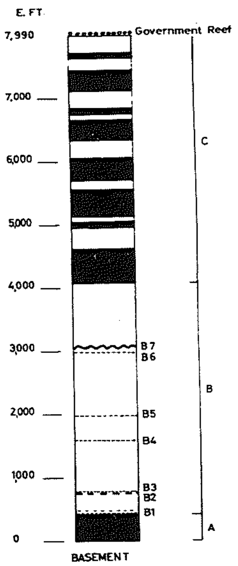
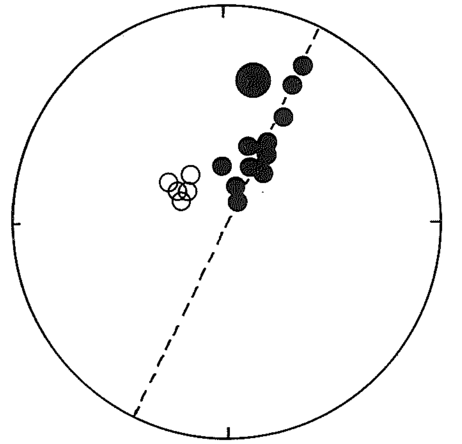

GENERALISED STRUCTURAL GEOLOGICAL MAP OF THE KRUGERSDORP - FLORIDA HILLS AREA
to Hockpoort
to Muldersdrift
to Honeydew
to Tarlton
sub-area 19
sub-area 16
sub-area 15
sub-area 20
sub-area 18
sub-area17
sub-area14
sub-area 12
sub-area11
sub-area 9
sub-area13
sub-area10
Kings Kloof
Sterkfontein Hospital
Cemetry
Munsieville
KRUGERSDORP
Witpoortjie Falls
Little Falls
Allens Pass
FLORIDA HILLS
3000 0 3000 6000 9000 12000 15000
ENGLISH FEET
key
Government Reef
Tilloid, Government Reef Series
Contorted Bed
Ripple marked Quartzite
Magnetic marker in Water Tower Slates
Hospital Hill Series
Undifferentiated predominantly arenaceous members of the Lower Division of the Witwatersrand System
Black Reef unconformity
Bedding
Cleavage
Synclinal axial trace
Macro-fracture
Road

Fig. 3



STRATIGRAPHIC COLUMN OF PORTION OF THE LOWER DIVISION OF THE WITWATERSRAND SYSTEM IN THE KRUGERSDORP-FLORIDA HILLS AREA

Fig. 4



COMPOSITE PLOT OF BEDDING PLANE MAXIMA FROM INDIVIDUAL SUB-AREAS OF THE WEST RAND SYNCLINE. OPEN CIRCLES; TARLTON-BANK AREA. SMALL DOTS; KRUGERSDORP-FLORIDA HILLS AREA. LARGE DOT; MAXIMUM OF CLEAVAGE PLANE POLES.

Fig. 12

Fig. 13

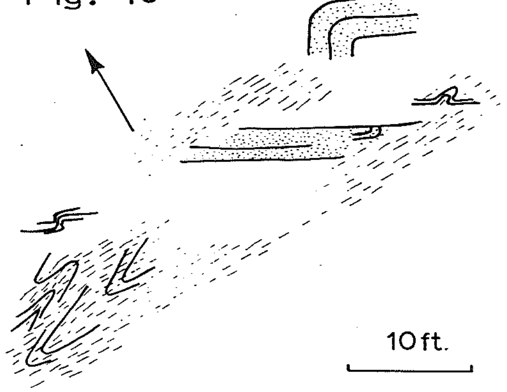
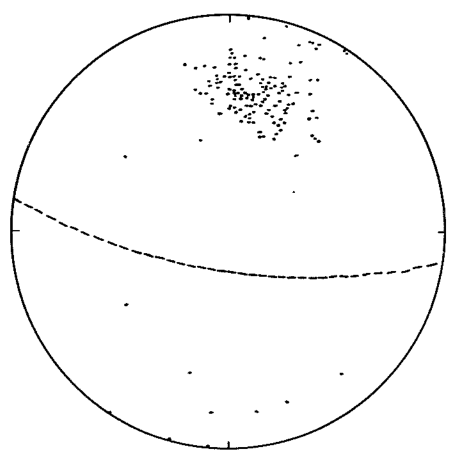
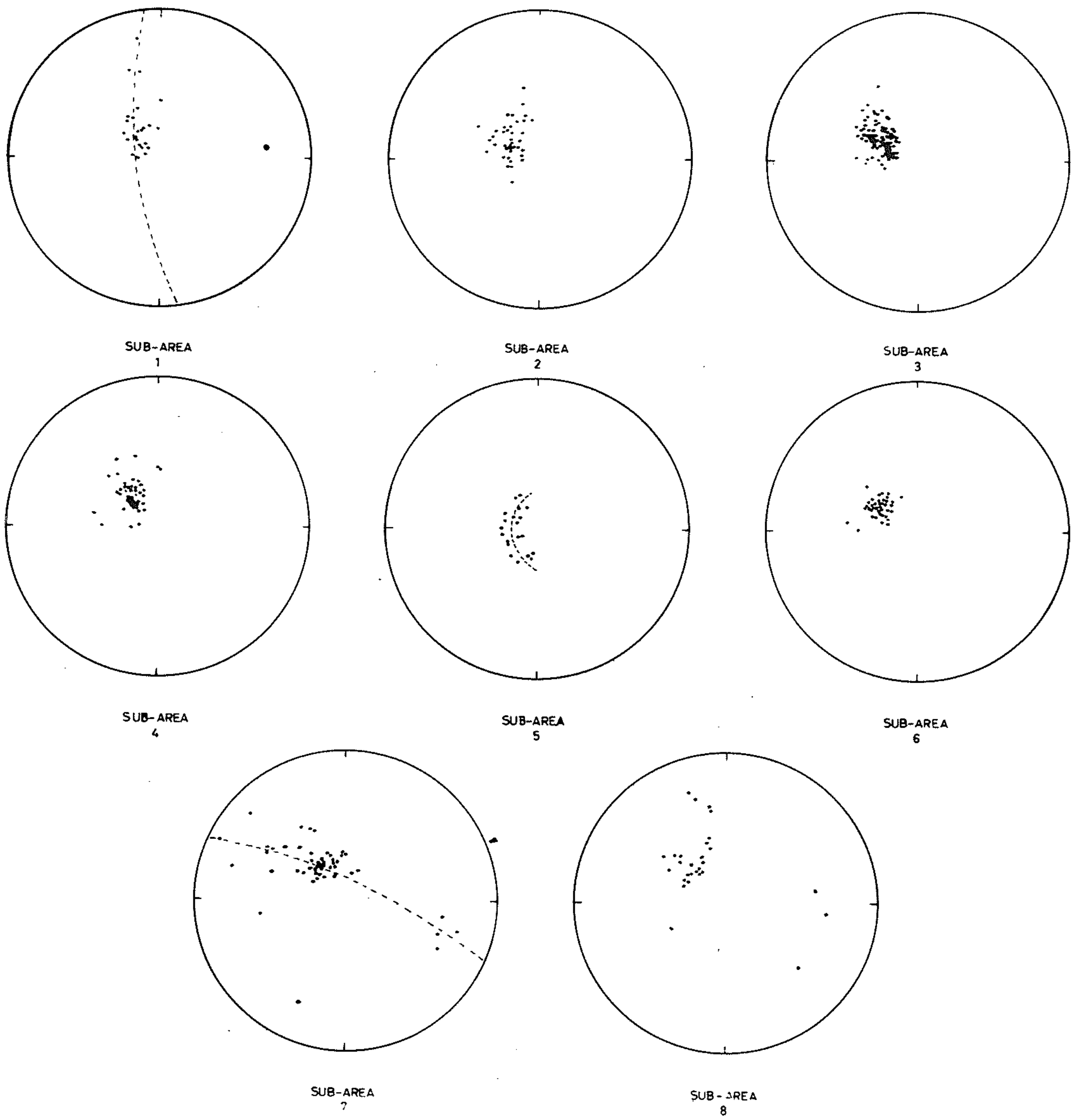


Fig. 14



PLOT OF THE POLES TO CLEAVAGE PLANES IN THE KRUGERSDORP-FLORIDA HILLS AREA

TARLTON-BANK AREA



STEREOGRAPHIC PROJECTION OF BEDDING-PLANE DATA

FIG. 5

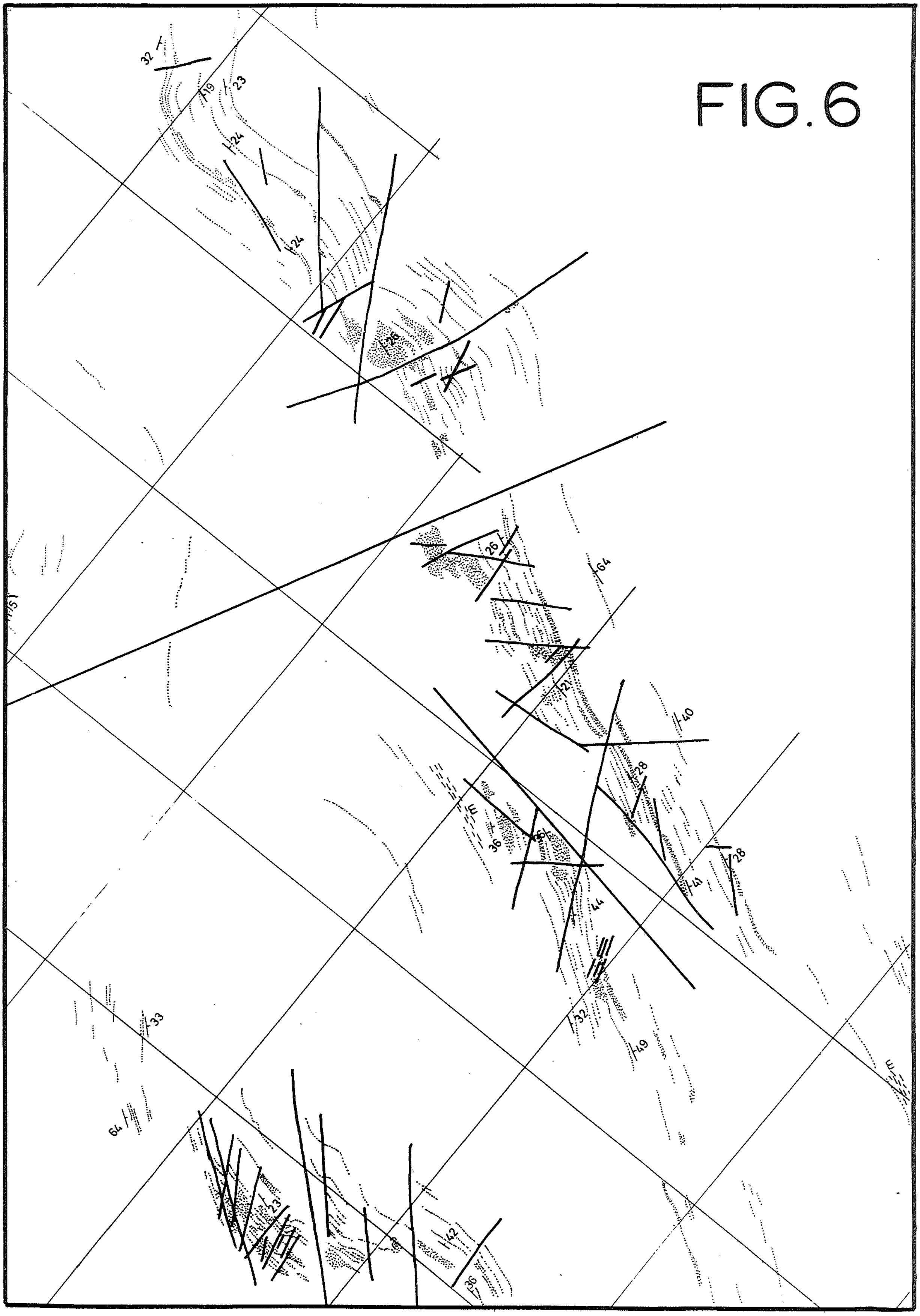
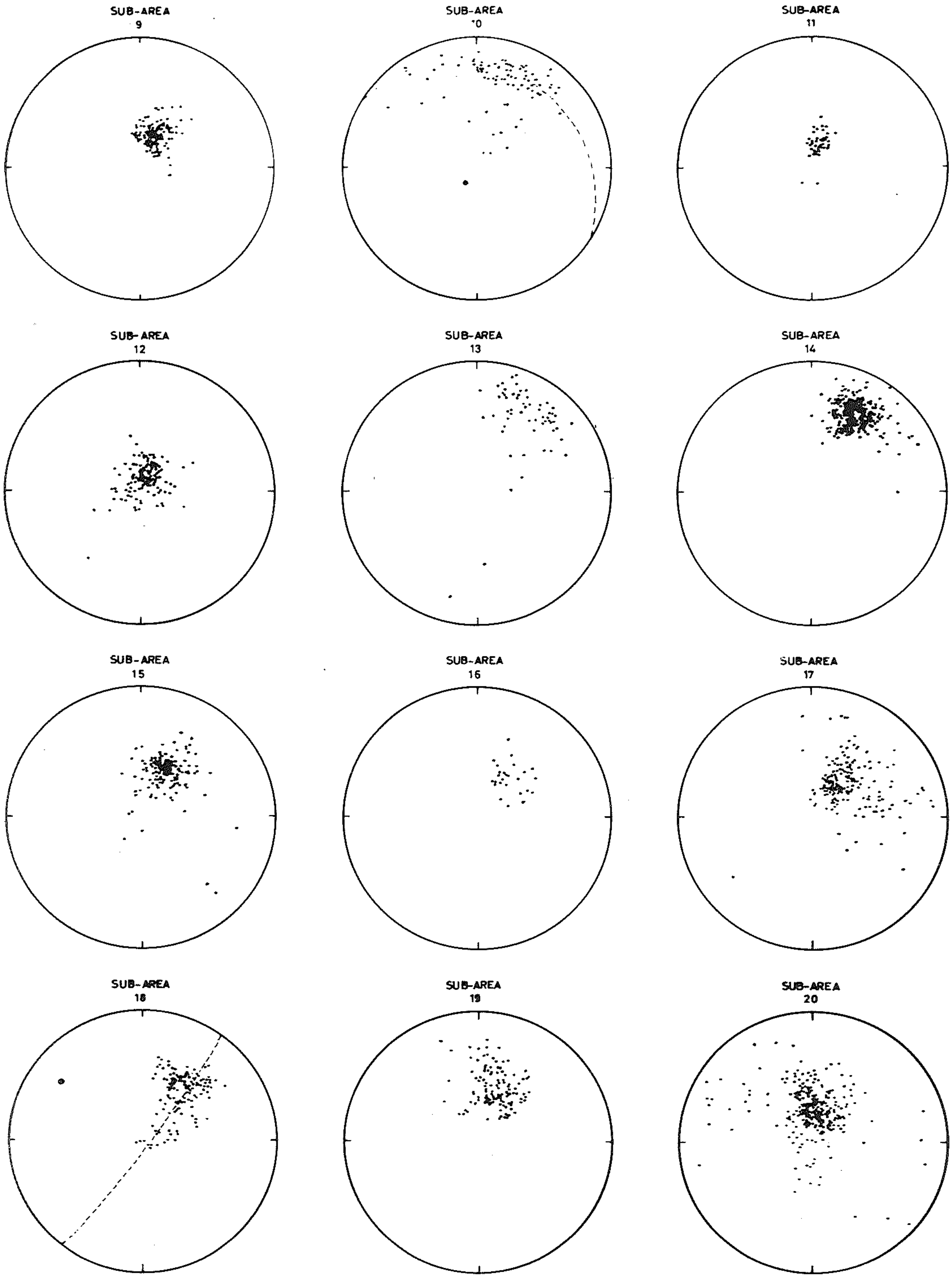


FIG.6

KRUGERSDORP-FLORIDA HILLS AREA



STEREOGRAPHIC PROJECTION OF BEDDING-PLANE DATA

FIG. 7

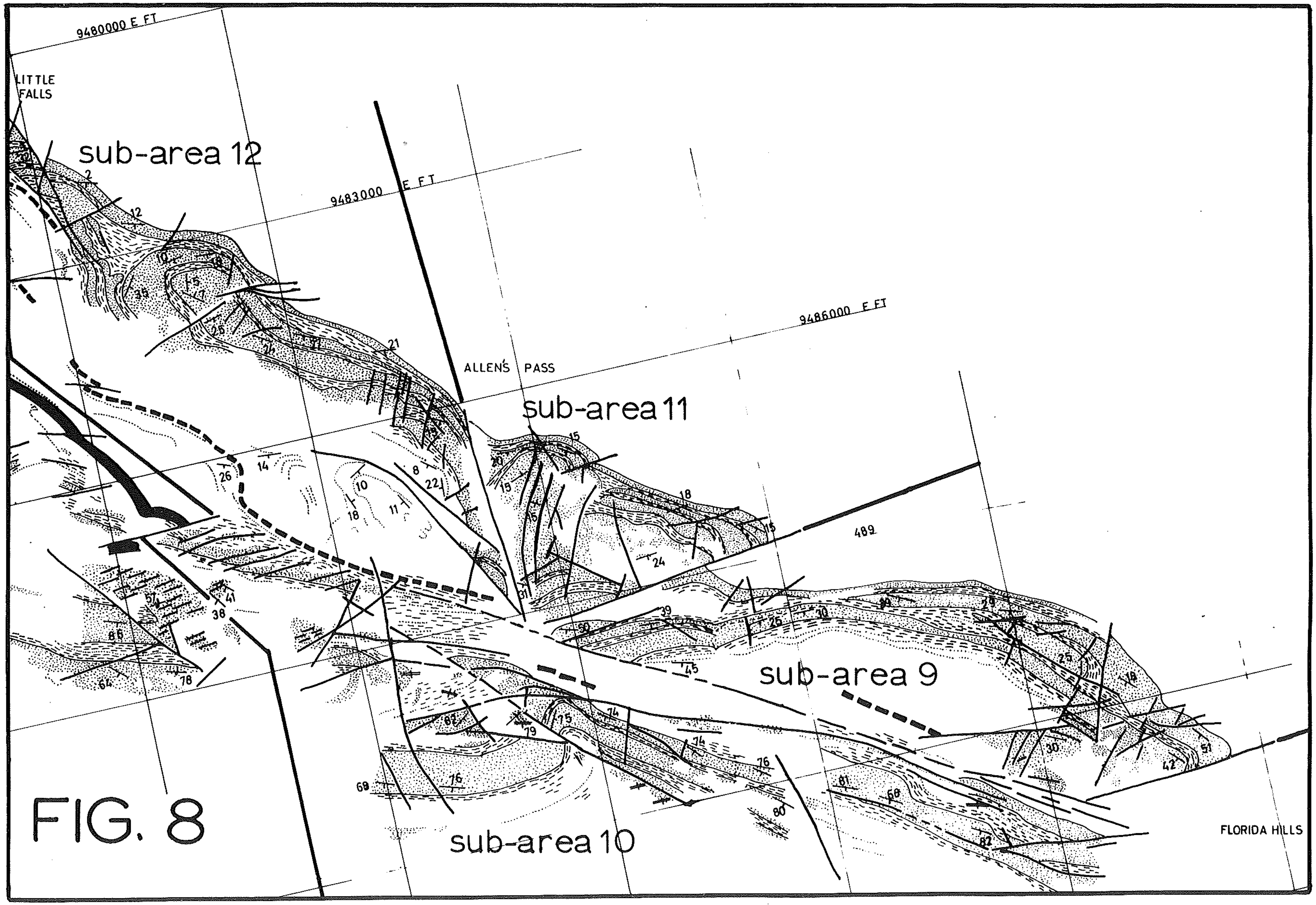
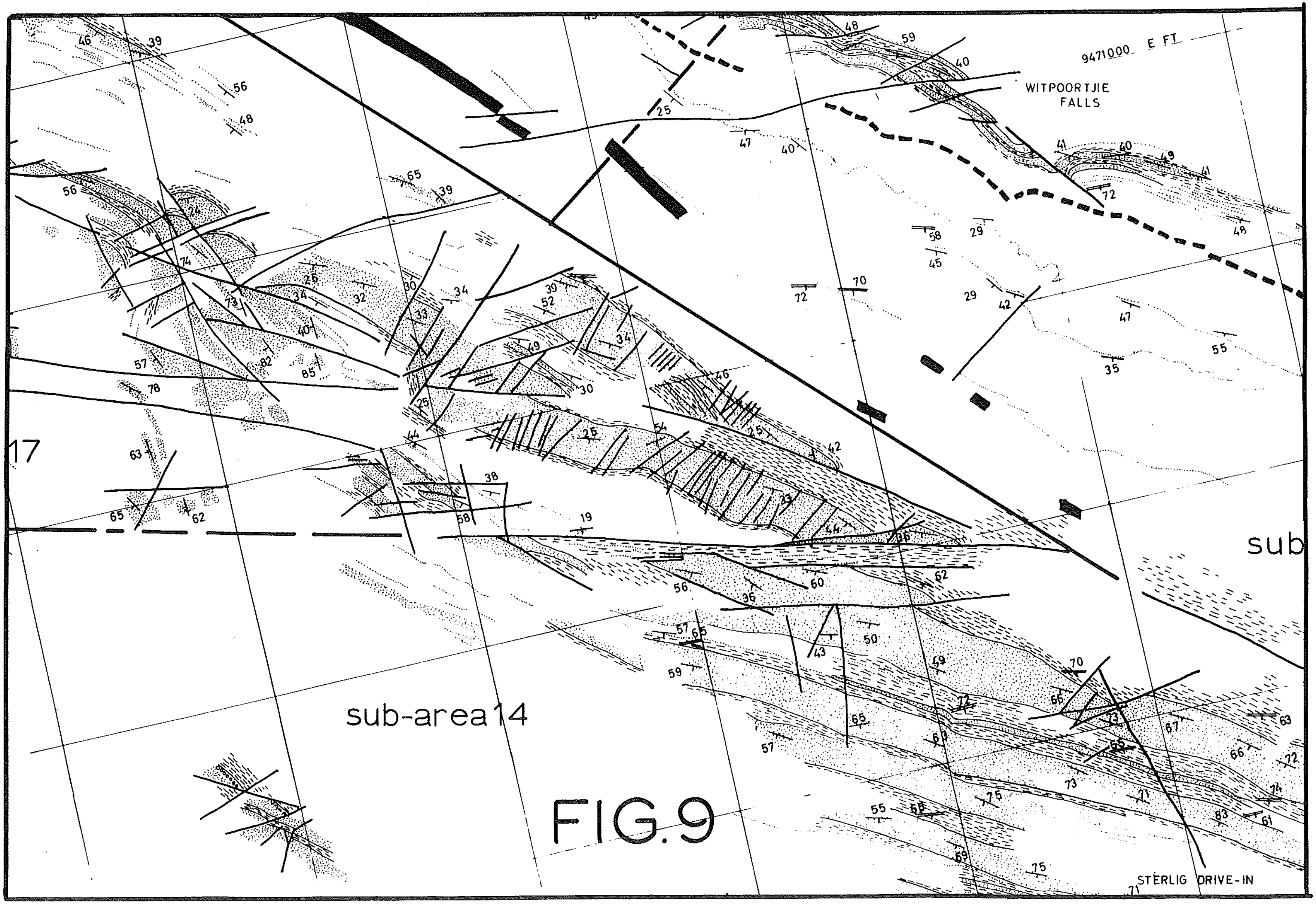

9480000 E FT
LITTLE FALLS
sub-area 12
9483000 E FT
ALLEN'S PASS
sub-area 11
9486000 E FT
489
sub-area 9
sub-area 10
FLORIDA HILLS

FIG. 8


9471000 E FT
WITPOORTJIE
FALLS
sub-area14
sub
17
STERLIG DRIVE-IN
FIG.9

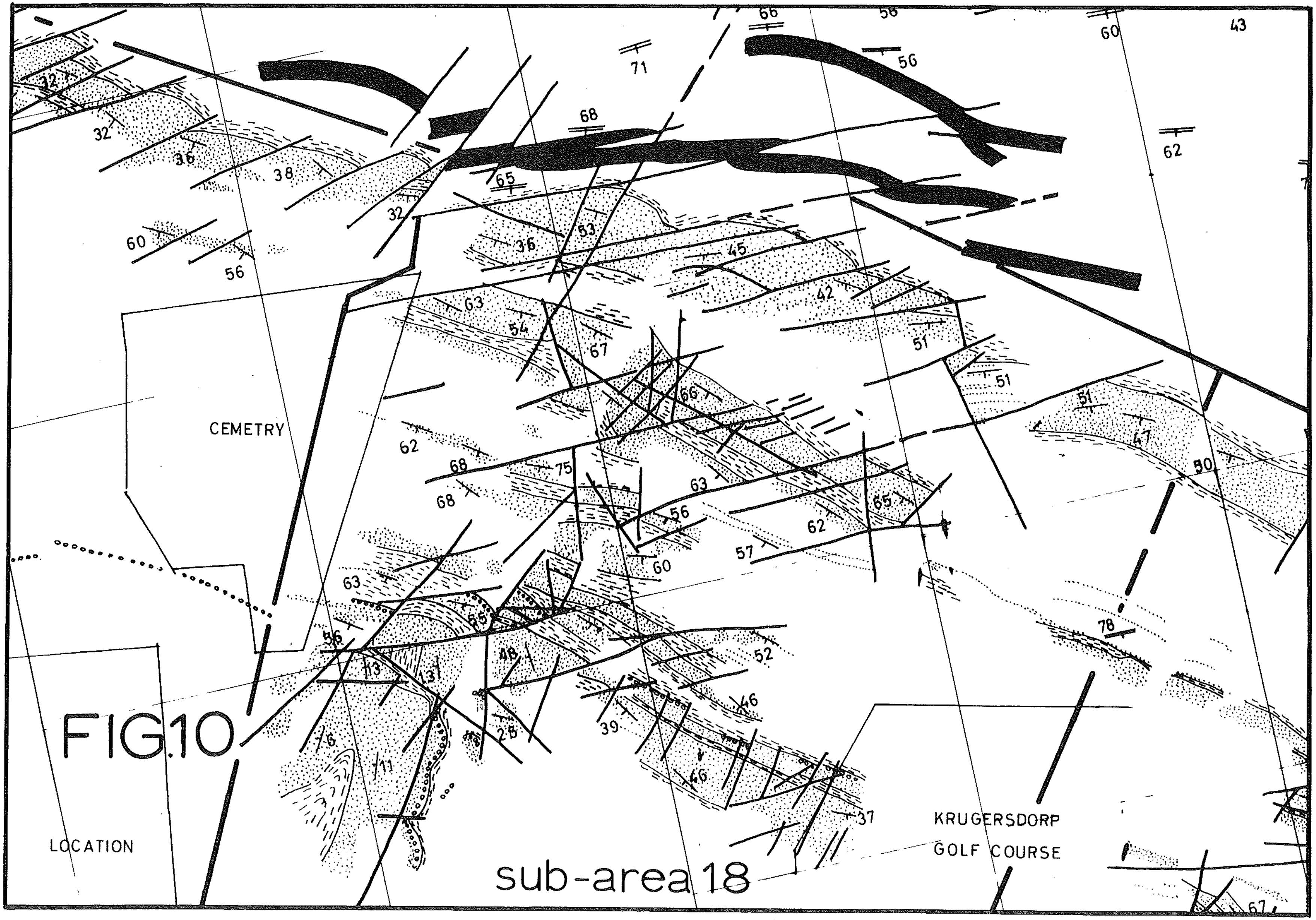


FIG.10

sub-area 18

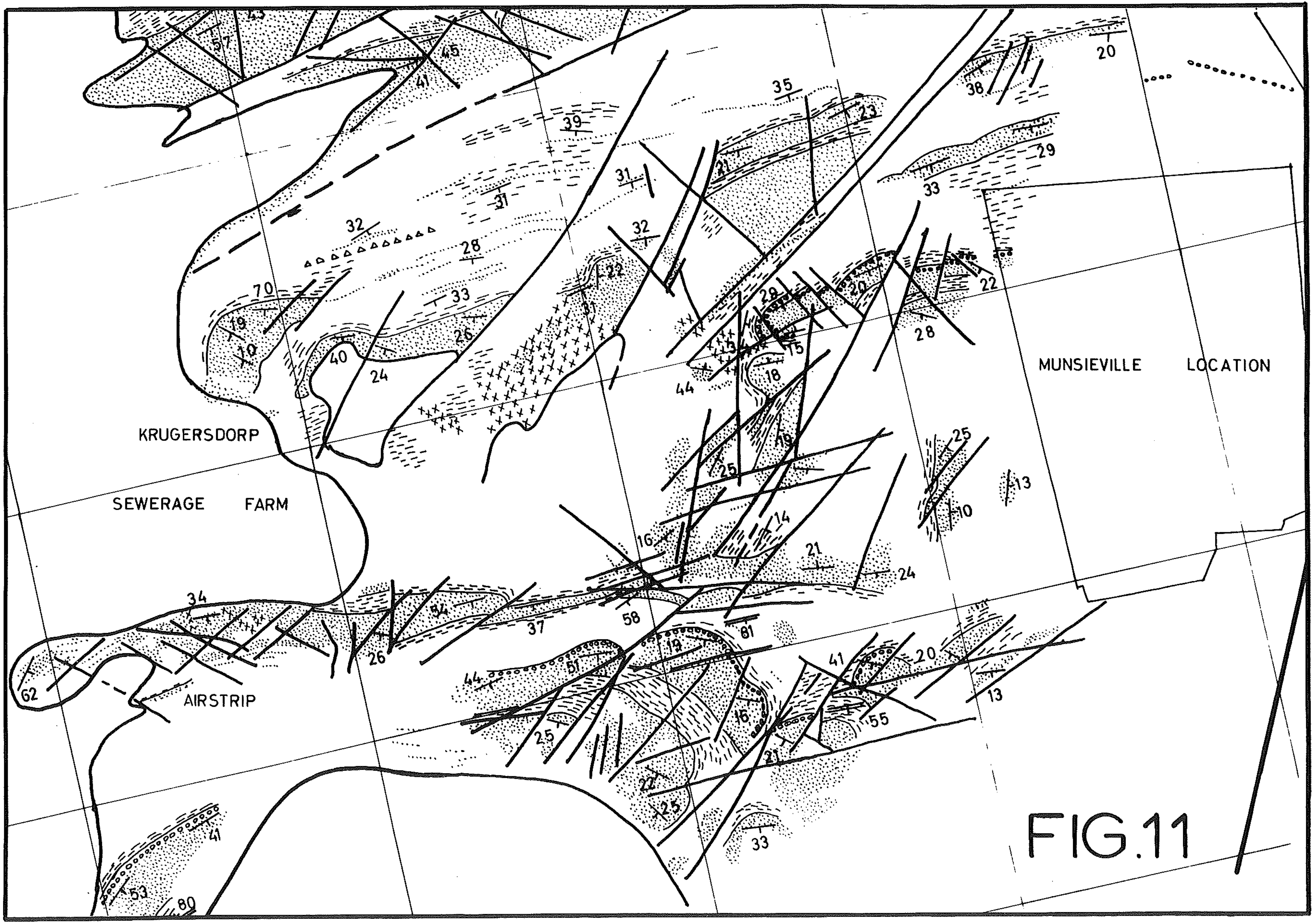
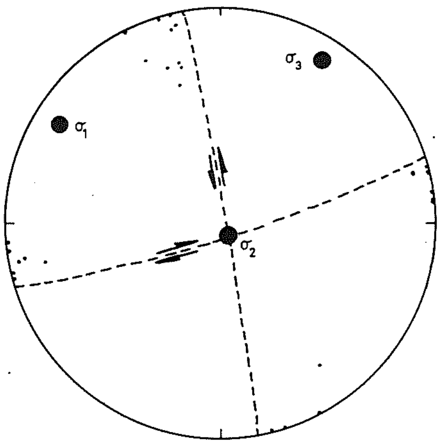

MUNSIEVILLE LOCATION
KRUGERSDORP SEWERAGE FARM
AIRSTRIP

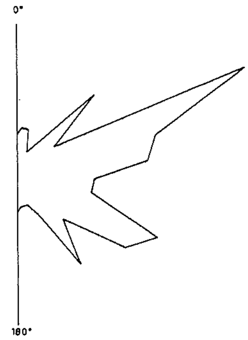
FIG.11

Fig. 15



ORIENTATION OF AXIAL PLANES OF CONJUGATE FOLDS AND CONSTRUCTED PRINCIPAL STRESS AXES, ADJACENT TO MAJOR FAULT IN SUB-AREA 10.

TARLTON-BANK AREA

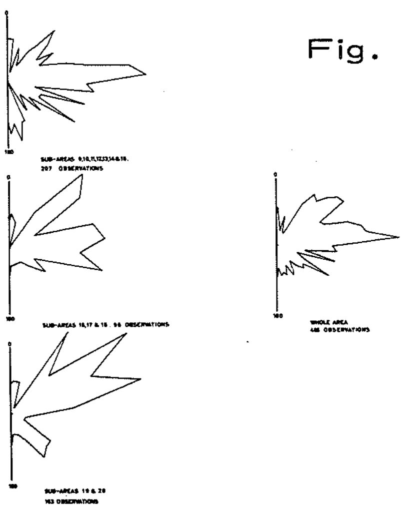


FREQUENCY DISTRIBUTION OF MACRO-FRACTURE AZIMUTHS. 138 OBSERVATIONS

Fig. 16

KRUGERSDORP-FLORIDA HILLS AREA

Fig. 17



Frequency distribution plots of azimuths of macro-fractures.

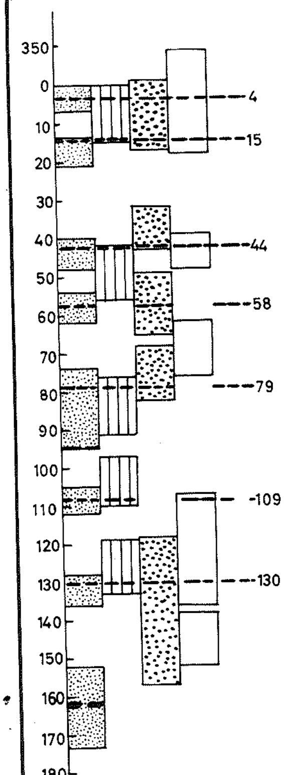


Fig. 18

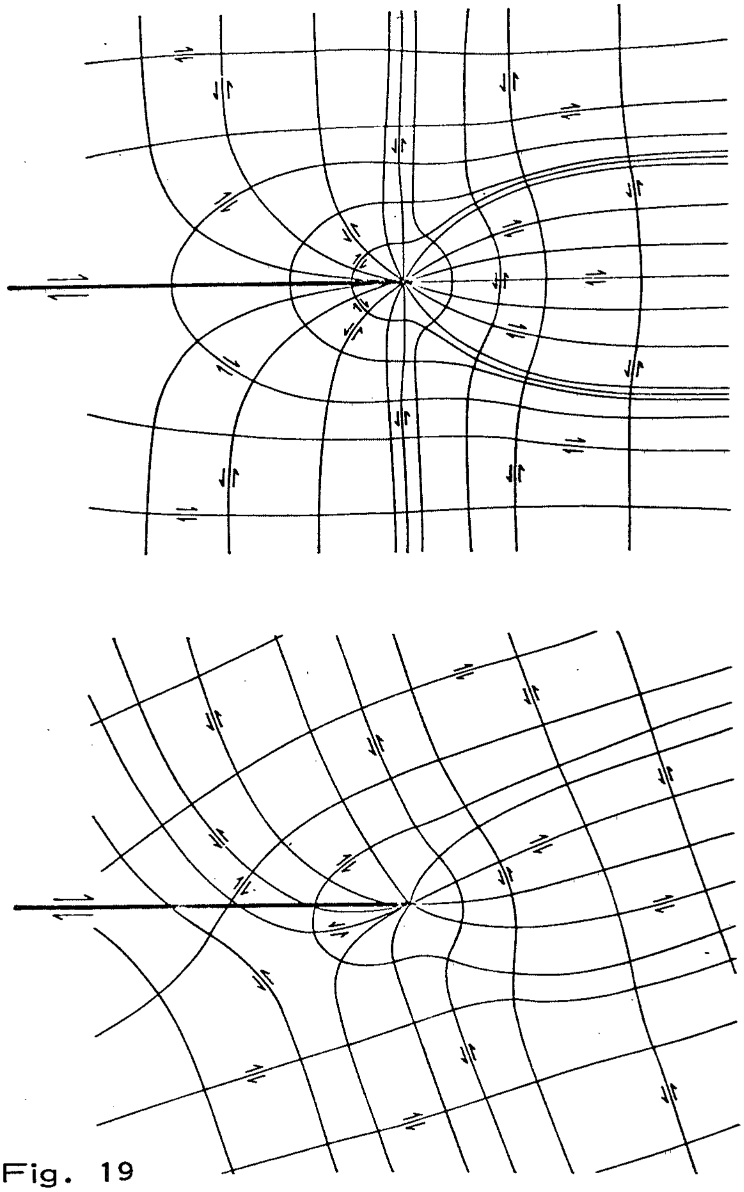


Fig. 19

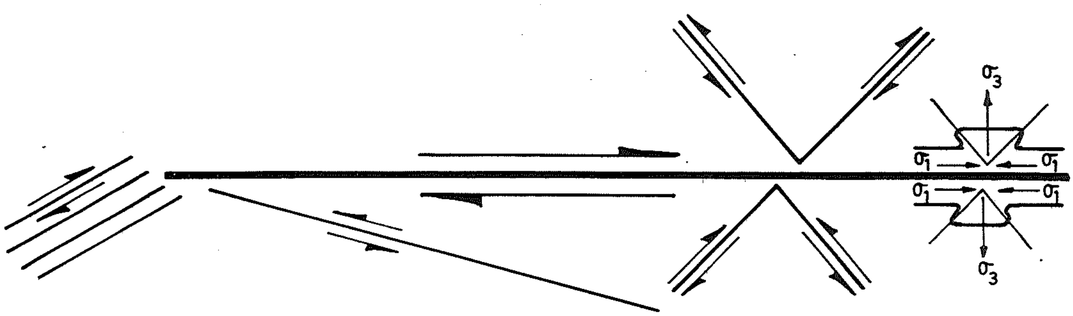


Fig. 20

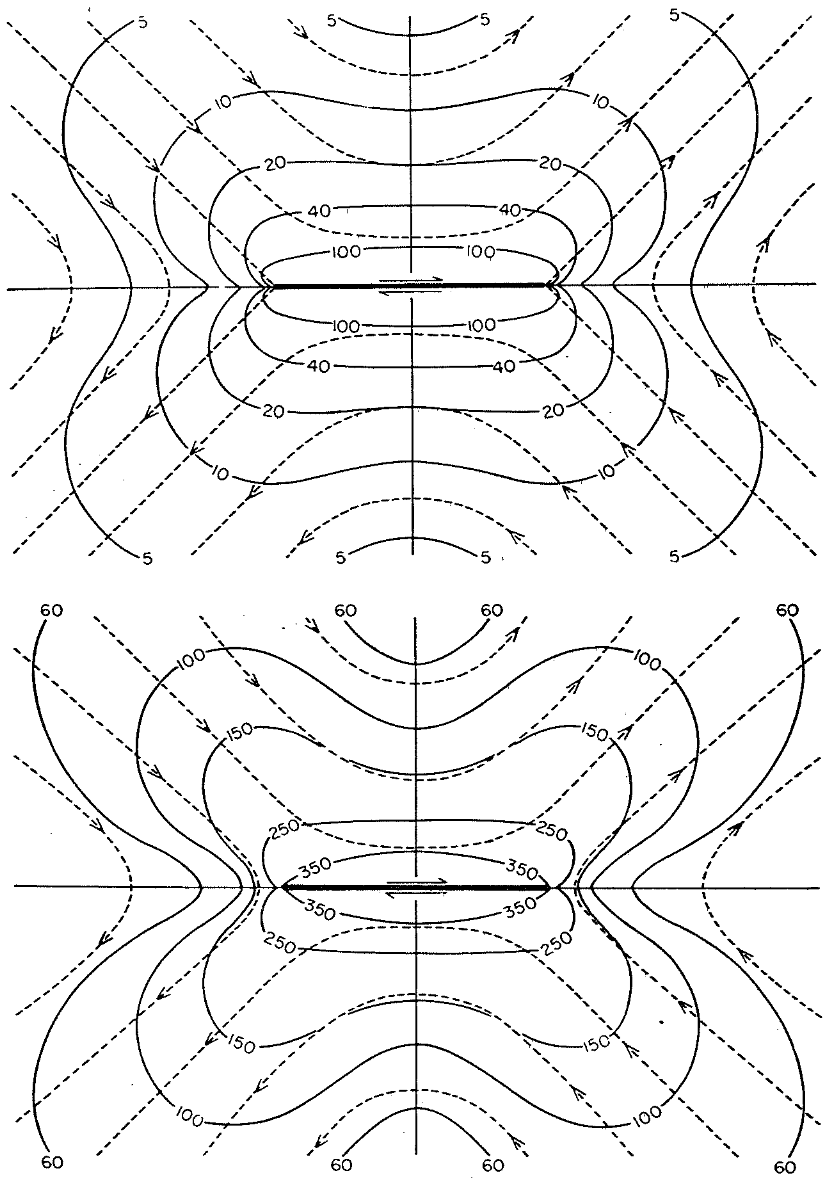


Fig. 21

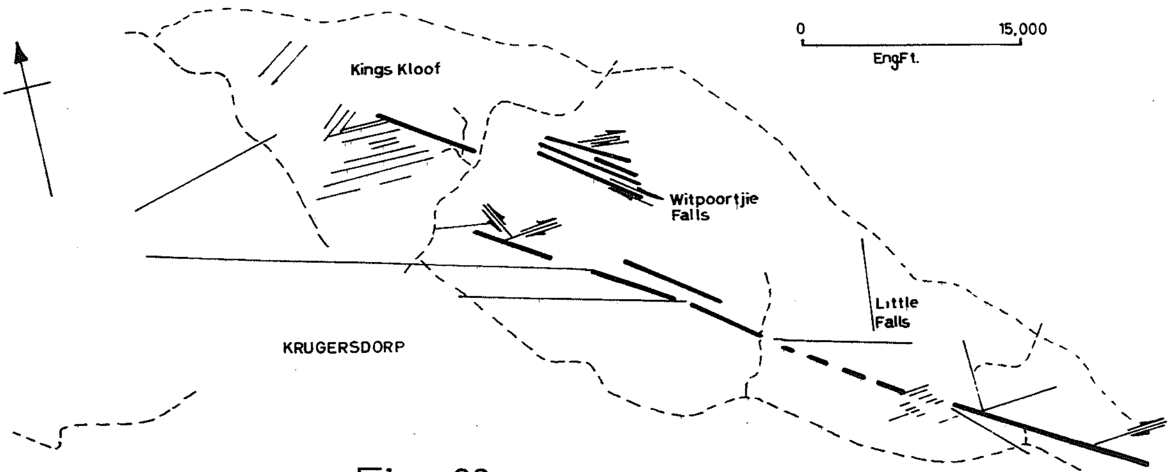
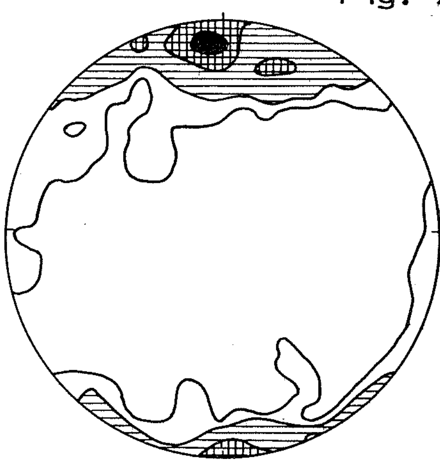


Fig. 22

Fig. 23



EQUAL AREA PROJECTION OF FAULTS FROM THE KRUGERSDORP-FLORIDA HILLS AREA. 128 OBSERVATIONS, CONTOURED AT 1/2, 10, AND 20 POINTS PER UNIT AREA. SEE TEXT.