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FAULTING AND DYKING IN THE MINES OF THE CENTRAL RAND GOLDFIELD

G. GROHMANN

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by

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ABSTRACT

The Central Rand Goldfield is terminated in the west by the Saxon/ Roodepoort Fault-Zone, a series of normal faults with an aggregate upthrow of about 900m towards the northwest. In the east, between the ERPM and New Kleinfontein mines, the strike of the Witwatersrand sediments changes abruptly from east-west to north-south, while dips change from southerly to easterly, marking the transition from the Central Rand Goldfield to the East Rand Goldfield. Most reefs of the Main-Bird and Kimberley horizons are present and have been worked, though never all in one locality. A total of ten reefs has been exploited. The Main Reef Leader and the South Reef have provided the bulk of the mined material, but significant tonnages also have been obtained from the Main Reef and the Kimberley Reef. Stratigraphic thicknesses decrease from west to east. The South Reef truncates the Main Reef Leader in the Rose Deep/Waverley (Wit Deep) area and cuts off the Main Reef in the ERPM Mine. The angle of the Main Reef-South Reef disconformity is about three minutes and of the Main Reef-Kimberley Reef disconformity about 30 minutes. The South Reef and the Kimberley Reef continue from the ERPM Mine into the East Rand Goldfield. The so-called Boksburg Gap does not represent an hiatus in sedimentation, but a change in the strike of strata as a consequence of folding.

Brittle deformation began during Witwatersrand deposition with the formation of east-west-trending, normal faults, accommodating a rising of the source-area and a subsidence of the basin, contemporaneous with an east-west-trending, left-lateral wrench-system. Wrenching persisted into early-Ventersdorp times, when it was accompanied by thrusting to the north-northeast. Intrusion of igneous material appears to have been very limited during early-Ventersdorp times. On cessation of wrenching and associated compression, the network of detachment-planes created by the wrenching formed the pathways for the intrusion of Ventersdorp igneous material and set the pattern for the majority of later dislocations and intrusions, which followed pre-existing breaks, to a large extent.

Sediments and faults are draped around the Johannesburg Dome, and steep, east-west-trending, reverse faults persist some distance down-dip from outcrop. Draping and reverse faults are due to the dome's rising, mainly after basin-formation, during late- or post-Transvaal times. Sediments and existing faults were tilted, which caused shortening of strata around the dome's perimeter. Some gravity-sliding occurred in at least one area. The felsic sills in the ERPM Mine probably are associated with this event, and the Saxon/Roodepoort Fault-Zone and associated horst, as well as a major overfold in the Durban Deep and Rand Leases mines, also are attributed to the diapiric activity of the dome.

The Bushveld period began with strong east-west compression and large-scale intrusion of igneous material into all pre-existing fault/dyke planes, excepting those with a northerly trend. Vertical displacements often are equal to the thickness of the intrusive. Some east-west shortening occurred. A large block of Witwatersrand sediments, comprising the greater part of the Crown Mines, Village Main, Robinson Deep, and City Deep mines, was displaced northwards, to

accommodate east-west compression and large-scale intrusion into this region. A magma-chamber appears to have been located under, or just to the south of, this area. Ventersdorp-age wrenches east of the Metropolitan Fault were reactivated in a right-lateral sense. Injection of Bushveld igneous material into existing northeast-trending fault/dyke planes began with the relaxation of east-west compression. Some subsidence occurred over the magma-chamber.

Relaxation of compression allowed emplacement of Pilanesberg intrusives, in a preferred northwest-southeast direction, into the western half of the study-area.

Insufficient information prevented the positive identification of Karoo-age intrusives.

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THE NATURE OF THE INVESTIGATIONS

The present study deals with the geological structure, particularly as reflected in brittle deformation, of Upper Witwatersrand rocks exposed in the underground workings of the Central Rand Goldfield. These workings are contained within an arc of gold mines stretching from Durban Roodepoort Deep Mine, some 18km west of central Johannesburg, to ERPM Mine at Boksburg, about 16km to the east of the city, the total length of outcrop being approximately 48km. In 100 years of mining, more than 400sq.km. of mineralized strata have been removed.

Structure-contour plans on a scale of 1:10 000, showing reefs, faults, and dykes first were compiled from 1:1 000 mine-plans. Statistical and structural analysis of the faulting and dyking was undertaken subsequently. As original mine-plans of the study-area make use of three different survey-grids, a new grid was devised for the area.

The new grid (Nx and Ny) coincides with the grid used on Durban Deep Mine (Goldfields grid). However, to facilitate computerization of data and to allow for any future extension of the study-area, the origin was shifted to the southwest of the Welkom Goldfield in the Orange Free State. Grid-conversions are as follows :

DURBAN DEEP GRID	:	Nx(m)=200.000-DDx(m) Ny(m)=400.000+DDy(m)
ROBINSON DEEP/CITY DEEP GRID	:	Nx(m)=219.619-RCx(f)*0,3047972654 Ny(m)=398.547+RCy(f)*0,3047972654
ERPM GRID	:	Nx(m)=259.070-ERx(m) Ny(m)=383.356+ERy(m)

Since correlation between the three original grids was determined from 1:10 000 shareholders' plans, it probably contains a small error.

Fault/dyke-reef intersection-lines (traces) have been used in this study, as fault-strikes and -dips are often lacking, or obscured, on the older mine-plans. Also, the relation between fault- and reef-plane was considered to be more important than the fault's absolute orientation in space. Since most of the dislocations have very steep dips, generally there is little difference between strike- and trace-bearings. Significant differences do occur in the case of Bushveld-age sills which, however, are easily recognized by their shallow dips and predominantly-reverse displacements.

For digitization, fault/dyke structures were broken up into straight-line segments, i.e. at each direction-change, a new section was started. Section-length and -bearing were calculated and recorded, together with dip-angle, dip-heading (east, west, etc.), type of dislocation (normal, reverse, wrench, etc.), age of dyke, if known, and co-ordinates and elevation of starting- and end-point of each section. For plotting purposes, dyke- or fault-traces wider than about 40m were digitized on both sides. One side, generally the up-thrown side, was marked with an identification symbol, to facilitate its exclusion during statistical calculations.

In order to cover the largest possible area, digitization was carried out on the Main Reef plan of Durban Deep Mine, up to the Rand Leases Dyke. From there to the Syenite Dyke in Simmer and Jack Mine, the Main Reef Leader plans were used. East of the Syenite Dyke, the South Reef plans were utilized. This produced 19 818 individual fault/dyke segments, of which 15 987 were statistically significant, while 3 831 were used for plotting purposes only. A total of 1 728km of dislocations was measured. An average 'straight' fault/dyke length, thus, is about 108m, while dislocation-density over the 196sq.km. study-area is about 8,8km/sq.km., ranging from 7 to 10km/sq.km. in individual blocks.

The resulting computer-files were used to produce rose-diagrams, in order to separate different fault-groups. This method was very effective in the eastern third of the study-area. However, due to the fact that each successive deformation-process made use of pre-existing planes of detachment, it was only partially successful in the central area. This section, stretching from Crown Mines to Rose Deep/Waverley Mine, hosts the highest concentration of Bushveld-age intrusives.

Problems were created by the non-availability of plans (Rand Leases, CMR, Stanhope, and Old Heriot mines) during the period of data-acquisition, as well as by the poor condition of some plans, by the lack of peg-elevations (portions of Rose Deep and Village Main mines), and by errors in, or absence of, geological annotations. In some instances, mylonitic material has been mis-identified as dyke material. Nevertheless, it is true to say that the majority of dislocations are accompanied by intrusive material. Some dips are sometimes demonstrably wrong, the direction of dip commonly being reversed. On Langlaagte, northeastern City Deep, Geldenhuis, and northwestern Simmer and Jack mines, no dips at all have been recorded. Where fault/dyke dips are missing, it was attempted to calculate these from the difference between the trace on the South Reef and on the Main Reef or Main Reef Leader. However, it was soon realized that considerable movement has occurred along bedding-planes, both in an E-W and a N-S direction, making calculated dips misleading.

A further problem was encountered in the fact that the survey-grid of Simmer and Jack Mine is in disagreement with those of the adjoining mines, being displaced about 100m to the north. Correcting this error appeared impractical and was not attempted. The apparent displacement of the Goch and Simmer dykes, where they cross the Simmer and Jack boundary in the west and east, respectively, is a function of the discrepancy in the survey-grids.

Positive identification of the ages of dykes in the ERPM area was obtained from the work of Jeffery (1975) and Fumerton (1975) and from a limited number of samples collected during the present study. Samples were also obtained from several dykes in Durban Deep, Rand Leases, Village Main, and Simmer and Jack mines. The Circular Dyke of Durban Deep Mine is known to be of Pilanesberg age (V.W. Werdmuller, pers. comm., 1986), and the Robinson Dyke was given a Pilanesberg age by Schreiner and Van Niekerk (1958). Allocation of ages to the dykes in the central part of the study-area was attempted, using criteria such as direction, thickness, angularity, and displacement (or lack thereof), in comparison with the known dykes in the eastern and western portions of the Central Rand Goldfield.

THE REEF HORIZONS OF THE CENTRAL RAND GOLDFIELD

The succession of reefs in the Central Rand Group of the Witwatersrand Sequence is too well known to justify detailed description here, and only a brief account of the extent of the succession in the Central Rand Goldfield is given below, starting at the base of the Main-Bird Sub-Group and working upwards :

The NORTH REEF has been worked in a few isolated patches in Village Main and Simmer and Jack mines, and fairly extensively in the northwest (Angelo) section of ERPM Mine, where it is called the Angelo Leader.

The MAIN REEF has been worked extensively in Durban Deep Mine, but only a few patches of it have been mined in the western section of Rand Leases Mine. From Rand Leases eastwards to City Deep Mine, little, or no, Main Reef has been stoped, although it is present. It again was exploited from Geldenhuis/Simmer and Jack Mine eastwards into ERPM Mine, where it is cut off by the South Reef.

Erosion channels, containing BANDED PYRITIC QUARTZITES, as well as remnants of the Main Reef, occur in several localities on the Central Rand. Exploitation, generally, was restricted to the Main Reef-derived conglomerates at the top of the channel. Since such workings usually were shown as Main Reef stoping, it has not been possible to establish channel-boundaries with accuracy. In the Village Main Mine, however, deposits in a large erosion-channel were worked fairly intensively, and channel-boundaries could be delineated. Three horizons were mined : the Top Reef consisted of reworked Main Reef, while the Middle and Bottom Reefs were true banded pyritic quartzites. The Top Reef occasionally graded into the Main Reef, with workings following steeper dips over the channel-margins and then returning to normal strike and dip on the actual Main Reef. The The Bottom Reef, usually some 20m below the Main Reef Leader, could be followed, in some places, for short distances under the North Reef, proving it to be older than the latter. The upper channel reefs are younger than the Main Reef, indicating that the channel was filled intermittently from pre-North Reef to post-Main Reef times. Channel-deposits have strikes and dips closely following those of the overlying Main Reef Leader. The approximate position of a related channel in the City Deep and Geldenhuis mines was established from old mine-reports.

The MAIN REEF LEADER has been mined sporadically on the eastern boundary of the Durban Deep Mine and continuously from the Rand Leases Mine to the Simmer and Jack/Rose Deep/Waverley mines, where it is cut off by the South Reef. The cut-off lines for both the Main Reef and the Main Reef Leader against the South Reef have northeasterly trends. However, in neither case is there a sharp boundary, as the angle of the disconformity is very small, about one minute.

The MIDDLE REEF, between the Main Reef Leader and the South Reef, has been worked in a few places in the northwestern section of Village Main Mine.

The SOUTH REEF has been mined throughout the study-area from Durban Deep Mine to ERPM Mine and, in fact, continues into the East Rand Goldfield. At ERPM Mine, after cutting off the Main Reef, it is called the Composite Reef, as it contains much material from both the Main Reef and the Main Reef Leader, so much so, that it was long mistaken for the Main Reef Leader, as it was on the East Rand also. Strictly speaking, it should be called the Composite Reef as far west as a line through Waverley, Rose Deep, and Simmer and Jack mines, where it separates from the Main Reef Leader. In the separation area, the South Reef consists of up to seven small-pebble conglomerates, two of which have been worked, the upper one usually being called the South South Reef.

The BIRD REEF has been worked at Rand Leases, CMR, and Crown Mines.

The KIMBERLEY REEF has been mined extensively on Durban Deep Mine and, to a lesser degree, from there to City Deep Mine. It has been prospected at Simmer and Jack and ERPM mines, but is economically exploitable again only in the East Rand.

DISPOSITION OF THE REEFS

The stratigraphic thickness of the package of sediments between the exploited reefs decreases from west to east. At Durban Deep Mine, the interval between the Main Reef and South Reef is about 40m and between the Main Reef and the Kimberley Reef about 1400m. The Main Reef Leader is truncated by the South Reef in the Simmer and Jack/Rose Deep/Waverley (Wit Deep) area, while the Main Reef is cut off in the ERPM Mine. The overall angle of disconformity between the Main Reef and the South Reef, therefore, is about three minutes. Separation between the Main Reef and the Kimberley Reef decreases to 1150m at Simmer and Jack Mine, indicating an angular difference of about 30 minutes. The South Reef and the Kimberley Reef continue into the East Rand Goldfield.

While there was no break in deposition in the Boksburg area, there was, however, a regional high which persisted throughout Central Rand Group times, forming the western boundary of the East Rand Goldfield. It is significant that stratigraphic thickness increases gradually from the Boksburg area to the west, reaching its greatest development on the western limb of the Central Rand, suggesting that the Central Rand represents the extreme eastern limb of the West Rand fan.

Reef dips are generally steep on outcrop, the steepest dips being encountered in the central area around the City Deep Mine (80° to vertical). They decrease eastwards and westwards, to about 30° on either flank. Dips also flatten with depth and decrease to about 30° or 40° within one kilometre south of the outcrop. There is an overturned section of Main Reef and Main Reef Leader in the deepest portions of the eastern side of the Durban Deep Mine and the western side of the Rand Leases Mine. The dip of the overturned strata can be as low as 65° to the north. The South Reef has not been mined into the roll-over, but it can be anticipated as also being overturned. The Kimberley Reef in Durban Deep steepens to vertical in this section, but rolls back to normal over a short distance. The overturned structure is probably due to diapiric activity of the Johannesburg Dome.

FAULTING OF WITWATERSRAND AGE

Plates 1-4 show fault/dyke traces for the whole of the study-area.

Initial brittle deformation of Central Rand rocks began during deposition, with the formation of east-west-trending faults with southerly dips and downthrows, accommodating uplift of the source-area and subsidence of the basin. These faults are numerous throughout the study-area, cutting the plane of the reef at 50°-70° in such a way that they dip to the south, when the reef-plane is rolled back to horizontal. Their present dips range from steeply-south to steeply-north, depending on the degree of tilting which affected them and the reef during uplift of the Johannesburg Dome. In spite of the fact that they have been reactivated extensively during subsequent periods of deformation, some of them still exhibit downthrows to the south. Those faults which have been tilted sufficiently to be overturned and dip to the north now appear to have reverse displacements. Some of this reverse attitude is real, however, since these faults were reactivated in the reverse sense during the dome's emplacement, as an adjustment to shortening around the dome's perimeter.

A left-lateral wrench-system, which was active during early-Ventersdorp times, also operated during Witwatersrand deposition (Stannistreet et al., 1985), and is described below. It is thought likely that the east-west-trending faults are related to this wrench-system. However, these faults were reactivated by the rising Johannesburg Dome and again by Bushveld compression, making it impossible to ascertain whether they had an original wrench component.

FAULTING AND DYKING OF VENTERSDORP AGE

(a) Wrench-Faulting

A left-lateral wrench-system was active during early-Ventersdorp times. The network of steep dislocations which it created set the pattern for most later faulting and intrusion.

Figure 1 is a strain-ellipse, showing the types of faulting caused by left-lateral wrenching. In the early stages of wrenching, a conjugate pair of steep strike-slip faults is created. One set forms at a shallow angle to the main wrench-strike, or principal-shear direction, while the second set forms at a high angle (Wilcox et al., 1973). These faults are called Riedel and Riedel-conjugate shears, respectively (Tchalenko and Ambraseys, 1970). Sense of movement along the Riedel shears is the same as that of the main wrench (i.e. left-lateral in this case), while on the Riedel conjugate shears it is in the opposite direction. Displacement on the Riedel conjugate shears is usually small, and such shears may constitute joints or fractures only, depending on the intensity of wrenching. The short axis of the ellipse (B-B' in Fig. 1) lies along the direction of maximum compression and bisects the acute angle between the Riedel and Riedel-conjugate shears. The long axis (A-A') represents the direction of maximum extension. As deformation progresses, the main wrench fault forms along the principal shear direction, and a second low-angle, left-lateral set, called P shears by Tchalenko (1970), connects the Riedel shears. The strike of Riedel and Riedel-conjugate shears lies in an anti-clockwise direction from the main wrench, while that of the P shears is turned clockwise. Normal faults can develop at right-angles to the line of maximum extension (A-A'), while reverse and thrust faults, if formed, are orthogonal to the maximum compression direction (B-B'). The angle between Riedel and principal-shear directions is normally 10°-30°, between Riedel-conjugate shears and principal shears 70°-90°, and between Riedel-conjugate and Riedel directions 60°-70°. All three angular relations depend on the nature of the rock being deformed and the magnitude of wrenching.

The rose-diagram in Figure 3 shows all faulting in the area east of the Nx+232.000m co-ordinate (Waverley Mine to ERPM Mine). Only the prominent set of north-northeast-trending dykes can be distinguished readily. By plotting only 'normal' faults steeper than 75° (the term is used here only to indicate sense of displacement), this set can be isolated and its average strike calculated to be about 030° (Fig. 4). Figure 5 shows true normal faults with easterly dips to be insignificant (the scattered northeast-trending group averages about 042°). Figure 6 indicates a small group of westerly-dipping normal faults, which strike approximately 062°.

Figure 7 shows the wrenches which strike from about 075° to 130°. These strikes can be separated into Riedel shears averaging 084,5° (264,5°), principal shears averaging 112,5° (292,5°), and P shears averaging 132° (312°). The latter two directions make up Jeffery's (1975) Group 5 dykes, while his Groups 3 and 4 dykes occupy the 030° direction, which corresponds to the Riedel-conjugate shear direction. All three groups have been identified as Ventersdorp in age.

Thrusting is represented on Figure 8. Although much disturbed by folding, an average strike of about 140° can be obtained from mine-plans.

Figure 2 shows a left-lateral strain-ellipse which employs the strikes calculated above. It is apparent that the dislocations of the ERPM area fit a left-lateral wrench model : the acute-angle between Riedel-conjugate and principal-shear directions is 82,5°, between Riedel and principal shear 28°, and between Riedel-conjugate and Riedel shears 54,5°. The last-mentioned figure is slightly below ideal (the area shows evidence of later folding which has influenced these figures), while the other two fit well. East- and west-dipping normal faults should strike about 057°, but, in fact, strike 042° and 062°, respectively. The east-dipping component is insignificant and can be ignored. The west-dipping group is within 5° of the theoretical value. The thrust, at 140°, is within 7° of the ideal value and, hence, also fits.

On Plate 5, the various fault-types have been marked, and Figures 9 and 10 show wrench- and thrust-traces separately, for clarity.

On first appraisal of the wrenches in the eastern third of the study-area (east of the Metropolitan Fault, which runs southeast through City Deep and Simmer and Jack mines), the most prominent feature observed is the right-lateral displacement of many of the northeast-trending dykes, which occupy the Riedel-conjugate plane of the wrench-system. Closer inspection, however, shows that where the wrenches cross the strike of the sediments, displacement of the reef is almost invariably left-lateral. Up to 200m of such displacement can be measured. Since intrusion of igneous material into the Riedel-conjugate could occur only towards the closing stages of wrenching, such dykes would have undergone little, if any, left-lateral displacement during Ventersdorp wrenching.

For these reasons and because of the good fit of the left-lateral strain-ellipse to the fault-pattern of this area, it has been concluded that the wrenches were formed in a left-lateral system. It will be shown later that Ventersdorp wrenches east of the Metropolitan Fault were reactivated in a right-lateral sense during Bushveld compression. They show predominantly-right-lateral displacement of the dykes occupying the Riedel-conjugate plane, while retaining a large measure of left-lateral displacement of the sediments. Right-lateral displacement was not large enough to obliterate the earlier movement, and, if the two opposing displacements are added, original left-lateral dislocations of 200-300m can be calculated, in places. By definition, displacement along Riedel-conjugate shears is right-lateral, and such movement can be observed occasionally, though it is always small. In some instances, it manifests itself merely by strike-changes in the sediments next to the Riedel-conjugate plane indicating a right-hand drag.

A 16km-long strike-slip fault runs from the southwestern corner of Crown Mines east-southeast to the southeast corner of City Deep Mine, striking from 080° to 115°. This fault, here called the Crown-City Wrench, does not terminate at either of these locations, but turns slightly to the south and leaves the mined areas. It follows reef-strike for most of its length, showing little displacement of sediments, except at its eastern end, where it crosses the reef-strike and where some left-lateral movement can be observed. This wrench, however, does move a very few northerly-trending, near-vertical dykes for up to 200m in a left-lateral sense. In Crown Mines, this fault is accompanied for 7km along its western course by a second shear (100-800m to the north and called the Crown Wrench in this study), showing similar characteristics. Both faults are associated with numerous Riedel conjugates. These strike at 020°-040° and form angles of 40°-75° to the main strike-slip faults, thus fitting the left-lateral model.

The Village Dyke of the Robinson Deep Mine also forms part of a long strike-slip fault, which begins in the central portion of Crown Mines, about 500m north of the Crown Wrench, and strikes at 085°, initially, swinging gradually round to 110°. It runs east for about 15km, ending some 300m short of Robinson Deep's eastern boundary.

While some components of these strike-slip faults occupy the principal-shear direction of the wrench-system, their association with the numerous, prominent Riedel conjugates makes them rather-large Riedel shears. Because these strike-slip faults occur only in the southern half of the area of these mines and because their respective displacements increase towards the south, it would appear that the main wrench of this system must lie still farther to the south.

The above strike-slip faults show varying amounts of left-lateral displacement of reef, but very little such displacement of other structures. They are, however, themselves crossed, and sometimes displaced, by a host of other faults and dykes, indicating that they ceased to operate very early in the deformational history of the Central Rand, i.e. in early-to-middle-Ventersdorp times. Unlike wrenches further east, they were not reactivated in a right-lateral sense, though some dyke-emplacement and vertical movement seems to have taken place during Bushveld times.

A structure similar to the Village Dyke, here called the South Village Dyke, branches away from the Village Dyke about 600m east of the Robinson Dyke. Initially it strikes at 120° for 500m, but then turns to run at about 090°, sub-parallel to the Village Dyke, for about 1,3km, then at 100° for 1,9km, at 080° for 700m, at 130° for 800m, crossing the Crown-City Wrench, and ultimately at 140° for 600m, where it leaves the mined areas. The South Village Dyke, while generally dipping to the south at 70°-85°, occasionally shows shallow, southerly dips, 40°-55°, unlike the Crown, Crown-City, and Village Dyke wrenches which have near-vertical dips. It also exhibits a measure of reverse displacement. It, therefore, is thought to be a Bushveld intrusive, which made extensive use of the Ventersdorp Riedel, principal, and P-shear detachment-zones.

The wrench-system described above appears to be analogous to that of the Vogels Tear Fault, a large, left-lateral wrench-fault with measurable displacements of up to 1km. The Vogels Tear Fault traverses the southern third of the East Rand Goldfield, a distance of some 30km, striking at about 295° (115°). On leaving the East Rand, in the area of the Van Dyke Mine, it turns west, to strike at about 280°-285°, and passes about 3,5km south of ERPM's Far East Shaft. The change of direction occurs where the fault crosses the Boksburg High and is probably due to a different strain-environment on opposite sides of the high. A measure of later folding also appears to be involved.

Folding around the Johannesburg Dome is shown by the changing reef-strikes and the courses of the Crown and Crown-City wrenches. This can be demonstrated by the use of rose-diagrams. Figure 11 is a rose-diagram showing all steep fault/dyke planes in the block between the Nx+220.000m and Nx+224.000m co-ordinates (western City Deep and eastern Village Main), where dykes in the Riedel-conjugate direction, on average, strike at about 034°. An incipient orthogonal at 325° is close to the P-shear trend. Figure 12 represents the wrenches, in the same area, which strike at about 281°. Figure 13 depicts wrenches in the Robinson Deep Mine to be almost due east-west. In Figure 14, the amount of folding, thought to have been caused by both the Johannesburg Dome and the intrusion of the South Rand/Vierfontein dyke-system, can be gauged by the dispersion of strikes. Nevertheless, the Riedel-conjugate direction is recognizable at about 062° and the strike-slip faults at 282°. In Figure 15, all steep faults in the south-central part of Crown Mines (between Nx+212.000 to Nx+214.000 and Ny+397.000 to Ny+395.000) are shown. The regional effect of the folding, which shows up as a pronounced scatter of strikes in the larger (4km-E-W) blocks used above, is reduced in this area. The Riedel-conjugate direction averages 067,5° and the wrenches 282,5°. The prominent group at 340° represents the Pilanesberg direction, though none of the dykes following it here could be identified positively. Figure 16 covers the same area as Figure 14 and shows the wrenches at about 283°. Figure 17 refers to the eastern portion of the Rand Leases Mine and the western section of the CMR Mine. Here, no wrenches could be identified on the mine-plans. The majority of steep faults strike at about 065° and 345°. It can be seen from these rose-diagrams that there is a clockwise-rotation of the fault-pattern in the western half of the study-area, with the greatest change occurring around the South Rand/Vierfontein dyke-system.

An average strike of 285°, from its last-known position on the Van Dyk Mine, would take the Vogels Tear Fault to join the Crown-City Wrench in the south-eastern corner of the City Deep Mine. However, there is no evidence to suggest that this is the case. Maximum measurable displacement on the Crown-City Wrench is only 300m, and it is thought likely that the Vogels Tear Fault follows a course similar and sub-parallel to that of the Crown-City Wrench. It should pass, therefore, to the south of the Central Rand mines, some 3-4km south of the Robinson Deep boundary.

(b) Thrust-Faulting

The Phoenix Fault of the ERPM Mine is the eastern limb of a thrust fault which runs from the southeastern area of the mine some 3km to the northwest, dipping 40°-65° to the southwest. In the vicinity of the outcrop, uplift caused by the Johannesburg Dome tilted up reef- and thrust-planes to their present respective dips of 60° and 80° to the south and turned the strike of the thrust further to the west. Wrenching and a prominent fold accompany the change of direction. The thrust continues to the west-northwest, more-or-less parallel to reef-strike, for 3,5km. Vertical displacement in this area is 300-400m and stratigraphic throw 200m. This section was called the Comet Fault by Jeffery (1975).

The thrust then changes direction to the southwest and flattens back to about 55° in the Balmoral/Driefontein area, where it is folded to the north and then to the west and tilted up, to dip about 70° to the south-southeast. In the area of the Glenluce Shaft (Waverley Mine), it is displaced by a prominent fault occupying the P-shear direction of the wrench-system. This latter fault was strongly reactivated during Bushveld compression. It has been named the East Metropolitan Fault, as it obviously is related to the Metropolitan Fault further west. The thrust, now labelled Knight's Thrust, after the Knight's Deep Mine, then winds its way southwest, accompanied by the Glen Dyke (a Bushveld intrusive) for about 2km, until it ends in a large fold-area in the upper part of the Rose Deep Mine (Plate 10). Similarly, its eastern pin-down is marked by a fold in ERPM (Plate 11). The length of the thrust-front is about 12km, while depth of the bow, before deformation by the Johannesburg Dome and later Bushveld compression, was about 2km, giving a typical thrust ratio of 6:1. The strike of the 'bow-string' is about 140°. If the steep, central section of the thrust is rolled back to its original, near-horizontal attitude, its strike rotates clockwise and approaches the theoretical value of 147°, i.e. orthogonal to the direction of maximum compression, which is 057° (Fig. 2). The thrust, therefore, also fits the left-lateral model.

Since the thrust was formed during maximum compression, it must have pre-dated the dyke-swarm in the Riedel-conjugate plane (030°). Displacements of these dykes on the thrust-plane occurred during reactivation of this plane produced by the rising of the Johannesburg Dome and by Bushveld compression, the latter causing right-lateral movement and folding of the thrust-plane.

(c) Dyke-Emplacement

The preferred detachment-plane for intrusion of Ventersdorp dyke-material was that of the Riedel conjugates (030°). Since this plane was under compression while the system was operating, most of the dykes occupying these planes must have been intruded after cessation of wrenching. As no wrench-system operates with equal intensity throughout its history, it is likely that some of the Riedel conjugates were invaded during periods of reduced wrench-activity. Consequently, early-Ventersdorp intrusions made use of normal faults striking 055°-070° and, occasionally, Riedel conjugates. These early intrusives underwent sufficient left-lateral displacement for this effect still to be visible, in spite of later Bushveld movement in the opposite direction. The majority of intrusions occurred after cessation of wrenching, probably from mid-Ventersdorp times onwards, and such dykes were affected only by later, right-lateral displacement.

East-west-trending planes were also intruded, but these dykes subsequently were sheared beyond recognition. However, their chemistry indicates them to belong to the Ventersdorp assemblage (Jeffery, 1975).

In summary, it would appear that the left-lateral wrenching, and associated thrusting, of the Central Rand, which can be traced for some 35km from ERPM to Crown Mines, and probably further, belong to the same system as the Vogels Tear Fault. This fault is associated with northwest-trending folding which has been shown to be contemporaneous with Witwatersrand deposition (Antrobus and Whiteside, 1964). Therefore, the fault must have been active in Witwatersrand times (Stannistreet et al., 1985). Evidence from the present study supports this proposition and leads to the conclusion that a major left-lateral wrench-system, at least 65km long, operated in the Central and East Rand during Witwatersrand deposition, creating the above strike-slip faults after consolidation of sediments, i.e. from late-Witwatersrand to Ventersdorp times. Therefore, the subsidence of the depository in this area, possibly, was also a consequence of wrenching.

Plates 12a and b show all strike-slip faults recognized in the study-area, as well as the inferred course of the Vogels Tear Fault. The easternmost part of this fault, in the Van Dyk Mine, was established by actual intersections in 44 and 48 Level Drives South.

DEFORMATION ASSOCIATED WITH THE JOHANNESBURG GRANITE DOME

After the Ventersdorp activity, the next period of deformation was associated with the rising of the Johannesburg Granite Dome, which is considered to be a late- or post-Transvaal event (C. Roering, 1986, pers. com.). This is supported in the study-area by the fact that the numerous intrusions of Bushveld age do not appear to have been affected directly by the rising of the dome, thus making the domal deformation pre-Bushveld in age. Uplift of the dome caused tilting of sediments and existing faults to approximately their present dips and produced north-south shortening of strata around its perimeter. In the process, a zone of reverse faults was created within 500-1000m of the present Witwatersrand outcrop. Reverse faults represent reactivated Ventersdorp detachment-planes, many of them tilted sufficiently to acquire northerly dips, resulting in apparent reverse faults. However, some faults also were reactivated in a true reverse sense.

Movement on bedding-planes took place, and the felsic sills of the ERPM Mine could have been emplaced at this time. Fumerton (1975) reported a late-Transvaal age for these sills. The plane of the Knight's Thrust was reactivated, as were the Riedel conjugates closest to the dome. Movement along the Riedel conjugates caused some north-south disruption of the thrust, which was also tilted, to acquire its present, steep, southerly dips.

FAULTING AND DYKING OF BUSHVELD AGE

The Bushveld period of deformation began with strong east-west compression and large-scale intrusion of dyke-material into all pre-existing fault/dyke planes, except most of those with a northerly trend. Compression was probably due to the emplacement of the Bushveld dykes themselves, particularly of the substantial volumes injected into the eastern Transvaal (C. Roering, 1986, pers. com.). The Johannesburg Dome acted as a buttress in the Central Rand, so that westerly displacement of sediments increases with distance to the south of the dome. This movement made use of existing fault-planes, causing the numerous right-lateral displacements found throughout the eastern third of the Central Rand. East-west movement also took place on bedding-planes. The first Bushveld injection took place as a single emplacement of igneous material, under very high hydraulic pressure, simultaneously into the whole of the existing network of detachment-planes, excepting only most-northerly-trending ones which were held closed by east-west compression.

Samples were obtained of presumed Bushveld material from the Simmer, Rose, and Wit dykes, in the western section of the ERPM Mine, and from a sill present in the same area, which is very prominently developed in the Simmer and Jack Mine. This sill has been called the Dipping Dyke, but is referred to as the S&J Sill in this study. The samples all proved to consist of the same dark, noritic material, confirming Jeffery's (1975) findings on the Simmer Dyke. Material differed only in grain-size and amount of alteration, the latter of which is thought to be a deuteric, rather than a post-emplacement metamorphic, effect (C.R. Anhaeusser, 1986, pers. com.).

The Simmer Dyke follows pre-existing Ventersdorp breaks over its entire length, changing from apparent-reverse to normal throw and back again, depending on the attitude of the invaded plane. The Rose Dyke behaves in a similar manner, but strikes north-south for 2km along its upper course through the mined areas, where it also 'crosses' the Simmer Dyke, before swinging to the southeast and into the Ventersdorp P-shear direction. This it follows for about one km, before 'joining' the Wit Dyke, striking southwest for 500m, after which it curves away to the south. By their similar behaviour-patterns, other dykes, such as the Goch, Grahamstown, and South Rand/Vierfontein, can be recognized as belonging to the Bushveld assemblage.

The whole, complicated picture must be best understood as a single event, with intrusion of dyke-material taking place under strong east-west compression and with large blocks of Witwatersrand sediments being either lifted or depressed, in response to the compression and the attitude of existing fault-planes. Displacement generally is equal to the thickness of the intrusive, unless some previous displacement, caused by wrenching, is also present, in which case a composite throw results.

The Simmer and Rose dykes are not distinct intrusives, but owe their specific names to certain displacements, which persist along their courses. The throw on the Simmer Dyke is up on the west and on the Rose Dyke up on the east. The Glen Dyke also belongs in this category. It 'branches' away from the Rose Dyke in the northeastern corner of Rose Deep and runs for 2km in a northeasterly direction, following the course of the Knight's Thrust. In this instance, displacement is a combination of the thrust's displacement and thickness of the Glen intrusive.

A narrow, steeply-dipping dyke, called the 'S'-dyke in Simmer and Jack Mine, splits away from the Metropolitan Dyke in the southeastern corner of the Geldenhuis Deep Mine, crosses the S&J Dyke which runs roughly east-west, then turns gradually to the north, through the Rose Deep Mine, and leaves the mined area striking north-northwestwards in the western portion of the Waverley Mine. The Wit Dyke has a similar trend along its southern course, though, in its northern third, it follows the Ventersdorp Riedel-conjugate direction. The fault-planes occupied by these two dykes, the north-south-trending part of the Rose Dyke, and the folding of the Knight's Thrust are thought to be the result of Bushveld compression, part of a major event which can be recognized from the ERPM Mine westwards to the CMR Mine.

This compression reactivated the East Metropolitan and Metropolitan faults and a line of faults, dipping steeply to the southeast or south-southeast, which runs diagonally through Crown Mines from southwest to northeast to the Crown-Ferreira Dyke. A component of the last-mentioned fault-zone continues north of the Crown-Ferreira Dyke, striking east-northeastwards, until it meets the Robinson Dyke, near outcrop. The northeast-trending West Metropolitan Fault-Zone is symmetrical to the Metropolitan Fault. The block between the West Metropolitan and Metropolitan faults was displaced northwards, to accommodate compression, as well as the emplacement of Bushveld dykes, such as the South Rand/Vierfontein/South Village dyke-systems and the Goch Dyke. Movement in the West Metropolitan zone was left-lateral (up to 250m) and, on the Metropolitan Fault, right-lateral (over 300m, in places). Both fault-systems underwent a reversal of displacement direction. The West Metropolitan zone originated as Riedel-conjugate shearing created by the Crown and Crown-City strike-slip faults, and original movement would have been right-lateral, though probably not large. The Metropolitan Fault used the Ventersdorp P-shear and, hence, was initially left-lateral. Since a measure of original wrenching had to be obliterated before later movement could become evident, total displacement during Bushveld times must have been greater than now can be measured. Displacement along both fault-zones diminishes southwards. The Metropolitan Fault eventually joins the prominent P-shear south of the Simmer Dyke, in the southwestern section of ERPM.

The Grahamstown Dyke, which occupies the Riedel-conjugate-shear direction for most of its length, dips steeply east and also accommodates east-west compression with up to 200m of reverse upthrow to the east. The Goch Dyke occupies the Ventersdorp P-shear direction for most of its length, as do the eastern parts of the South Rand/Vierfontein and South Village dyke-systems. The wider dykes show displacement consisting of left-lateral (Ventersdorp) wrenching plus the thickness of the Bushveld intrusive. The Village, Crown, and Crown-City planes do not appear to have been invaded by Bushveld dykes. The major part of the Village and Vierfontein dyke-systems and the central portion of the South Rand Dyke occupy the Ventersdorp principal- and Riedel-shear directions, while the western third of the South Rand Dyke and extreme western portion of the Vierfontein Dyke used the Riedel-conjugate direction. The apparent 300m-left-lateral displacement of the South Rand/Vierfontein Dyke, where it crosses the Crown-City Wrench in the west, is considered to constitute an intrusion into a prominent Riedel conjugate, displaced during Ventersdorp wrenching, rather than representing a displacement of the Bushveld dyke. Nowhere in the study-area can left-lateral wrenching be established for any but the earliest part of the area's deformational history. The elliptical, ring-dyke-like structure of the South Rand/Vierfontein dyke-system is thought to be due to its location over a major Bushveld feeder or magma-chamber.

The block between the West Metropolitan and Metropolitan faults was pushed northwards, in response to east-west compression and the intrusion of the South Rand/Vierfontein dyke-system, while the block between the Metropolitan and East Metropolitan faults moved southwards, relative to each other and neighbouring blocks. The wedge comprising the eastern section of the Waverley Mine, the northern portion of the Driefontein and Balmoral mines, and the northwestern segment of the ERPM Mine was pushed to the northwest. The East Metropolitan Fault (a Ventersdorp P-shear) was reactivated in its original left-lateral direction, though, again, this need not have been a large fault originally. In no case did displacement occur only on the major planes described here, but smaller, similar movements took place on numerous sub-parallel surfaces. There also was movement along bedding-planes of the sediments, successively higher beds being pushed to the north.

The oval block bounded by the South Rand/Vierfontein Dyke has been raised up to 200m above the level of the surrounding country. It is, however, on approximately the same level as the ground to the east of the Grahamstown Dyke, the latter taking over the displacement of the South Rand Dyke at their point of junction. For 6km to the east of the Grahamstown Dyke, many dykes occupying the Riedel-conjugate-shear direction, 034° in this area, exhibit reverse upthrows to the east, like the Grahamstown Dyke, though smaller. The northern part of the Wemmer Dyke, some 400m west of the Grahamstown Dyke before converging on and crossing it, shows the same type of displacement. It is thought likely that the 200m-relative-elevation of the block encircled by the South Rand/Vierfontein dyke-system was achieved partly by uplift and partly by subsidence of the immediately-surrounding terrane into the depleting magma-chamber.

To the west of the West Metropolitan Fault-Zone, there is an approximately 4km-wide belt of faulting showing essentially the same patterns as the faults in the West Metropolitan zone. Non-availability of the original 1:1 000 mine plans of Rand Leases and CMR mines rendered it impossible to obtain dips for many of the structures in this area.

There are numerous Bushveld sills throughout the Central Rand. They can be recognized by their shallow dips and by displacements which are generally equal to their thickness. The most prominent one, the S&J Sill, cuts out much of the Main Reef, Main Reef Leader, and even South Reef in the Simmer and Jack Mine. From below, it cuts through the Main Reef about 1300m south of the reef's outcrop, then continues to roll in and out of the reefs for some 1700m, before steepening and returning to the footwall. Most of Simmer and Jack is affected over a strike of some 4km east-west, beyond which the sill then can be traced into the Rose Deep and ERPM mines where, fortunately, it is steeper and causes less disruption. It is possible that not all the intersections of the 'sill' in the southeastern part of the Simmer and Jack Mine are actually igneous. In this area, the South Reef begins to cut off the Main Reef, and it is likely that the Black Bar, an argillaceous sediment found above the Main Reef, was mistaken sometimes for a sill. The S&J Sill is not shown on accompanying computer-plots, except in the east, through Rose Deep and into ERPM, where it steepens, to become a dyke. Its extent can be gauged, however, from the gaps in the 1000m, 1500m, and 2000m reef-contours of the Simmer and Jack Mine.

FAULTING AND DYKING OF PILANESBERG AGE

The last identifiable structural event in the Central Rand Goldfield was the emplacement of Pilanesberg-age dykes, during a period of extension. Figure 18 shows the strike-distribution of all known Pilanesberg structures in the study-area. The average strike is about 342°. As was shown above, in the western quarter of the study-area, this is approximately the Ventersdorp P-shear direction. All but one of the Pilanesberg structures occur in the western half of the study-area. The Circular Dyke of the Durban Deep Mine (named after the Circular Shaft) and the Robinson Dyke have an anomalous north-south orientation. The reason for this has not been determined. All known Pilanesberg structures between these two dykes have a strike of 330°-340°. West of the Circular Dyke, folding caused by the Saxon/Roodepoort Fault-Zone rotated the strike of sediments and of existing fractures in an anti-clockwise direction, and Pilanesberg dykes in this area have slightly-more westerly strikes (320°-330°).

Two phases of Pilanesberg intrusion have been recognized : an early, mafic phase, which always contains some sulphides, and a later, pink-to-red, syenitic phase. In the west of the Durban Deep Mine, No. 1 Dyke consists of a dark-green-to-black mafic and a pink syenitic phase. No. 2 Dyke was assigned a

Pilanesberg age because of its behaviour, no actual dyke-material being available. No. 4 Dyke consists of the mafic phase only. Nos. 5 and 6 dykes are probably Pilanesberg, although no specimens were available for study. The Circular Dyke shows both mafic and syenitic phase (V.W. Werdmuller, 1986, pers. com.).

There are three large Pilanesberg dykes in the Rand Leases Mine. One large dyke-system, just inside of the Durban Deep Mine boundary, named the Rand Leases Dyke in this study, is made up of numerous, tree-like branches in the upper parts of the mine. These consolidate into one large trunk, up to 140m thick, with depth and distance from outcrop. Branching near outcrop, such as shown by the Rand Leases and Bantjes dykes, was found during mining to be typical of Pilanesberg dykes (V.W. Werdmuller, 1986, pers. com.). The Rand Leases Dyke, where intersected in a borehole drilled from 42Lev.X-Cut South in the Rand Leases Mine, is represented by a very coarse mafic phase, with abundant sulphides. This dyke was described in old mine records as having a 'reddish' syenitic phase 'just west of its centre', but the mafic phase was thought to be of Karoo age (Ermert, 1952). Another prominent dyke cutting through the middle of Rand Leases, here called the Central Dyke, has been identified as Pilanesberg (M. Mullins, 1986, pers. com.), and the upper portion of the Bantjes Dyke, which cuts through the northeastern corner of Rand Leases, before entering the CMR Mine, represents a mafic Pilanesberg phase. North of the Ny+400.000m co-ordinate, the area from the Central Dyke to about 2km east of the Bantjes Dyke contains numerous smaller dykes which strike approximately 340° and, therefore, could be of Pilanesberg age. A pronounced orthogonal set in this area possibly also belongs to this age-group. All the above Pilanesberg dykes dip either vertically or steeply to the east. Displacements are not common on these dykes, but, where present, are usually normal. Where not, they are generally throws inherited from older fault-planes.

The next feature east of the Bantjes Dyke, which can be identified as of Pilanesberg age, is the 12-Shaft Fault of Crown Mines. This differs from the Pilanesberg structures described above in that it has a westerly dip (70°-85°) and downthrow. Displacement ranges from about 80m, in the south, to 150m, near the outcrop. It consists of a fault-plane only over most of its length (V.W. Werdmuller, 1986, pers. com.). However, it displaces the South Rand/ Vierfontein Dyke and is, therefore, post-Bushveld. It also occupies the preferred Pilanesberg direction of about 330°. In addition, north of the West Metropolitan Fault-Zone, it does contain dyke-material and splits up in typical Pilanesberg fashion.

The easternmost Pilanesberg dyke in the western half of the study-area is the Robinson Dyke which strikes north-south and dips vertically or steeply east, except north of the Crown-Ferreira Dyke, where it dips at 75° to the west. It has been dated at 1310 $\pm$ 50 Ma by Schreiner and van Niekerk (1958).

The only identified Pilanesberg intrusion in the eastern half of the study-area is the Syenite Dyke of the Simmer and Jack Mine. It is composed of coarse, dark-red syenite, and it is not known whether the mafic phase also is present. It dips vertically or steeply east or west and has an average strike of 330°-340°. However, unlike the Pilanesberg intrusions further west, it is very erratic in its course. A similar structure, some 1300m to the west of the Syenite Dyke, could not be identified, because of non-availability of material and absence of dip information along its northern half in the Geldenhuis Mine.

From the erratic course of the Syenite Dyke and the apparent scarcity of Pilanesberg intrusions in the eastern half of the Central Rand, it would appear that this area remained under compression during Pilanesberg times and, hence, was not amenable to dyke-intrusion. Unlike those of Bushveld age, Pilanesberg dykes seem to have made use of pre-existing detachment-planes only where these were reasonably close to their preferred strike of 342°.

DYKING IN KAROO AGE

Karoo dykes have been identified in the Durban Deep Mine (V.W. Werdmuller, 1986, pers. com.) in workings on the Kimberley reefs. It was not possible to positively correlate these with any dykes in the Main Reef group. There is also a dyke-swarm, striking at 340°, in the southeastern part of the ERPM Mine, tentatively identified as of Bushveld age by Jeffery (1975), which does not conform, however, to any of the above deformation-systems in its characteristics. It does appear similar to dyke-swarms of Karoo age found in the East Rand.

CONCLUSIONS

In spite of the difficulties inherent in using a mainly-historical data-base, the following conclusions can be drawn with some confidence :

1. A left-lateral wrench-system, active during Witwatersrand and early-Ventersdorp times, set the pattern for, and was re-used by, all subsequent deformation and intrusion. Ventersdorp wrenches show little or no vertical displacement, since movements occurred mainly in the plane of the reef. One thrust-fault only has been identified. Some normal faults do occur, but are small. Dykes were intruded in a preferred north-northeasterly direction, but east-west planes were also used.

2. The rise of the Johannesburg Granite Dome in post-Transvaal times modified the pre-existing pattern by tilting, reactivation, and folding. Few, if any, new fault-planes were created. Felsic sills appear to belong to this period.

3. Bushveld-age compression and intrusion made almost exclusive use of existing fault/dyke-planes, causing some modification by reactivation and folding. Displacements are large, predominantly reverse, but can appear normal, depending on the attitude of the invaded plane. The displacements often equal the thickness of the intrusion.

4. Pilanesberg-age dykes invaded mainly the western half of the Central Rand during a partial relaxation of pressure. They followed pre-existing planes of detachment where these were aligned close to 340°, but made their own way elsewhere. Little vertical displacement occurred, but, where present, is usually normal.

5. Karoo-age dykes are present, but need further study for proper identification.

Plates 6a and b, 7a and b, 8a and b, and 9a and b show deformations according to age. Each fault/dyke has been allocated to the last intrusion or movement, to which it was subjected.

ACKNOWLEDGEMENTS

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TABLE 1

STUDY-AREA

DIMENSIONS	:	46 x 4,25 km
OUTCROP-LENGTH	:	48 km
AREA	:	196 sq. km

DISLOCATIONS

TYPE	DIP	LENGTH (km)	% of TOTAL
NORMAL	VERTICAL	363,4	21,0
	EAST	298,9	17,3
	WEST	279,1	16,1
	NORTH	48,6	2,8
	SOUTH	48,0	2,8
SUB-TOTAL		1038,0	60,0
REVERSE	EAST	108,4	6,3
	WEST	91,4	5,3
	NORTH	35,6	2,1
	SOUTH	113,1	6,5
SUB-TOTAL		348,5	20,2
WRENCH		173,9	10,1
THRUST		17,2	1,0
UNIDENTIFIED		150,6	8,7
SUB-TOTAL		341,7	19,8
GRAND TOTAL		1728,2	100,0

FAULT DENSITY	:	8,8 km per sq. km
No. of FAULT-SECTIONS DIGITIZED	:	
For Statistics and Plotting	:	15987
For Plotting Only	:	3831
TOTAL		19818
AVERAGE STRAIGHT FAULT-LENGTH	:	108 m

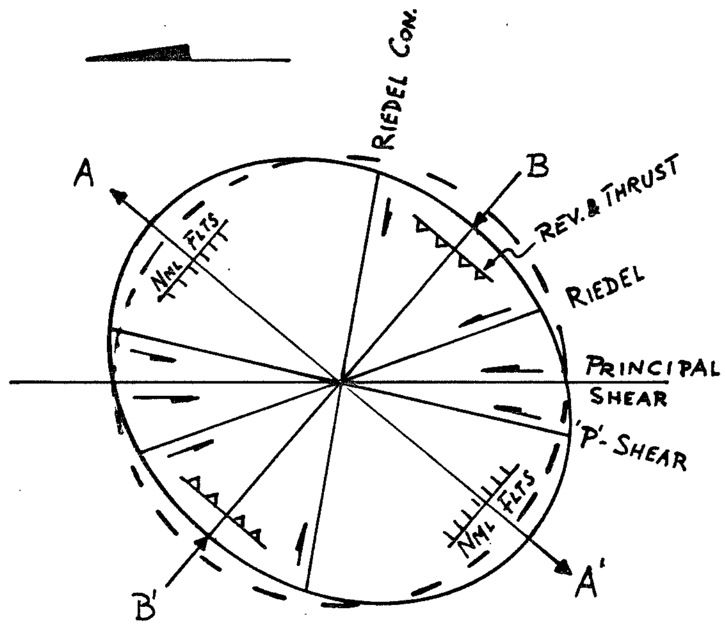


Fig. 1

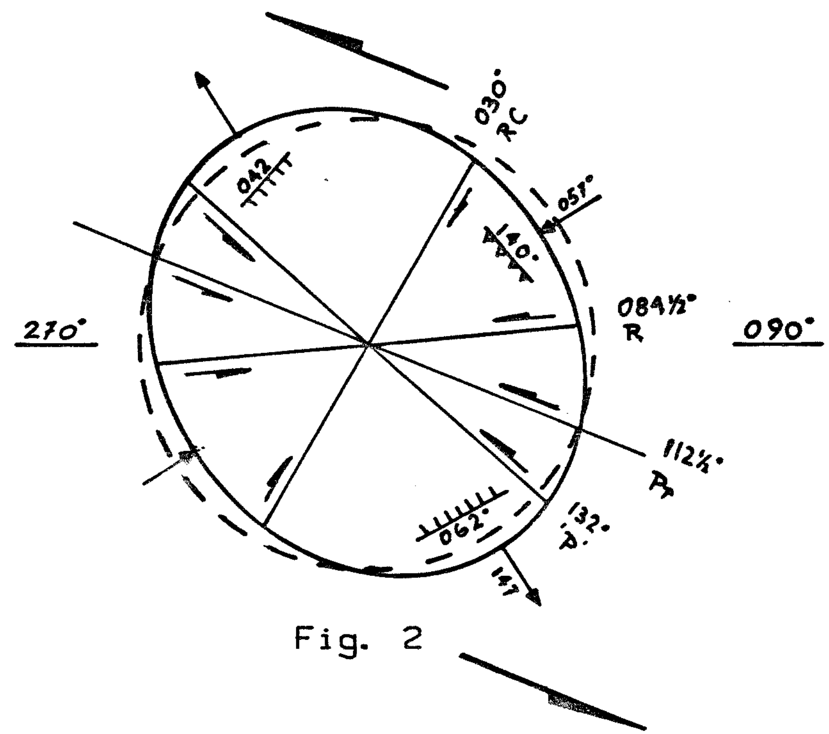
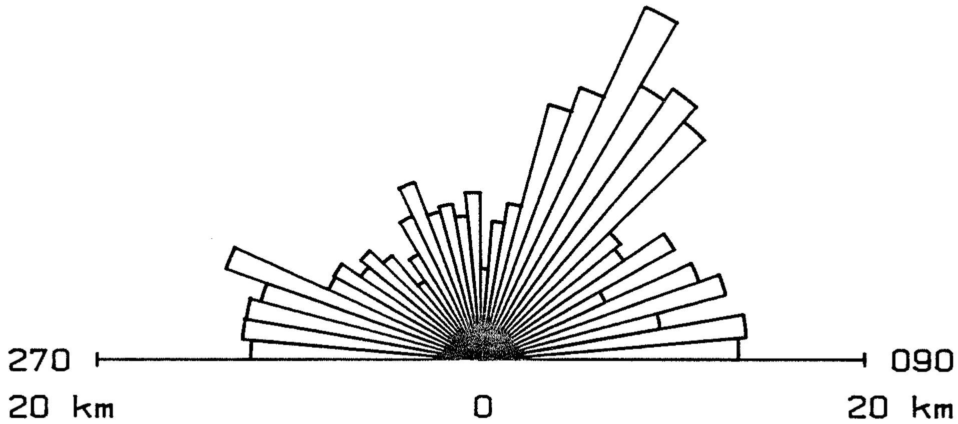
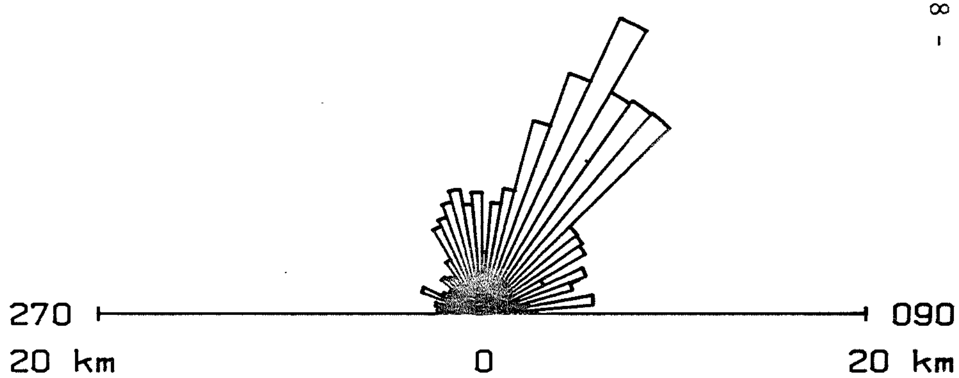


Fig. 2



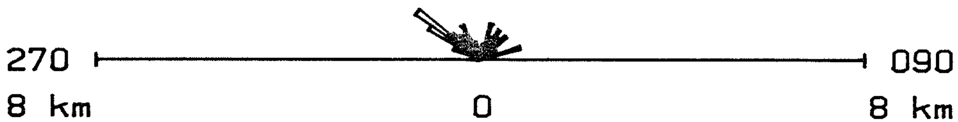
ERPM Area All Flts
Ttl Lgth 387.3 km

Fig. 3



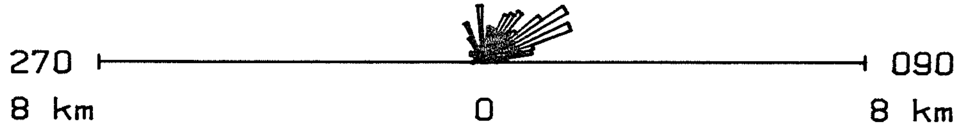
ERPM Area Nrm Flts All Hdgs Dip 76-90 Deg
Ttl Lgth 206.0 km

Fig. 4



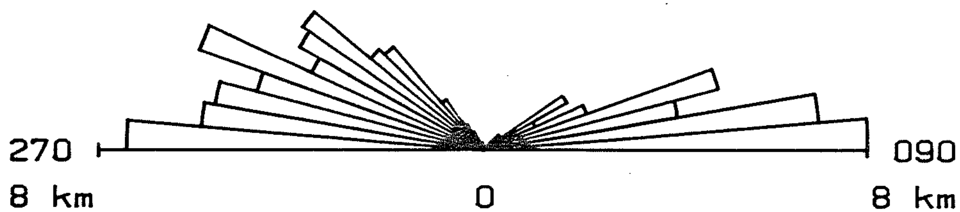
ERPM Area Nrm Flts East Hdgs Dip 46-75 Deg
Ttl Lgth 14.4 km

Fig. 5



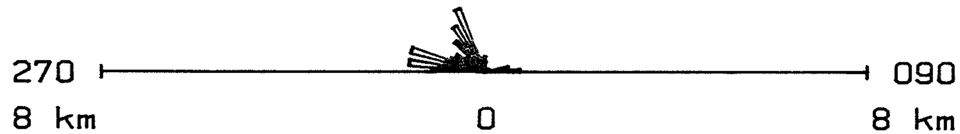
ERPM Area Nrm Flts West Hdgs Dip 46-75 Deg
Ttl Lgth 22.1 km

Fig. 6



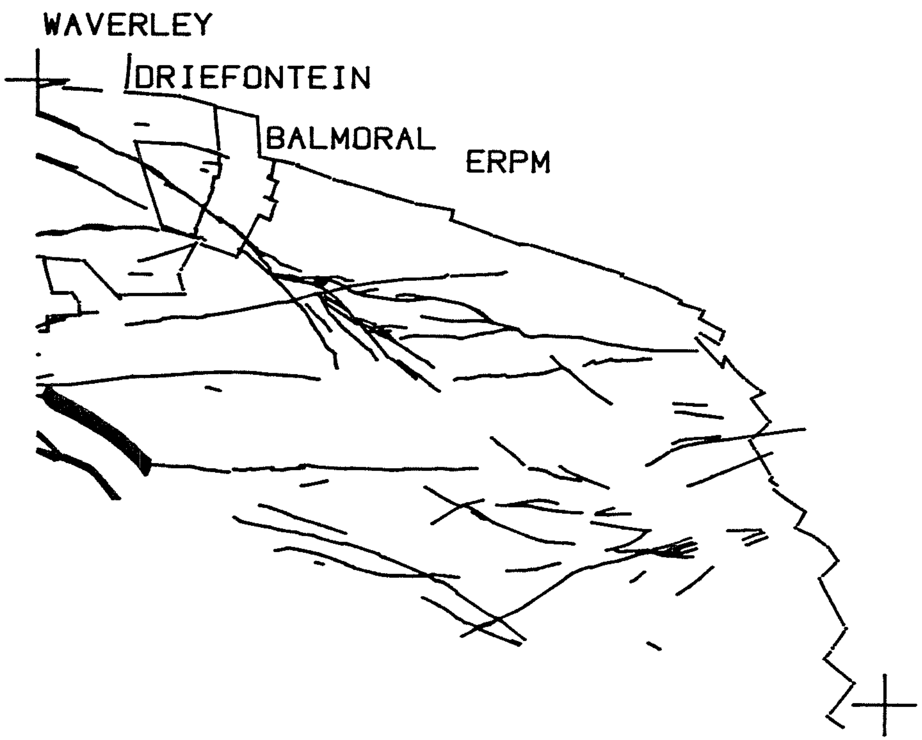
ERPM Area Wrn Flts All Hdgs Dip 1-90 Deg
Ttl Lgth 82.3 km

Fig. 7



ERPM Area Thr Flts All Hdgs Dip 1-90 Deg
Ttl Lgth 15.6 km

Fig. 8



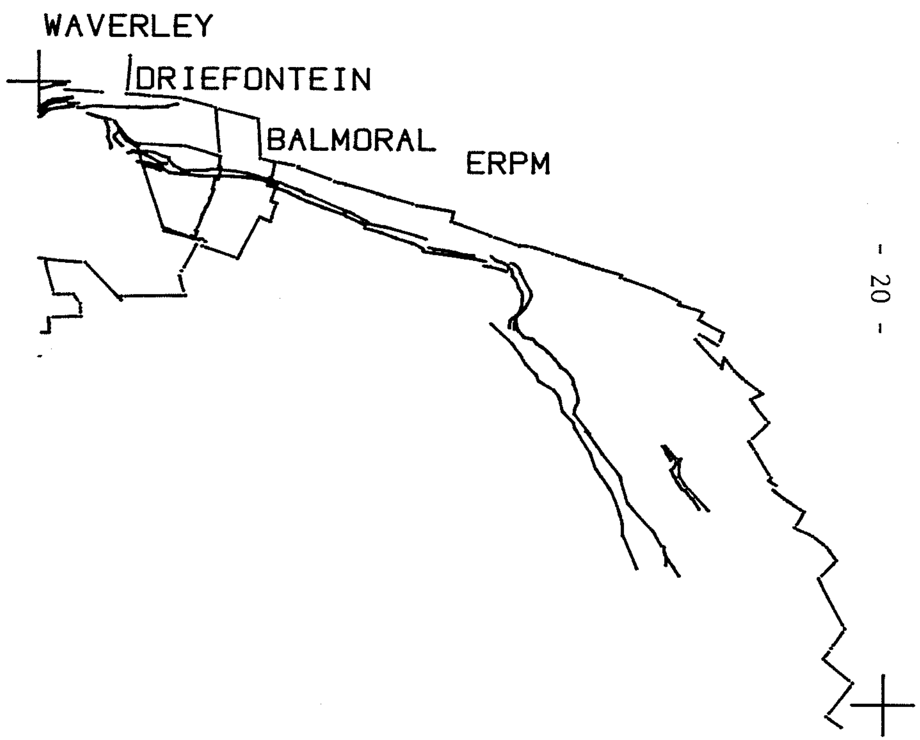
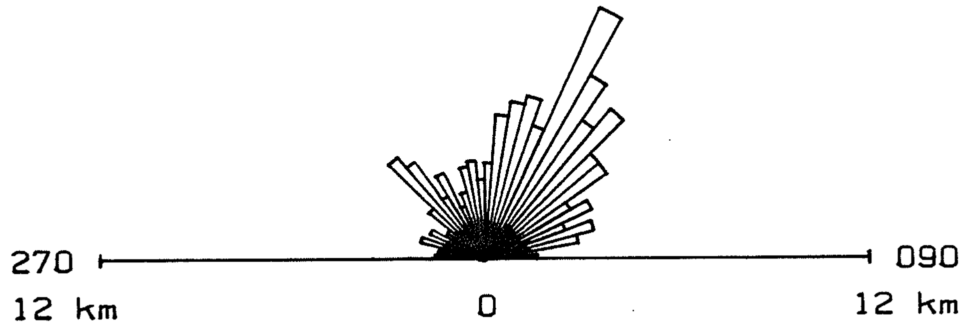
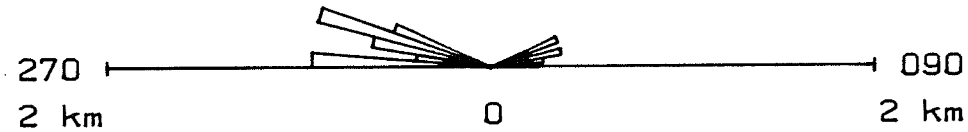


Fig. 9 Wrench Faults ERPM Area 1:100.000 Fig. 10 Thrust Fault



Cty West All Flts All Hdgs Dip 75-90 Deg
Ttl Lgth 116.9 km

Fig. 11

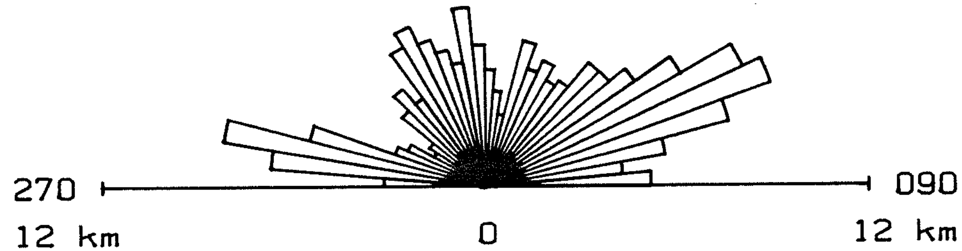


Cty West Wrn Flts All Hdgs Dip 1-90 Deg
Ttl Lgth 4.8 km

Fig. 12

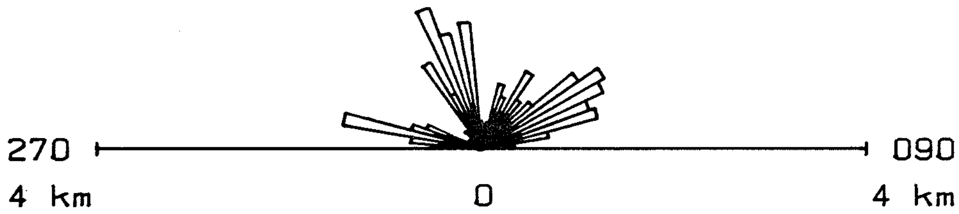
Rob & VM Wrn Flts All Hdgs Dip 1-90 Deg
Ttl Lgth 8.7 km

Fig. 13



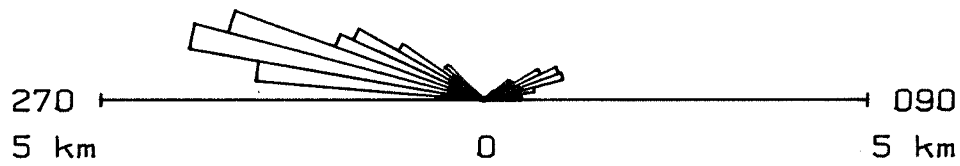
Crn West All Flts All Hdgs Dip 70-90 Deg
Ttl Lgth 173.3 km

Fig. 14



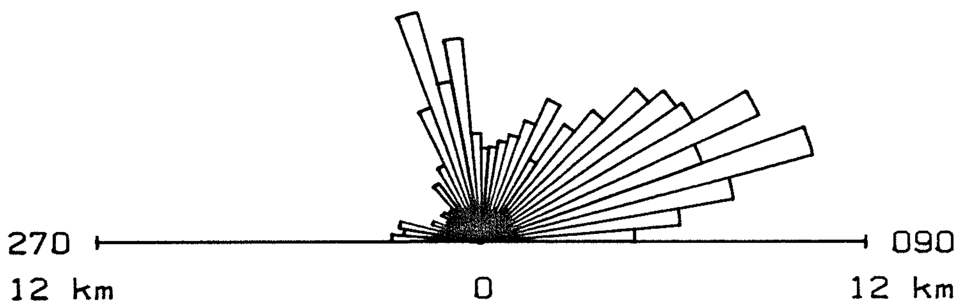
Crn West All Flts All Hdgs Dip 70-90 Deg
Ttl Lgth 24.1 km

Fig. 15



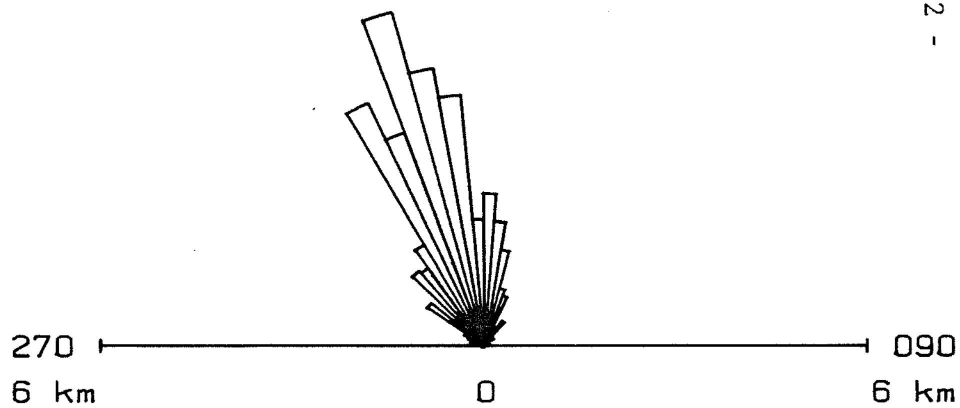
Crn West Wrn Flts All Hdgs Dip 1-90 Deg
Ttl Lgth 22.7 km

Fig. 16



RL & CMR All Flts All Hdgs Dip 70-90 Deg
Ttl Lgth 153.5 km

Fig. 17



DD to S&J Pilanesberg All Flts
Ttl Lgth 40.8 km

Fig. 18

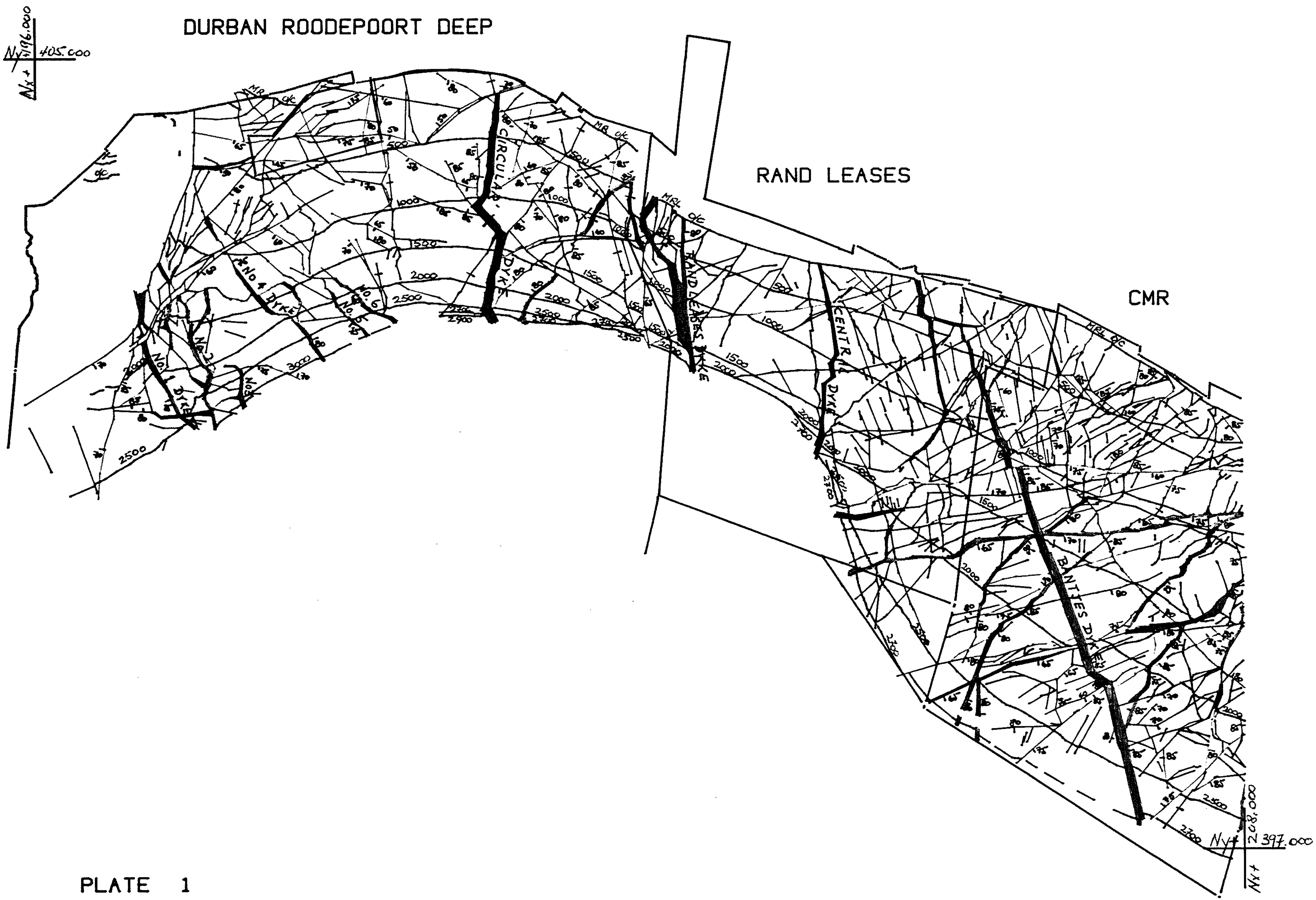


PLATE 1

FAULTS & DYKES DURBAN DEEP to CMR 1:50.000

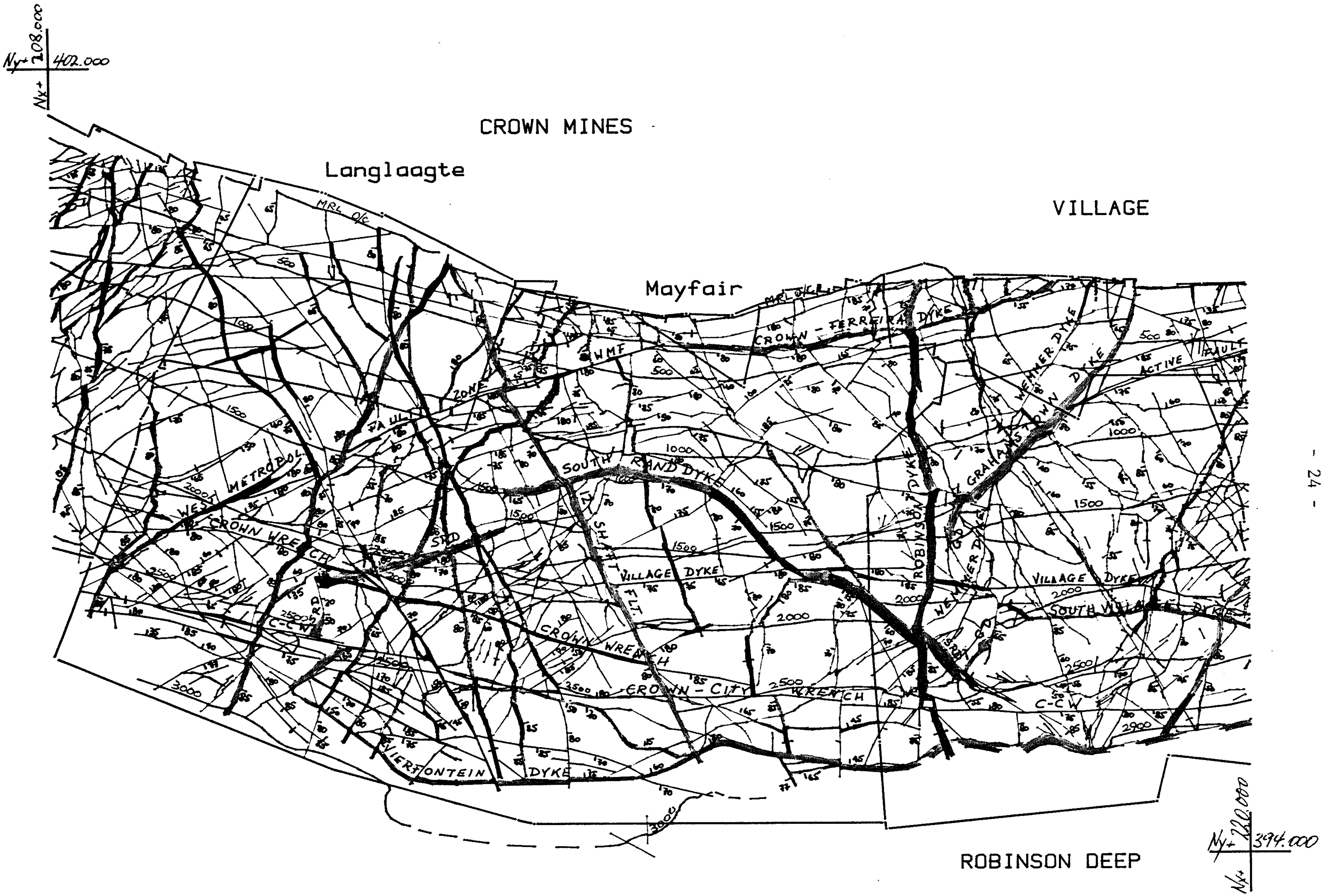


PLATE 2

FAULTS & DYKES CMR to ROBINSON DEEP 1:50.000

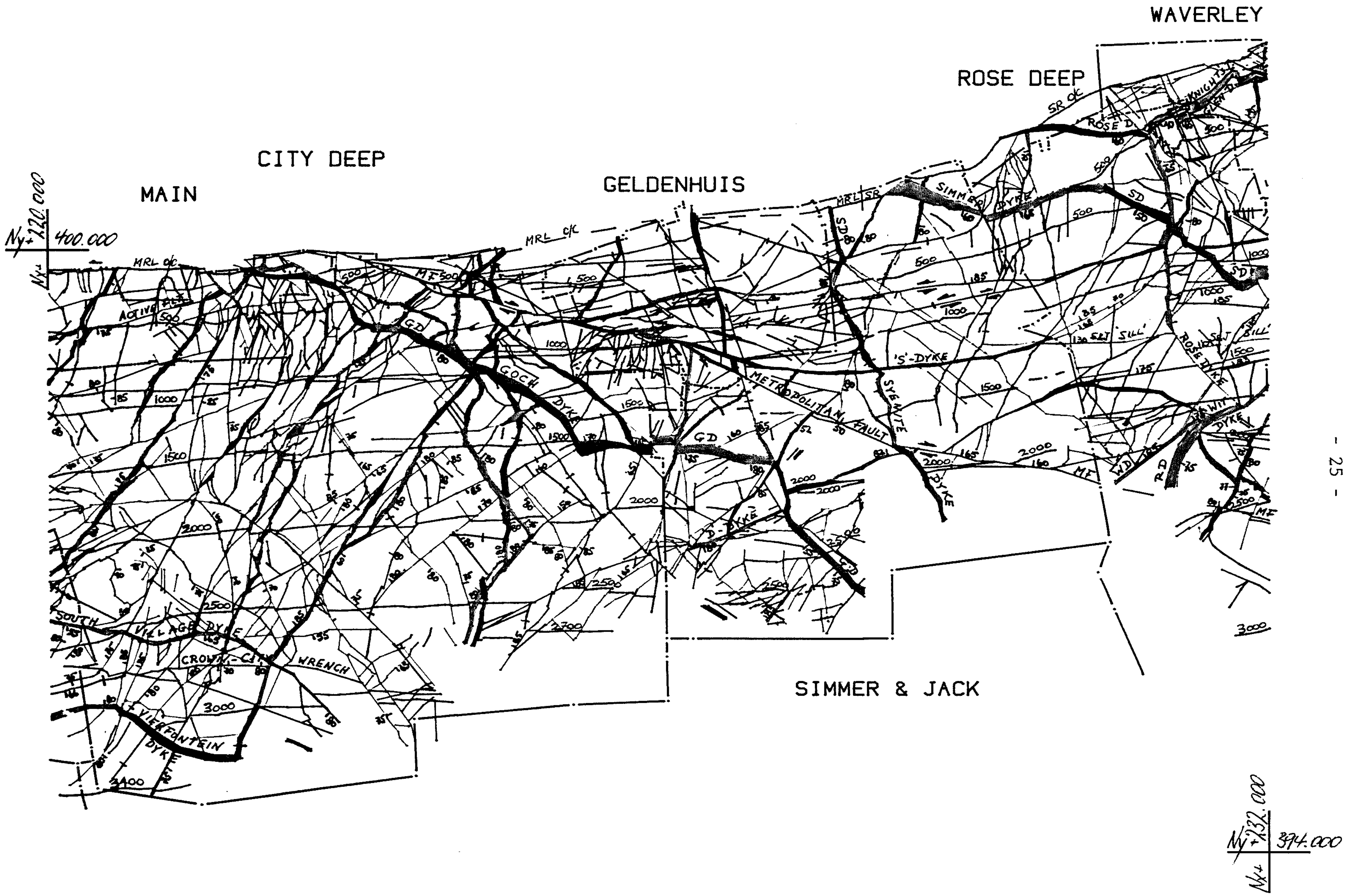


PLATE 3

FAULTS & DYKES CITY DEEP to ERPM 1:50.000

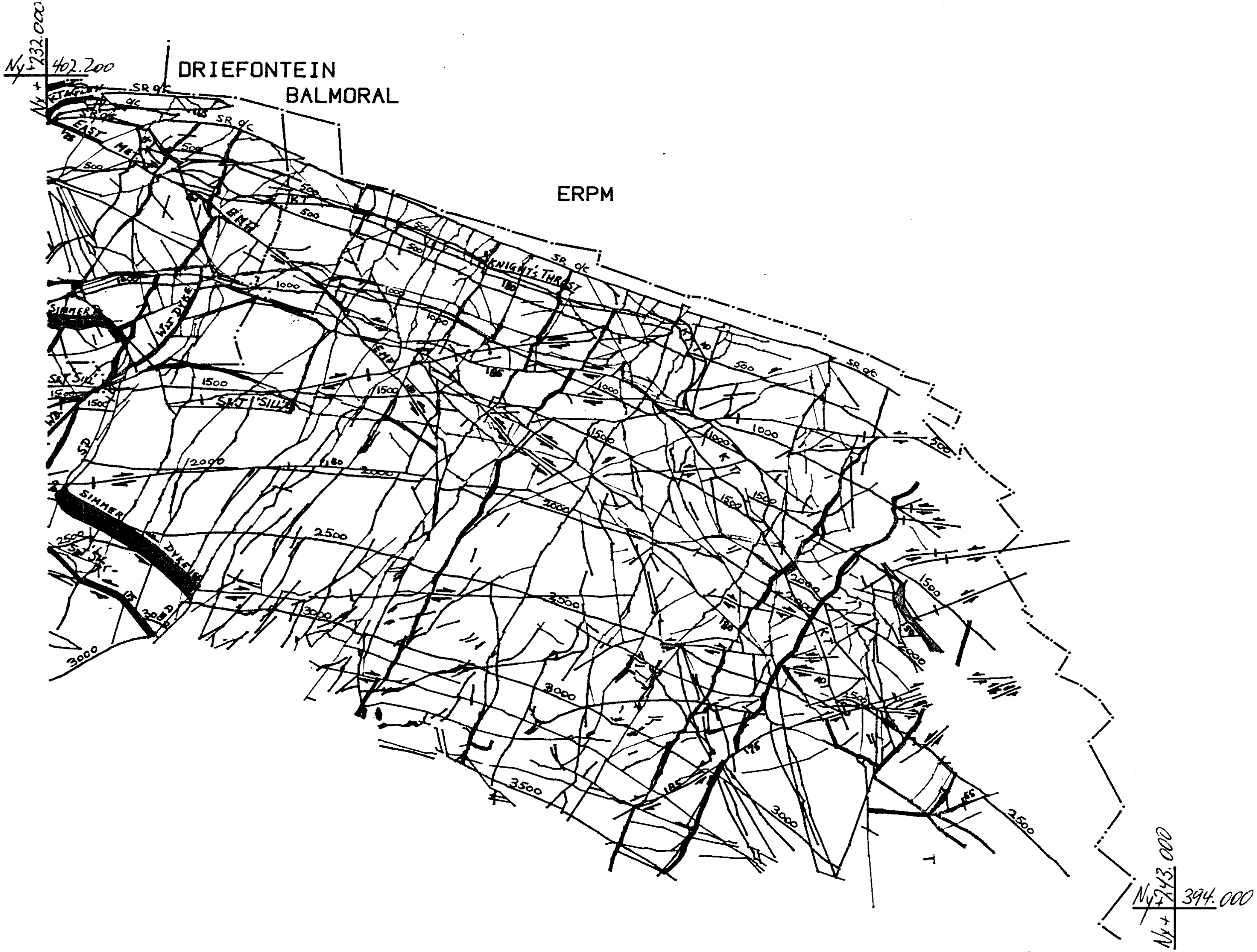


PLATE 4

FAULTS & DYKES WAVERLEY and ERPM 1:50.000

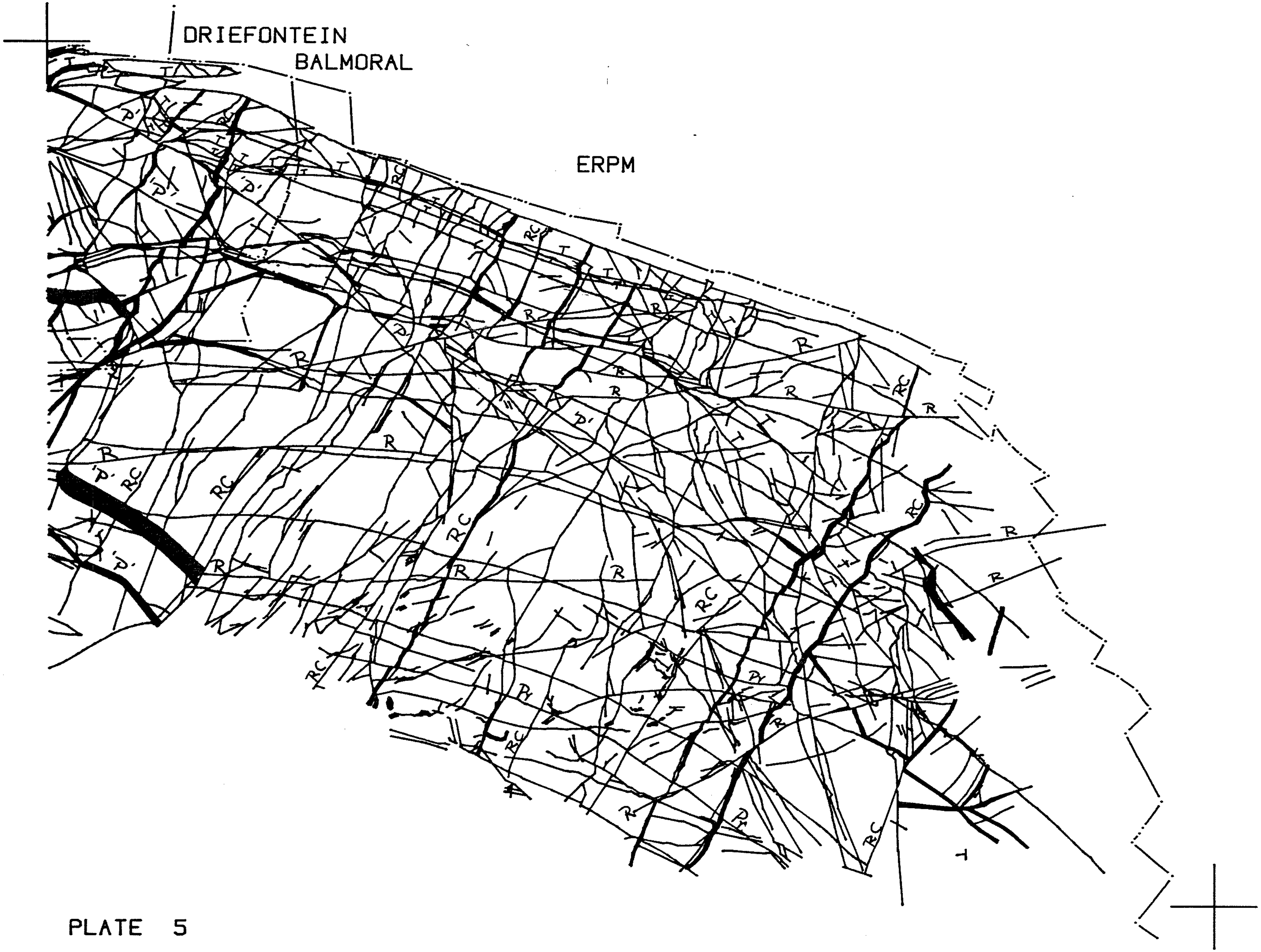


PLATE 5

WRENCHING in ERPM AREA 1:50.000

R = Riedel RC = Riedel Con. Pr = Principal 'P' = 'P'-Shear

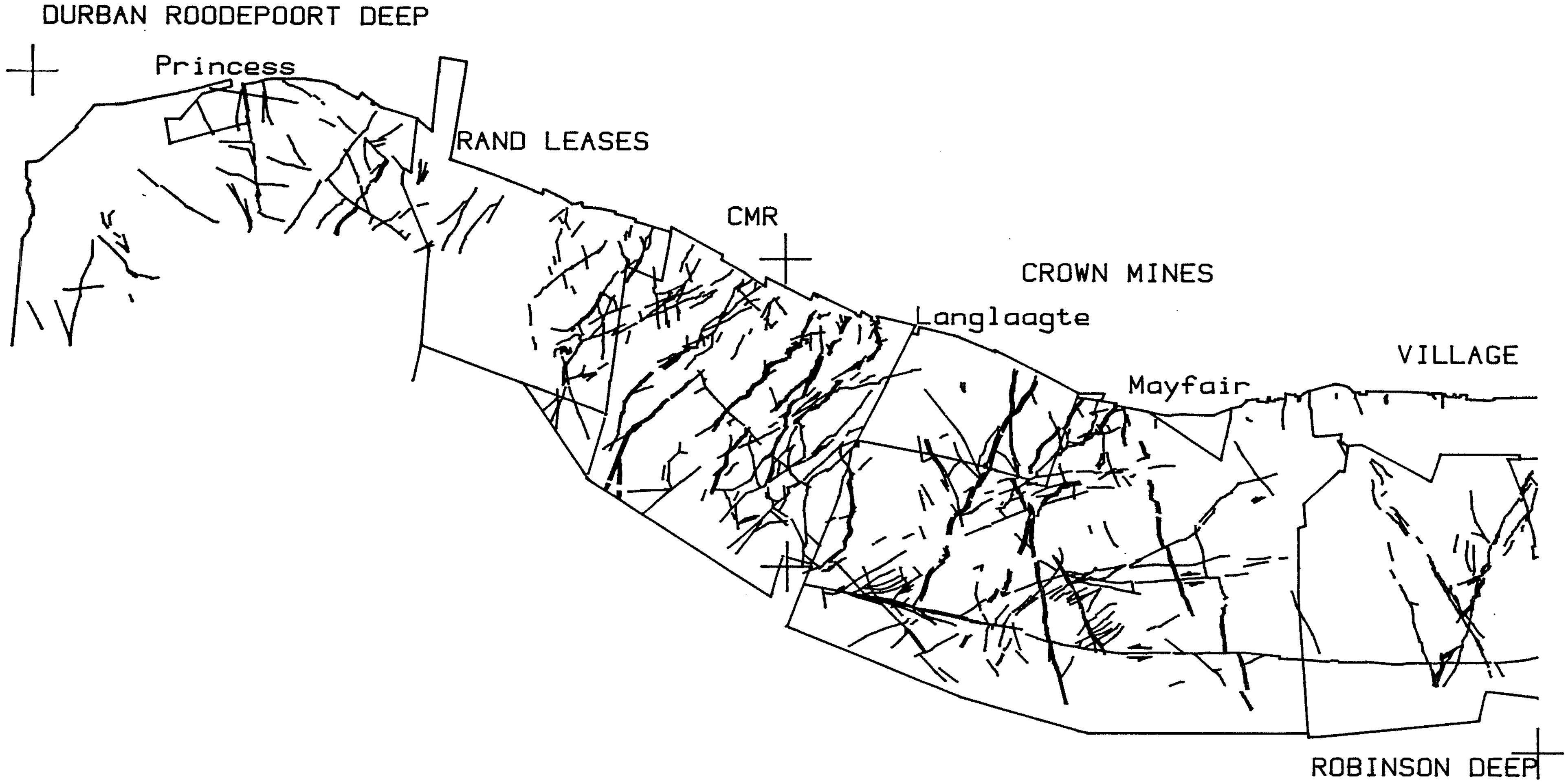


PLATE 6a

DISLOCATION AGES VENTERSDORP DURBAN DEEP to ROBINSON DEEP 1:100.000

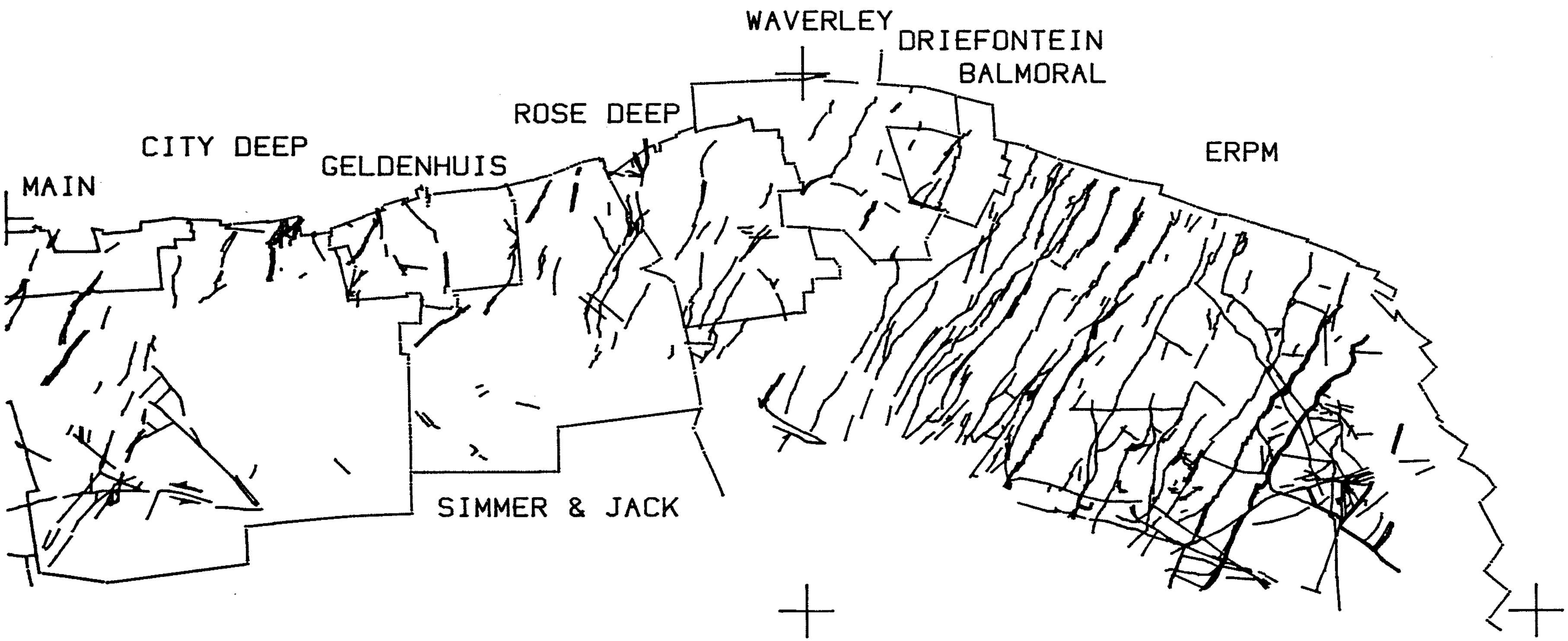


PLATE 6b

DISLOCATION AGES VENTERSDORP CITY DEEP to ERPM 1:100.000

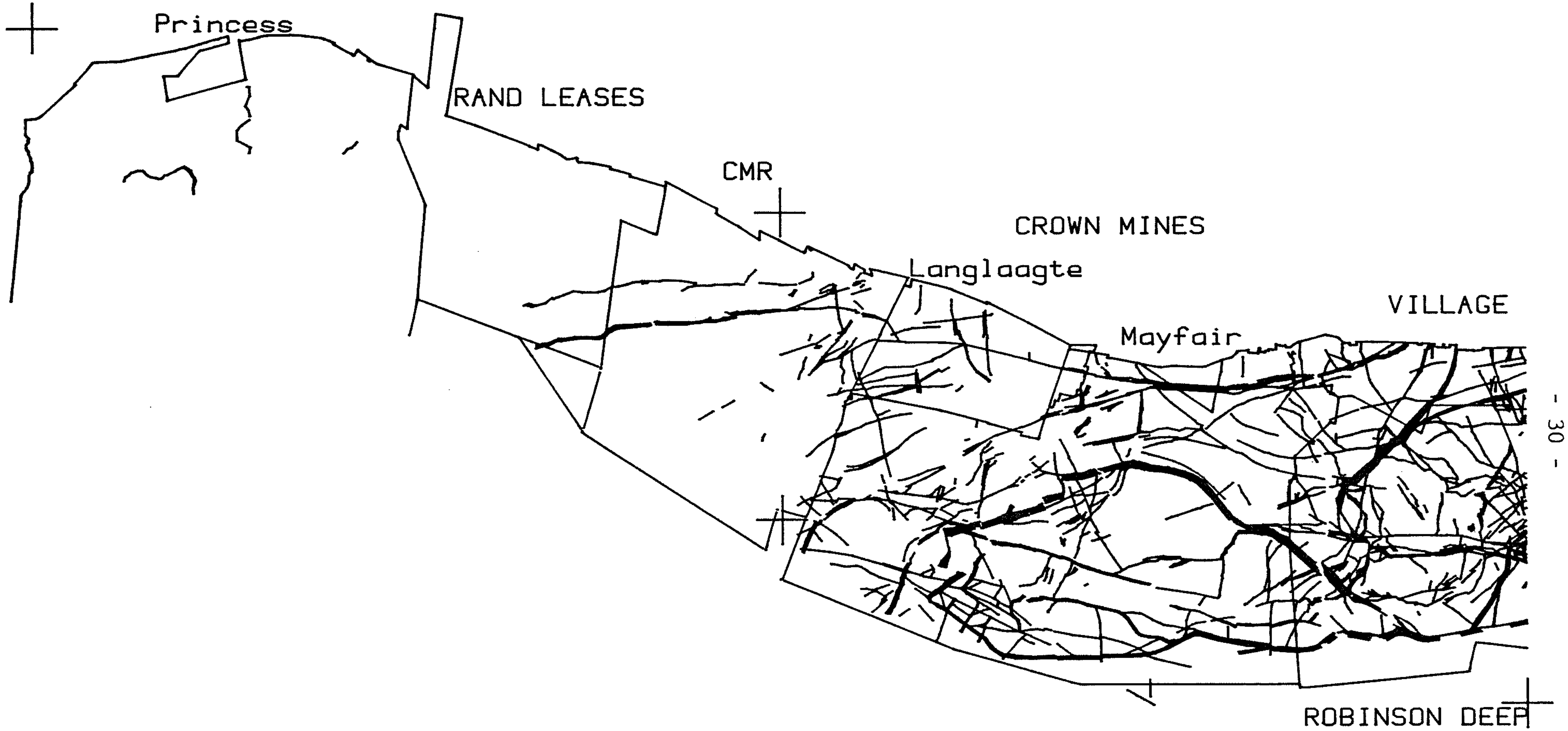


PLATE 7a

DISLOCATION AGES BUSHVELD DURBAN DEEP to ROBINSON DEEP 1:100.000

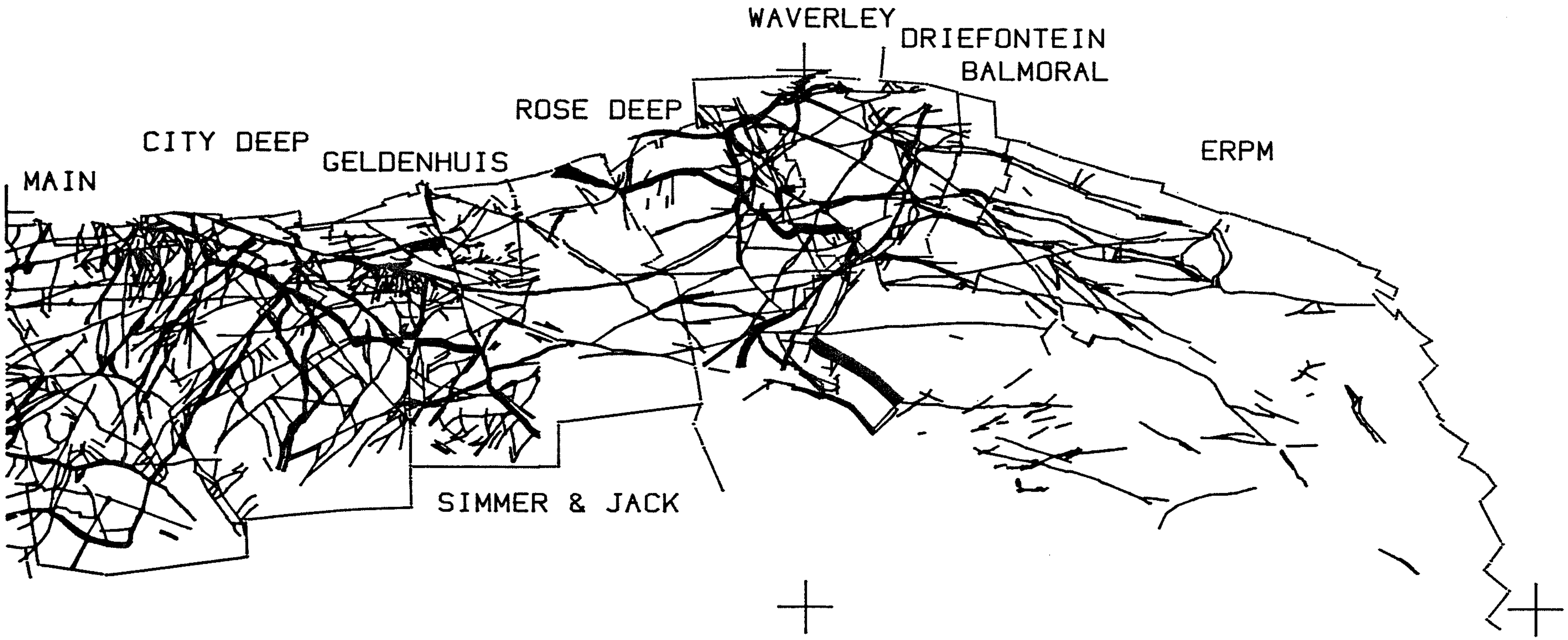


PLATE 7b

DISLOCATION AGES BUSHVELD CITY DEEP to ERPM 1: 100.000

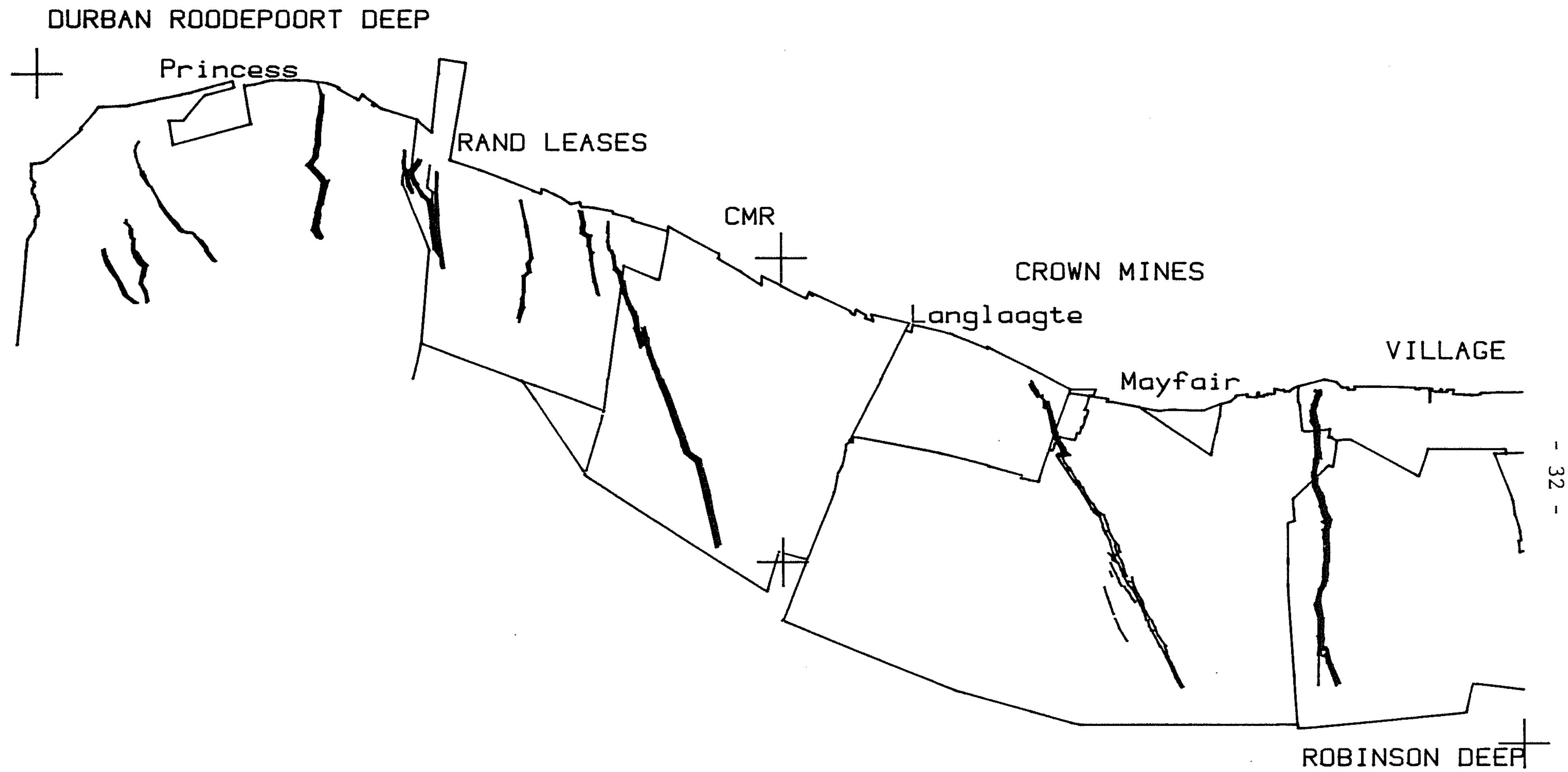


PLATE 8a

DISLOCATION AGES PILANESBERG DURBAN DEEP to ROBINSON DEEP 1:100.000

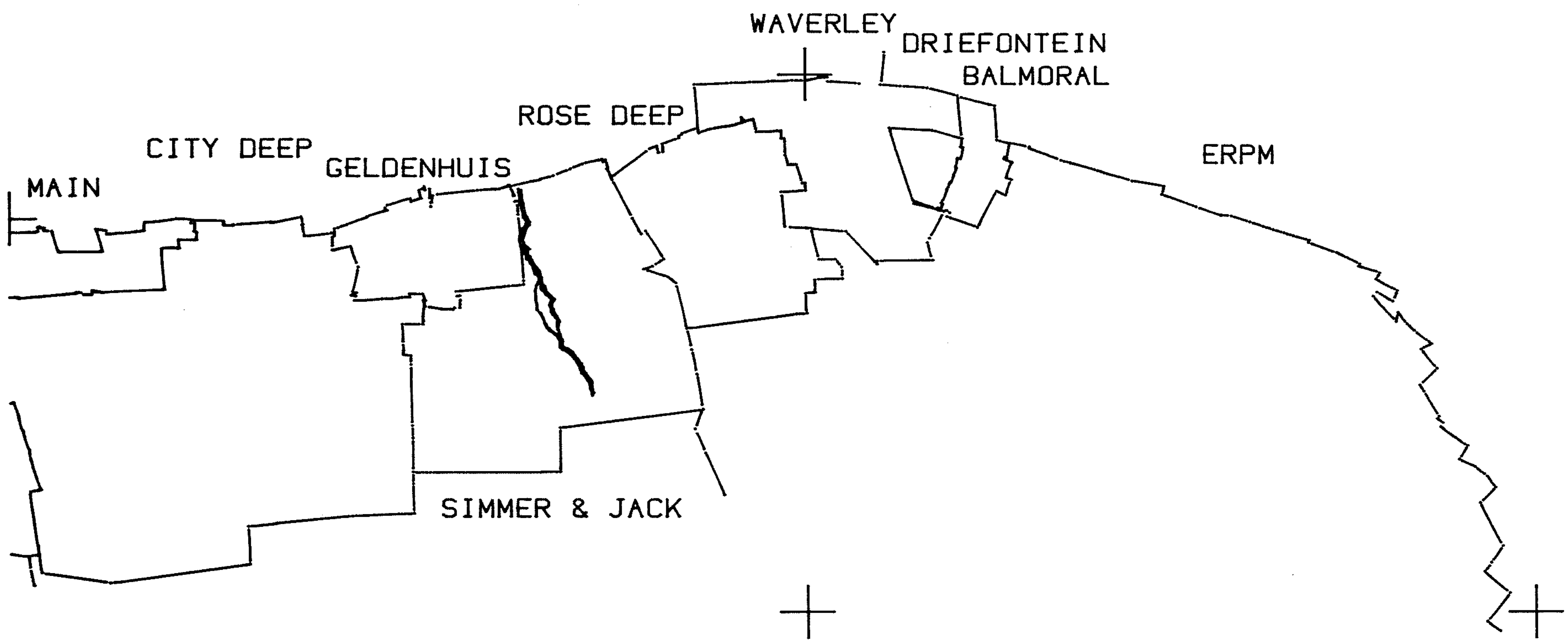


PLATE 8b
DISLOCATION AGES PILANESBERG CITY DEEP to ERPM 1:100.000

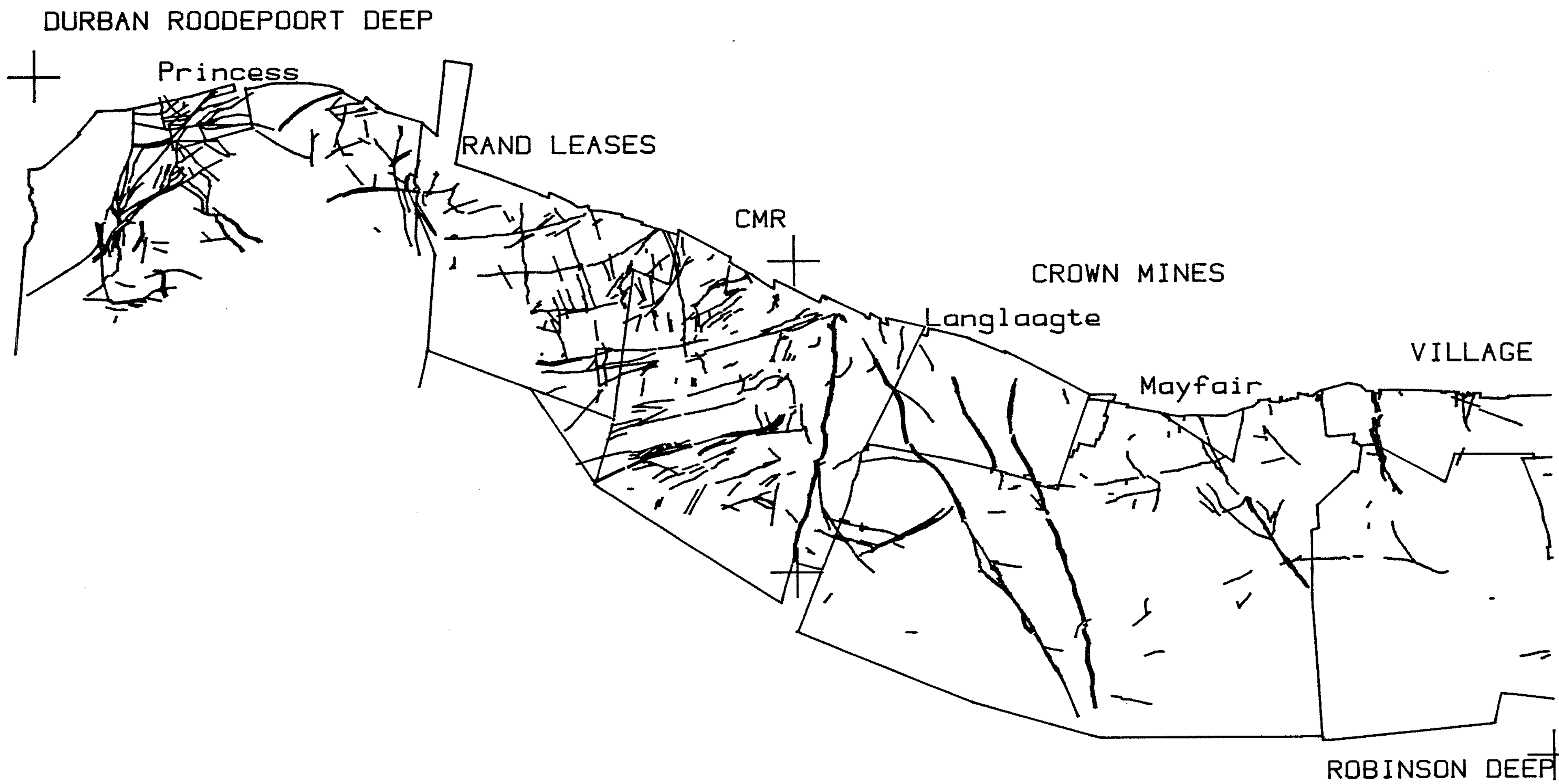


PLATE 9a
DISLOCATION AGES RESIDUAL DURBAN DEEP to ROBINSON DEEP 1:100.000

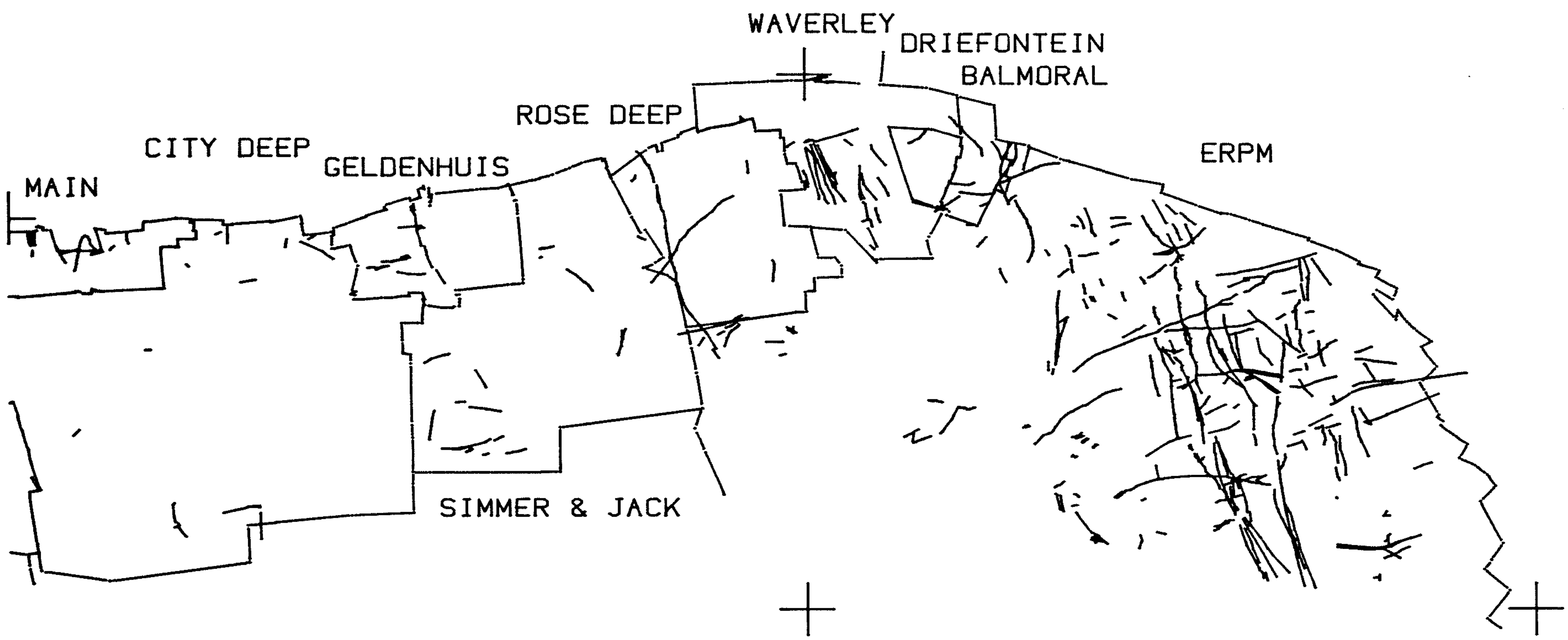


PLATE 9b

DISLOCATION AGES RESIDUAL CITY DEEP to ERPM 1:100.000

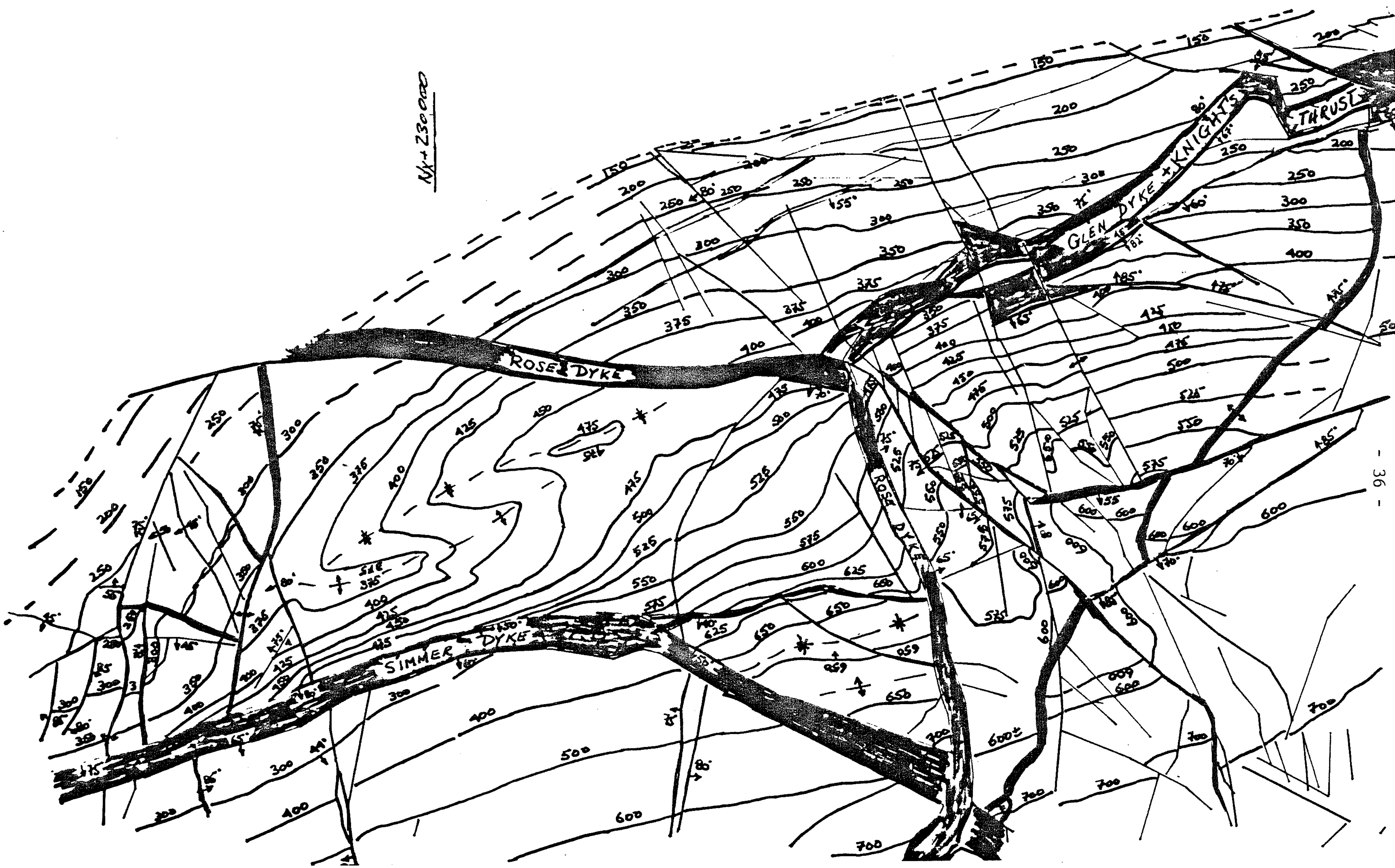


PLATE 10

KNIGHT's THRUST WESTERN PIN-DOWN ROSE DEEP 1:10.000

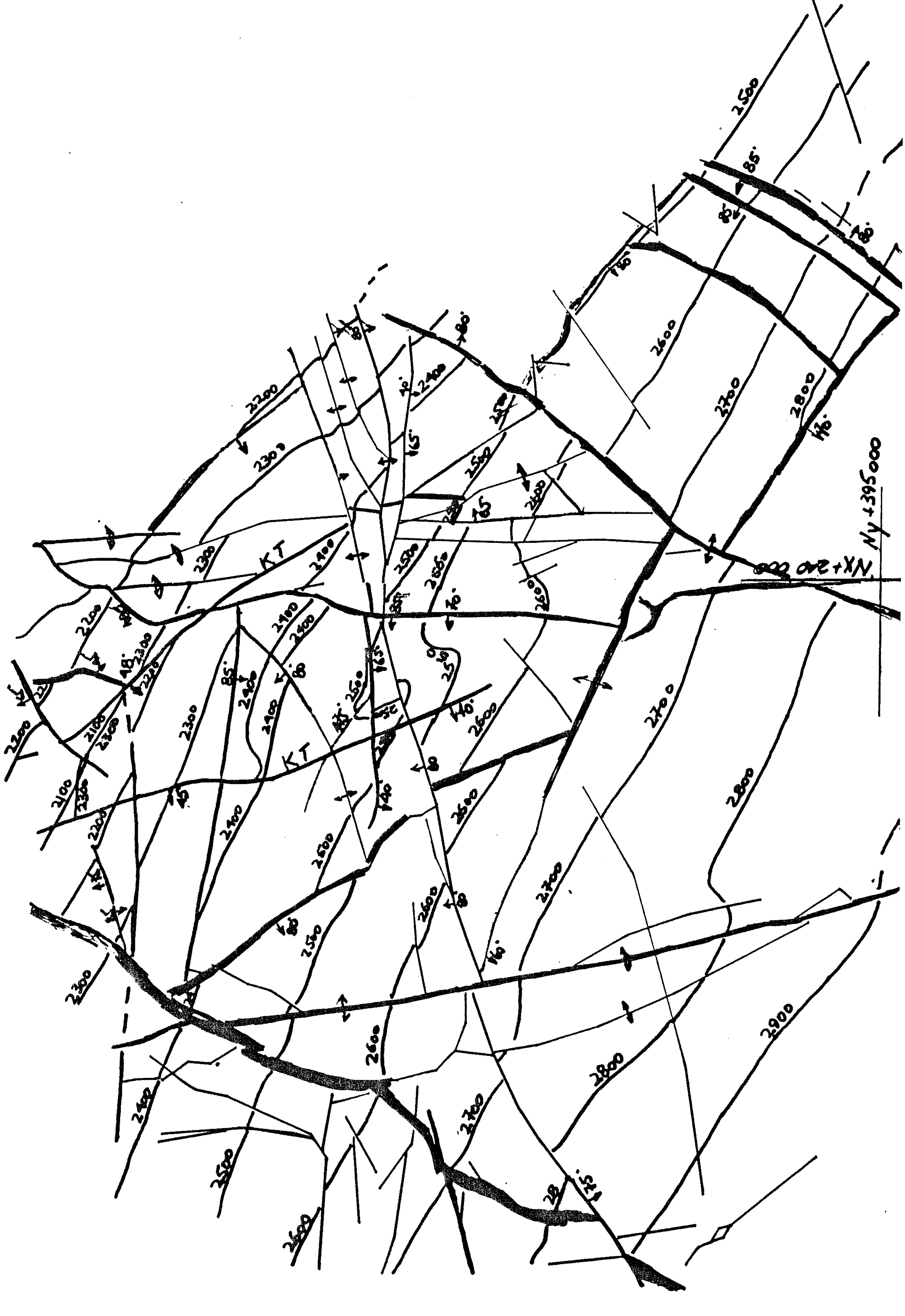


PLATE 11

KNIGHT's THRUST EASTERN PIN-DOWN ERPM 1:10.000

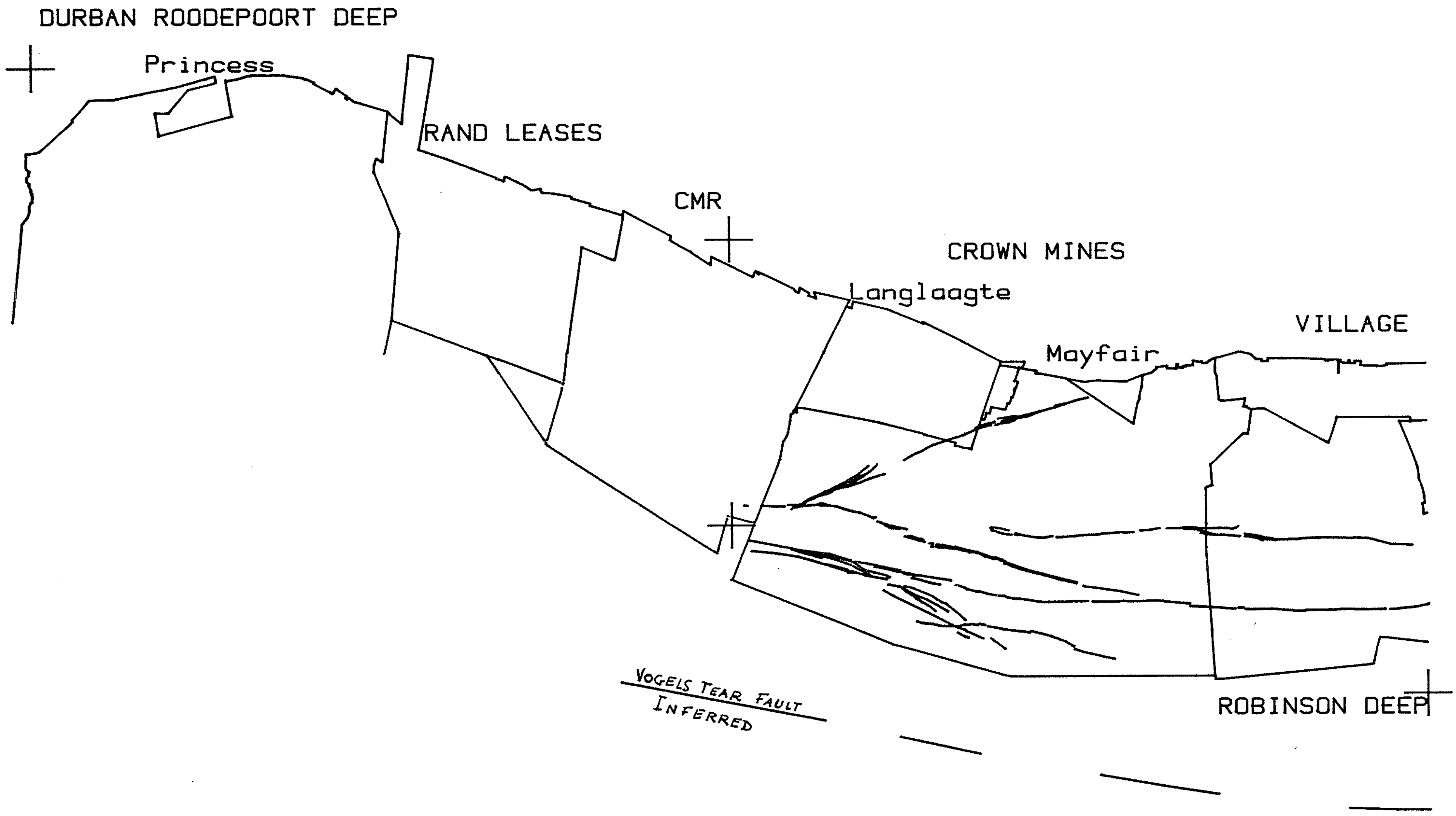


PLATE 12a

WRENCH FAULTS DURBAN DEEP to ROBINSON DEEP 1:100.000

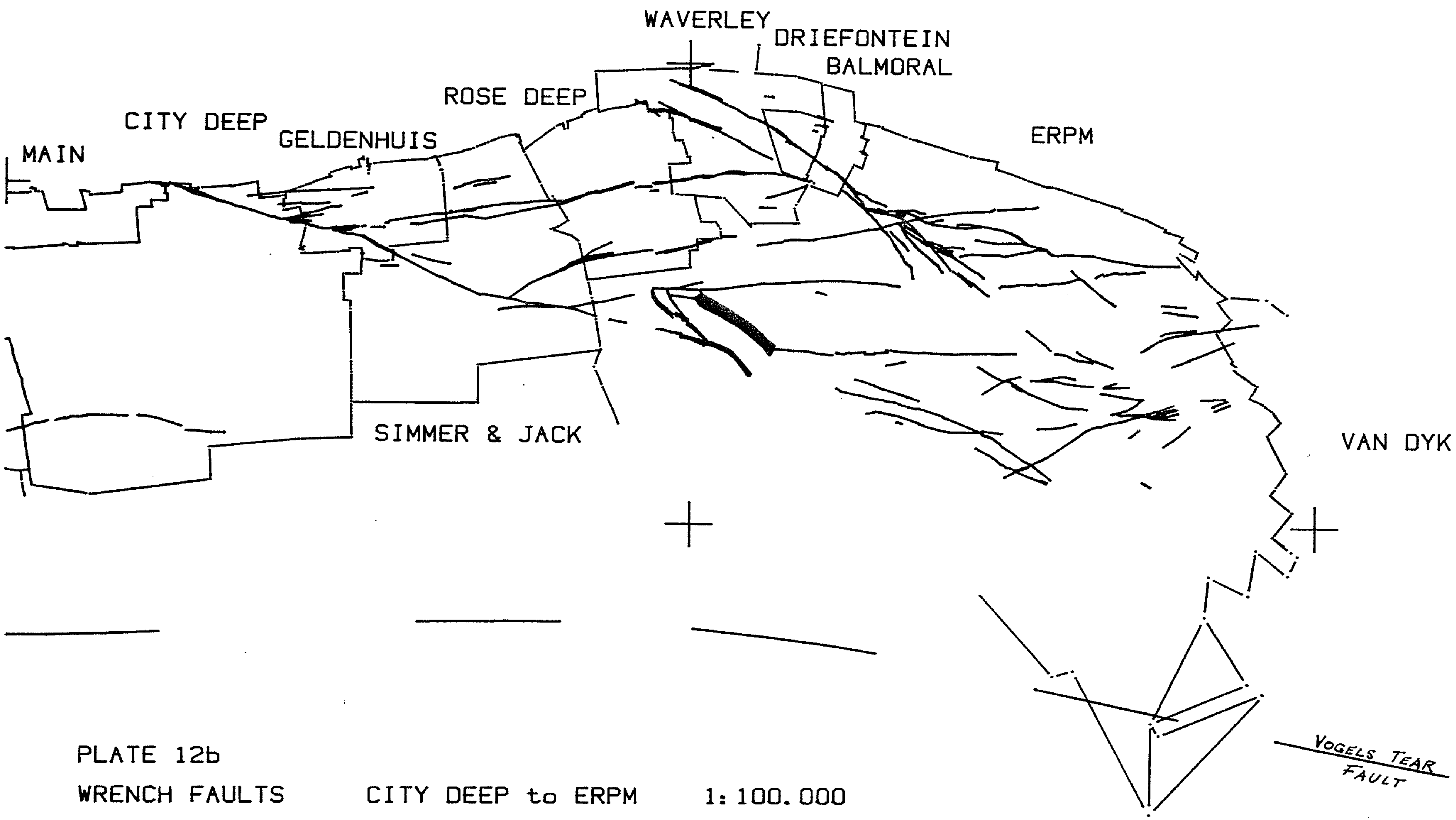


PLATE 12b

WRENCH FAULTS CITY DEEP to ERPM 1: 100.000