Seismicity in the Welkom Area, O.F.S. (With Special Reference to the Origin of the 1976 - 12 - 8 Event)

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(WITH SPECIAL REFERENCE TO THE ORIGIN
OF THE 1976 - 12 - 8 EVENT)

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DECLARATION.

I, Frank Walter Arnott, hereby declare that this dissertation is my own work and has not been previously submitted as a dissertation or thesis for any degree at any other University.

F. Arnott

University of the Witwatersrand, 1980.

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ABSTRACT

A detailed study was undertaken to investigate the seismicity of the Welkom, O.F.S. goldfields. The aim was to obtain a better understanding of the relationship between mining and seismicity for this region and in particular the association of a damaging event which occurred on December 8, 1976.

Using a combined surface and underground seismic array of portable field equipment, two periods of activity were recorded. The initial period from 12 December 1976 to the 10 January 1977 displayed a similar distribution but lower level of seismicity than the second period, July 1977.

No definite conclusions could be made about the location and cause of the main event. Although after the event there was evidence of a destressed zone between the Dagbreek fault and Enkeldoorn dyke which was coincident with the underground and surface damage. It was also apparent from the study that the surface damage had been influenced by the enhancement of surface energy in the unconsolidated Karoo overburden.

Analysis of the recorded seismic events demonstrated the influence of both the mining activity and geological structures on the stress adjustments. Geology was implicated by the unusual high incidence of activity below the mining levels. A number of these deeper events were associated with inferred major geological structures and composite strike-slip source mechanisms were markedly different to the normal source mechanism for the events associated with mining. As well as this change in the stress orientation for the deeper events the low effective stress drops of 0.001 to 0.1 bars combined with the large source dimensions were consistant with the concept of control by a highly fractured geological environment.

The high level of seismicity at blasting times implicated the mining, but a delay in this peak for the larger magnitude events indicated a relationship between the mining and the geological controlled stress releases.

[illegible]

At 06:58:[illegible] GMT [illegible] 1976 [illegible] seismic event with a local magnitude of [illegible], occurred in the environs [illegible] the town of Welkom. This event had the significance of being the largest single energy release to have ever occurred in any of the Witwatersrand gold mining districts. The seriousness on surface culminated in the collapse of a five storey block of flats, Tempesthof and the occurrence of other major structural damage within Welkom, whilst underground, although the damage was not as severe, one miner was killed and three others were trapped by rockfalls. The size and effects of this event dictated that all possible informatio[illegible] be gathered about it in order to assess its possible relevance to mining and thus to consider the possible reoccurrence of further activity of this level, particularly with the ever increasing depth and volume of mining. Actual assessment of the event was varied, even with respect to the magnitude. A location of between 27.9 to 27.8^0S and 26.6 to 26.8^0E with constrained depths was provided by different networks (local and WWSSN). Initial surface wave magnitude was given as 5.4, later to be adjusted to 5.1 by the local Geological Survey, while the International evaluation from body waves was 5.2 (Preliminary Determination of Epicentres, United States Geological Survey). Applying Richters relationship $M = 0.66I + 1.0$ to the maximum Mercalli intensity of VII the local magnitude would be 5.6, it should however be noted that intensity values are affected by the local geology and this fact was clearly shown by this study.

The question was raised to what extent had mining contributed to the triggering of such an event? The available data could not easily answer this and so the Anglo American Corporation of South Africa requested that the Bernard Price Institute of Geophysical Research undertake a study of the region. The philosophy behind this study was similar in nature to that carried out after the Ceres Earthquake in 1969 (Green and Bloch, 1971), the initial objective being to locate a region of aftershock activity which might occur immediately after the main shock. This aftershock activity could at some later stage be compared to subsequent seismic activity. In this way an attempt could be made to delineate causative structural features and to assess to what degree, if any, the natural tectonic stresses has contributed to this large event. Due to administrative delays, recording only commenced on the 11 December 1976, nearly three days after the main event. Thus a crucial period was unfortunately missed, particularly as it became clear later that if any possible major aftershock sequence had followed the main event, its decay was very rapid. Events were recorded by the South African Geological Survey for the first two hours after the main event, these had magnitudes of about 3.1 to 3.5 confirming the apparent existence of aftershocks.

An initial phase of recording from December 1976 to January 1977 provided hypocentres which had two unusual characteristics. Firstly, there was no evidence of a distinctive decaying aftershock sequence and secondly, a large number of events had located well below the level of mining, contrary to seismic trends in other gold mining districts of the Witwatersrand Basin. In mines such as East Rand Proprietary Mine (ERPM), the Klerksdorp group and even Harmony to the south of Welkom, the principal reported seismic activity occurred close to the stope faces, in particular, above the reef (McGarr, 1971b; van der Heever, 1978; Joughin, 1966). It was therefore proposed that a further period of recording (second phase) be implemented after a substantial time interval had elapsed. Thus, six months later an additional month of recorded activity enabled comparisons to be made between the assumed aftershock period in December and an interval during which only mine related activity was occurring.

Further examination of the data in the form of magnitude frequency relationships, focal mechanisms, source parameters and site effects was also undertaken. In this way comparisons were obtained against similar data from other regions both locally and internationally.

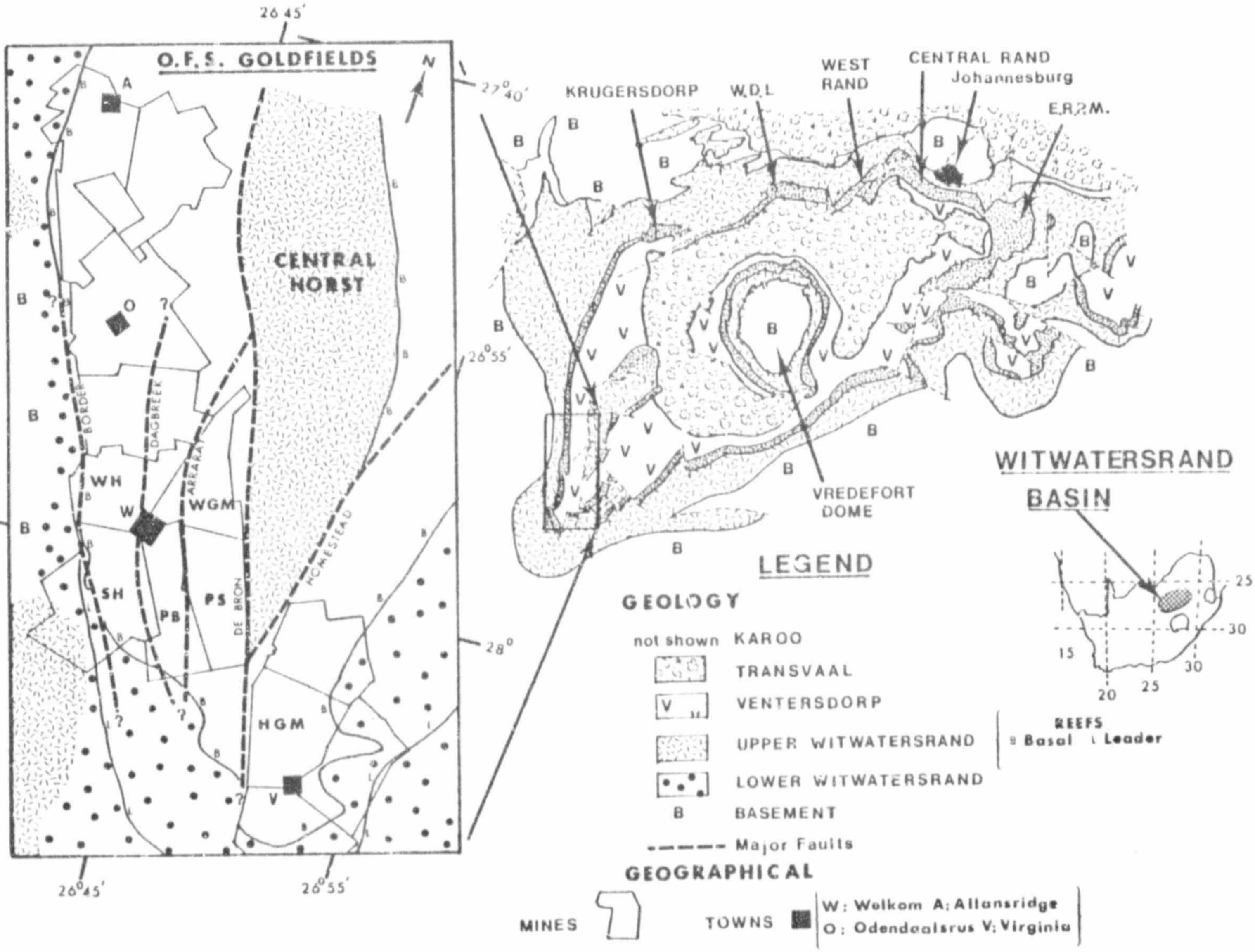


Figure 1.1 Locality and Geological Map of the Witwatersrand Basin and O.F.S. Goldfields. Ventersdorp, Transvaal and Karroo cover has been omitted. (Abbreviations for mine names are : W Western holdings; W.G.M. Welkom Gold Mine; S.H. Saint Helena; P.B. Presiden.. Brand; P.S. President Steyn; H.G.M. Harmony Gold Mine.)

1. GEOGRAPHY AND MINE ACTIVITY

1.1 Locality and Coordinate Systems

Figure 1.1 shows the relationship of the Orange Free State Goldfields (O.F.S.), to that of the Witwatersrand Basin. The particular mines that were monitored during December, January and July are shown in figure A1 - 3, (Appendix 1). The extremities and datum of this region both in mine and geographic coordinates, are provided in Table 1. These coordinates are related by a Gauss Conform Projection using the 'L_0' coordinate of 27°E. The constants required for this transform are also supplied in Table 1. Mine coordinates will be used throughout the study.

TABLE 1 Reference Coordinates

	Geographic		Mine Coordinates (Meters)	
	Latitude	Longitude	+Y	+X
Origin	28° 3' 11"	26°47' 59"	2000	18000
Maximum	27° 54' 31"	26°40' 42"	1400	2000

Transform Constants for L_0 = 27

+X to Latitude = +17678.241 +Y to Longitude = +3086102.792

Mine Vertical Datum

Above mean sea level = 1828,8 m Above mean ground surface ∿ 460 m

1.2 Environment

The terrain is extensively flat at an average elevation of 1340 m above sea level. The low annual rainfall of 491 mm falls during the summer months creating a relatively dry climate and correspondingly dry mining conditions.

1.3 Mining

The mines encompassed by this area are five controlled by the Anglo American Corporation (President Brand, President Steyn, Welkom Gold Mine, Western Holdings and Free State Geduld) and one Union Corporation mine (St. Helena). All of the mines are active gold mines. However, the degree of development is very varied and because of the large vertical displacements of the main auriferous reef, the depth of mining is also very variable. A range of 39 mining levels occurring between depths of 1.5 to 2.7 km below the datum with an average depth of 2.0 km. The mining depths of the other Witwatersrand mines referred to in this study vary between 1.5 to 4.0 kms. The mining methods are the same as those outlined by McGarr (1971b) and McGarr and Wiebols(1977) for the East Rand Proprietary Mine, (ERPM).

2. GEOLOGICAL AND TECTONIC SETTING

2.1 Regional Geology

The Dominion Reef, Witwatersrand Supergroup and Ventersdorp Supergroup form a sequence of sedimentary and volcanic rocks which, because of their structural and aereal relationship, have been collectively called the Witwatersrand Triad. This Triad is considered to constitute a major geological cycle (Brock and Pretorius, 1964) which lies unconformably on basement granite, gneiss and schist of the Swaziland Supergroup and has been overlain by Transvaal and Karoo sequences, Table 2. The outer margin of the Upper Witwatersrand sediments define an oval shaped intra-cratonic basin, the Witwatersrand Basin; which is located approximately between longitudes 26° 30'E and 29° 15'E and latitudes 26° 00'S and 28° 15'S, Figure 1.1. The major axis of this basin is orientated NE-SW over a distance of 320 km and at its southern extremity mining of the auriferous Upper Witwatersrand conglomerates occurs in the region known as the Orange Free State Goldfields. The Witwatersrand Supergroup is a succession of arenaceous and argillaceous sediments deposited in a sedimentary basin, which has not suffered any true orogenic deformation. Exposure of the sediments is mainly at the northern margin of the basin where extensive faulting and erosion has removed the younger rocks and in some instances the Upper Witwatersrand sequences as well. One other outcrop of significance is in the central region of the basin where an upthrust of basement granite has penetrated and overthrown the sediments in a northerly and northwesterly direction. This feature is known as the Vredefort Dome and has been considered to be the cause of some of the later stage (2000 m.y.) tectonic structures in the SW and NW margins of the basin (Threader, 1963). In the O.F.S. Goldfields the

AGE x 10^6 years	SUPERGROUP	SERIES	GROUP	FORMATION	MEAN STRATIGRAPHIC THICKNESS (meters)	MEMBER AND PRINCIPLE LITHOLOGY	GEOLOGICAL EVENTS (Phases, Tectonics, Intrusives)	SEISMOLOGICAL FEATURES
125 to 250	KAROO	(Beaufort) Ecca Dwyka			90 to 520	Upper most layer clays o possibly altered Ecca an not Beaufort. Silty carbonaceous shales clays, mudstones sand-stone and conglomerates	- Relatively stable period - Dolerite Intrusives - Karoo unaffected by faults occurring in lower groups ? Major Unconformity -?---?---?---?---?---	Seismic Energy trapped and magnification of particle velocity in very weathered surface layers. Mean density: Unweathered Karoo : 2.47 gm/cc Clay : 1.5 gm/cc Average phase velocities for unweathered Karoo V_p : 3.5 km/sec, V_s : 2.0 km/sec
	VENTERSDORP	Upper Ventersdorp			No significant deposits	Lava Sediments	- Low angle thrust faults in Khaki Shales - Strike slip and rotational faulting Major Unconformity -?---?---?---?---?---	Dioritic/Diabase Dykes are very competent and store residual stress
±2300		Lower Ventersdorp			0 to 1190	Amygdaloidal Andesites	VOLCANIC PHASE - Reverse faults and folding on the edge of the basin (Border fault) - Major normal faulting forming a horst and two block faulted grabben (De Bron, Daagbreek and Ararat faults)	Mean density of Lavas : 2.8 to 2.9 gm/cc Average phase velocities V_p : 6.4 km/sec, V_s : ±3.7 km/sec
	WITWATERSRAND Upper Division	Kimberley Elsburg	Elsburg	Upper	180 to 330	Quartzites	- Syncline forms ? -?---?---?---?---?---	Contact of Elsburg with Karoo in some areas
				Lower	0 to 240	Quartzites Conglomerates	(Intrusives: arrow spanning from Karoo to Syncline forms)	
			Kimberley	Gold Estates	70	Upper, Middle, Lower — Quartzites and Conglomerates	ONLAP PHASE Rapid uplift and associated deposition (transgressive stage)	Mean density of Quartz bearing rocks : 2.6 to 2.7 gm/sec Average phase velocities V_p : 5.9 km/sec, V_s : 3.7 km/sec
		Main Bird		Leader Reef	46 to 58	Upper Shale Marker Upper Main Bird — Argillaceous quartzite Leader Reef Quartzites Leader Reef — Conglomerate		
				Basal Reef	0 to 16	Leader Quartzites	STABLE PHASE Minimal or no uplift with slow depositional rates	Phyllitic unit very incompetent, possible line of transmission for stress adjustment in down faulted blocks
					0 to 5	Khaki Shales — Quartz, mudstone Shale and clay		
					0.1 to 3	Basal Reef — Auriferous conglomerate		Mining levels, the Basal Reef being the principle gold producing zone
			Livingstone	Upper Footwall	±240	U.F.1, U.F.2, U.F.3, U.F.4 — Quartzites and Conglomerates	OFFLAP PHASE Formation of a gently dipping monocline. Deposition having occurred well beyond the outer edge of the Witwatersrand Basin	Footwall quartzites more competent than hanging wall
			Main	Middle Footwall	±210*	M.F.1, M.F.2, M.F.3 — Quartzites (argillaceous) and conglomerates		
				Lower Footwall	±975*	Argillaceous quartzites and conglomerates		Major seismic activity associated with this stratigraphic horizon in Enkeldoorn Block
	WITWATERSRAND Lower Division	Jeppestown			±570*	Quartzites with a band of lava and shales		
		Government Reef			±1900 †	Quartzites, conglomerate and shale bands		
		Hospital Hill			±1500 †	Shales (ferrugenous) and Quartzites		
2800								
2900±150	DOMINION REEF						Major Unconformity	
3500	SWAZILAND							

* borehole data
† estimated from other regions

TABLE 2 Geological and Tectonic Table

Witwatersrand sediments are not exposed, they are covered by thin layers of Ventersdorp and/or Karoo sediments. The Transvaal Supergroup being absent.

2.2 O.F.S. Goldfields - Geological Environment

The detailed geology of the Witwatersrand Triad as it occurs in the Orange Free State has been discussed in a number of papers and books (Coetzee, 1960; McKinney et al., 1964; Brock and Pretorius, 1964; Houghton 1969; Pretorius, 1979). In a study of the associated seismicity much of this material is not of direct relevance. However, there are four major aspects that should be reviewed, these are:

General structure
Major lithological changes
Tectonic activity and trends
Intrusives

The seismolcgical significance of these are two-fold. The first to determine a simplified structural model for locating hypocentres, the second to understand the geological implications on the seismicity. Table 2 has been prepared from a number of references in an attempt to summarize the above and other signif:cant aspects of the O.F.S. geology.

2.2.1 General Structure

Figure 2.1 shows a schematic East-West section of the southwestern edge of the Witwatersrand Basin. This section can be subdivided into a number of major components or episodes. The earliest and broadest of these is a north plunging syncline of Witwatersrand and Ventersdorp rocks. Along the west side of the syncline's central axis an upthrown block of Lower

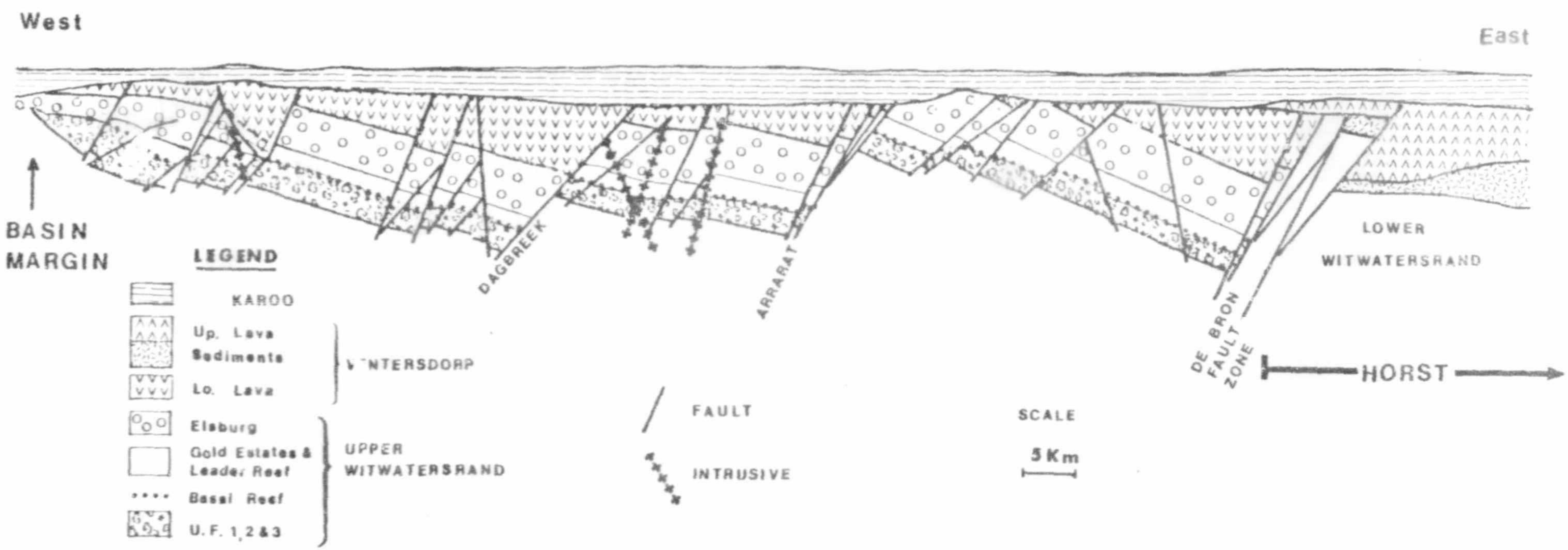
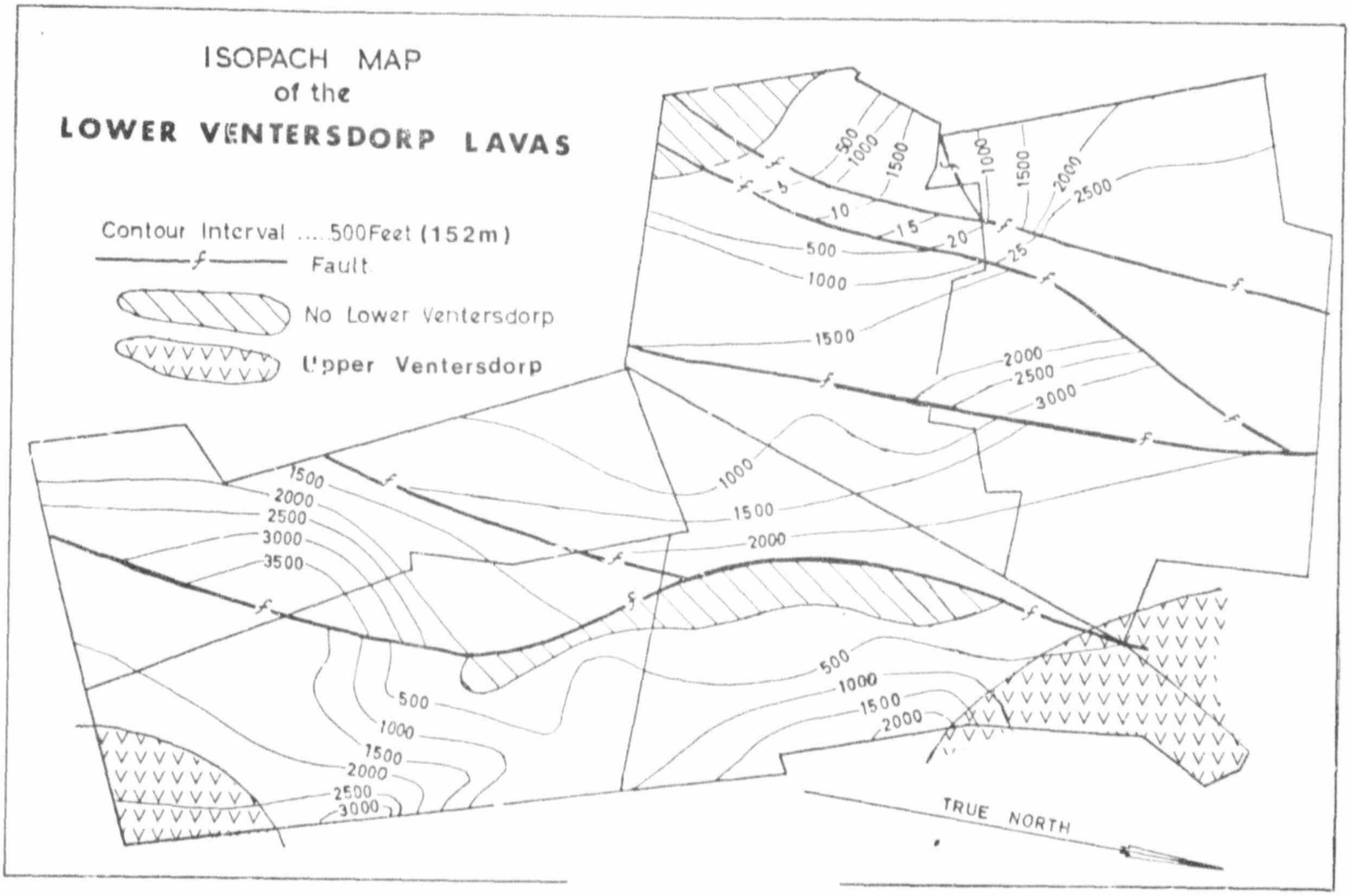


Figure 2.1 Schematic East-West section of the southwestern edge of the Witwatersrand Basin

Witwatersrand and Upper Ventersdorp has formed the De Bron horst. This has subdivided the syncline into a western and eastern graben, the horst-graben boundaries being the De Bron and Homestead faults (Figure 1.1). Various periods of faulting have then complicated the graben. This commenced with block faulting which had a levelling influence on the Witwatersrand sediments. Then strike slip, reverse faults and further normal faults occurred transverse and parallel to these faulted blocks. These progressive stages of faulting have also been preceded and accompanied by intrusives; primarily dykes of dioritic composition, which intruded into both the unfractured rocks and the preexisting fracture zones. This has resulted in sets of dykes orientated with both NS and EW strikes.

Welkom and the associated mines occur over the western or Odendaalsrus graben. The eastern boundary of the graben abuts against the horst and is bounded by the north-west striking De Bron fault (Figure 2.1), while the western boundary is not as clearly defined. The initial interpretation of the unconformity on this western flank was that of a major reverse fault, the Border fault (Figure 1.1). Alternatively, beds on this immediate western flank provide strong evidence for the occurrence of monoclinal flexure of the Witwatersrand sediments, (Brock and Pretorius, 1964; McKinney et al, 1964). Evidence of compression is however also clearly indicated by the presence of two anticlines a the north and southwest of the graben. Finally, this whole structure suboutcrops beneath a thin horizontal layer of Ecca and Dwyka sediments (Figure 2.1 and A1 - 8 to 13). The dip of the Witwatersrand sediments lie typically between 19^0 and 26^0 in all regions except the western margin, where they are considerably steeper due to the tectonism.



ISOPACH MAP
of the
LOWER VENTERSDORP LAVAS
Contour Interval 500Feet (152m)
Fault
No Lower Ventersdorp
Upper Ventersdorp
TRUE NORTH

Figure 2.2

2.2.2 Lithology

In the O.F.S. Goldfields, detailed stratigraphic descriptions are restricted to the Upper Witwatersrand and younger formations since mining activity has only provided geological sections to depths just below the Basal Reef, the principal gold producing zone. From a seismological view point, to some extent this problem is alleviated, because it is only the major changes in physical properties that are of importance. Information that is fundamental and not available is the attitude and distribution of the Lower Witwatersrand and its associated structures.

Based on density and the related phase velocities, there exist three major groups which are the Witwatersrand sediments, the Lower Ventersdorp lavas and the Karoo sediments. The Upper Ventersdorp lavas and sediments are restricted to the outermost northeast and southeast corners of the Odendaalsrus graben so they can therefore be disregarded (Figure 2.2). From Table 2 it is clear that the first major density, and therefore velocity change occurs between the silicious Upper Witwatersrand sediments and the Lower Ventersdorp intermediate andesites. This represents an average change in the compressional and shear phase velocities of approximately 0.4 and 0.1 km/sec respectively. The second significant seismic discontinuity is the unconformity between the Dwyka Series and the pre-Karoo rocks, which due to the very irregular pre-Karoo erosional surface can be either the Ventersdorp andesites or Elsburg quartzites. At this boundary the contrast in phase velocity is therefore, very variable and in addition this variation is further enhanced by the high degree of weathering of the Karoo sediments. The swaziland basement and Dominion Reef have not been considered since they are probably well removed from the observed seismic region, assuming that they have not been associated with any major displacements. Further they have similar seismic properties to the overlying Witwatersrand so do not constitute a major discontinuity.

The Witwatersrand sediments display a wide spectrum of compositions due to the large range of depositional facies. The lower division is principally a phyllitic unit but as previously mentioned, little is known about it in the O.F.S. Goldfields. The arenitic upper division petrologically has a composition consisting of subgreywackes with occasional sequences of ortho-quartzites, however, for simplicity the local connotation of quartzite will be retained. Discrepancy exists over the strength of the quartzites above (hanging-wall) and below (footwall) the main gold bearing reef. For ERPM and Klerksdorp mines laboratory measurements show the hanging-wall quartzites to have a higher compressive strength and be more competent than the footwall quartzites, (McGarr et al., 1975; van der Heever, 1978). In contrast McKinney et al. (1964) suggested that kimberlite intrusives on the President Steyn mine indicate that the hanging-wall quartzites are less competent in the O.F.S. mines. More recently though, a value obtained for the footwall quartzites (155 MPa) was less than the value for the leader reef quartzite in the hanging-wall (270 MPa) while values for the Leader Reef Zone (145 MPa) Dagbreek* Fault Zone (160 MPa) and Arrarat Fault Zone (190 MPa) were of the same order (Gay and Jager, 1980). It must be noted that the auriferous reefs in these three mining districts represent different stratigraphic horizons. Within the upper division there are also a number of thin phyllitic horizons of which the khaki shales are of particular seismic importance. They are

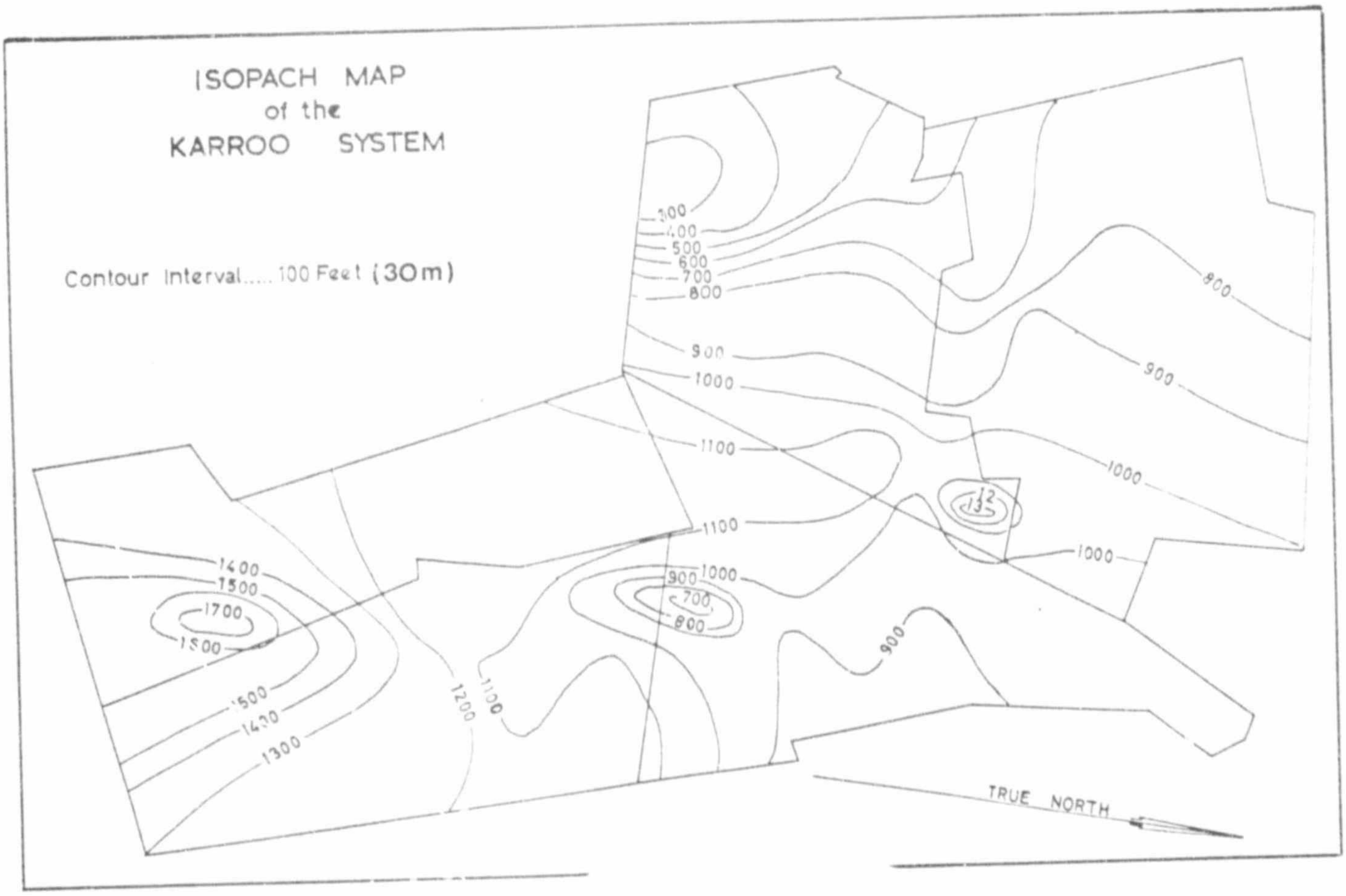

ISOPACH MAP
of the
KARROO SYSTEM
Contour Interval..... 100 Feet (30m)
TRUE NORTH

Figure 2.3

situated immediately above the Basal Reef and are well known for their ability to act as a transmission zone for stress adjustments in down faulted blocks (McKinney et al., 1964) and for their association with seismic activity and rockfalls in the Harmony mine (Joughin, 1966).

The Ventersdorp lavas have a relatively uniform composition and consist of amygdaloidal aphanitic augite andesite. These lavas are well stratified and are often interbedded with non-amygdaloidal horizons.

The lateral distribution of both the Witwatersrand and Ventersdorp is very irregular due to normal faulting, particularly, because of the large throws associated with the major strike faults (Figure 2.1).

In contrast the Karoo sediments over the Welkom area have a reasonably uniform thickness of between 300 and 400 metres. This is despite their uneven pre-Karoo depositional surface, which caused local thickening along a NNW-SSE axis just west of the Arrarat fault (Figure 2.3). The Dwyka and Ecca can be described lithologically as being shales, weathering to form clays at the surface. Interbedded in the Ecca shales are thin sandstone horizons and extremely thin coal seams (0 to 0,5 m), which because of their minimum thickness are not significant to the seismic considerations.

2.2.3 Tectonic Activity and Resulting Structures

Commencing with the cyclic deposition of the Witwatersrand Supergroup, the principal tectonic activity of the O.F.S. Goldfields can be grouped into a number of episodes. The sediments that formed the Witwatersrand

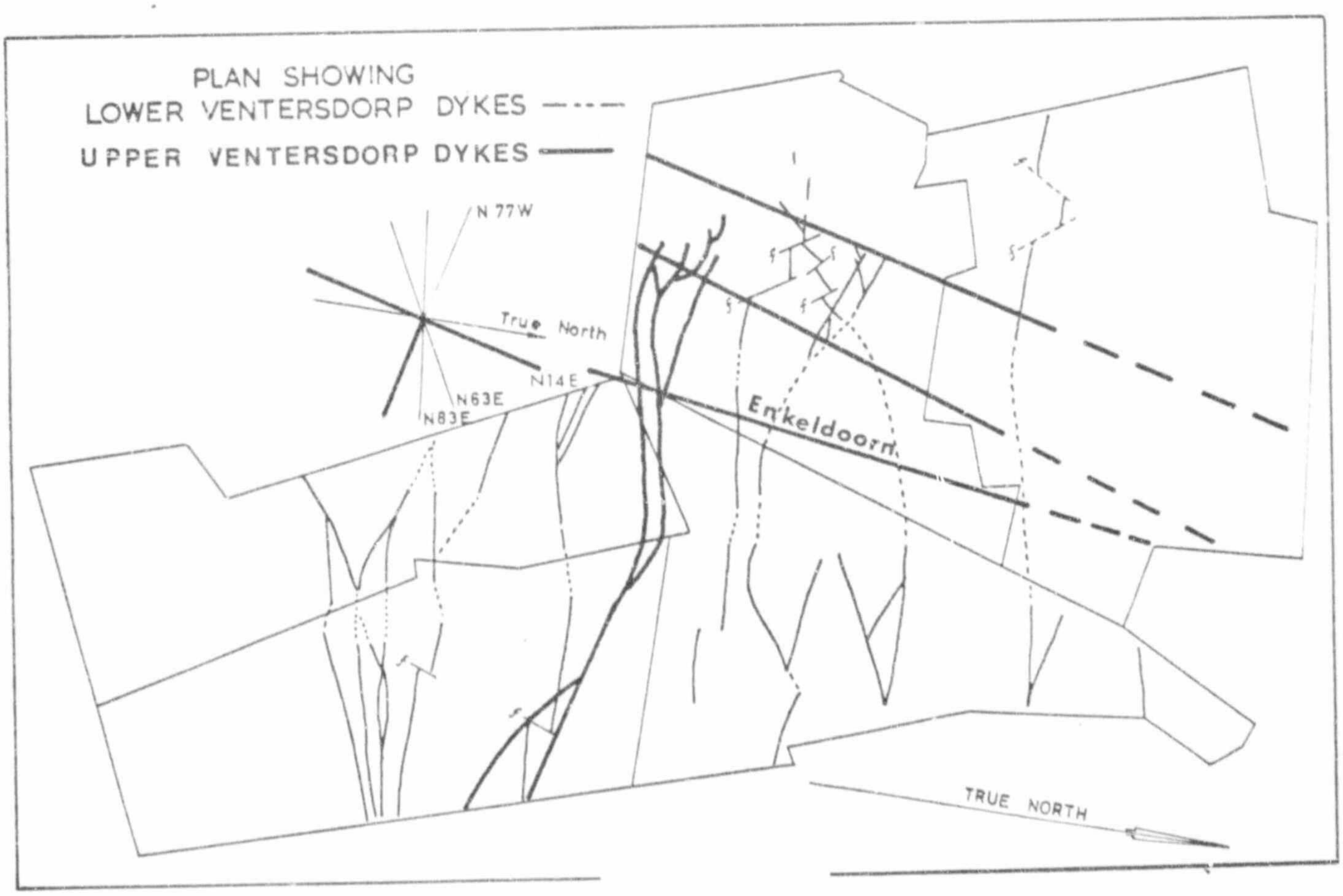

PLAN SHOWING
LOWER VENTERSDORP DYKES
UPPER VENTERSDORP DYKES
N 77 W
True North
N14E
N63E
N83E
Enkeldoorn
TRUE NORTH

Figure 2.4

basin were generated in three distinct phases (McKinney et al., 1964). The offlap, a period during which the sediments regressed towards the basin centre and because of the resulting load a gentle dipping monocline developed. A stable phase free of any major uplift which was accompanied by the deposition of the deltaic facies of the Basal Reef and Leader Reef Formations. Then finally, in response to rapid uplift a transgressive or onlap phase occurred, with coarser grained sediments being deposited away from the basin centre across the older sequences. A marked feature of this depositional sequence in the O.F.S. Goldfields is an absence of any of the major subsidence observed along the northern and northwestern margin of the Witwatersrand Basin. Despite a period of major disruptive tectonics which followed the deposition of the sediments in the O.F.S. there were no displacements similar in magnitude to those of the east, central and west Rand gold mining districts.

The deformation in the O.F.S. was initiated with the intrusion of Lower Ventersdorp lavas along east-west striking dykes (Figure 2.4). The strike of the dykes indicating a north-south tensional axis. Extensive vertical uplift then followed, with a maximum compressive stress acting along a north-south axis, centrally through the position of the De Bron horst and also with a bias towards the north. Through the application of this force, the horst and major dip slip faults developed, with strikes approximately parallel to the basin margin. The dips of these normal faults are between 50° and 60°, and their throws are between 800 and 100 m, the maximum throw occurring closes to the region of maximum stress difference. They are represented by the Virginia, Homestead, Geduld, President Brand, De Bron and Welkom faults and in particular, the Arrarat and Dagbreek which are two of the principal faults of this study (Figure 2.5 and A1-1).

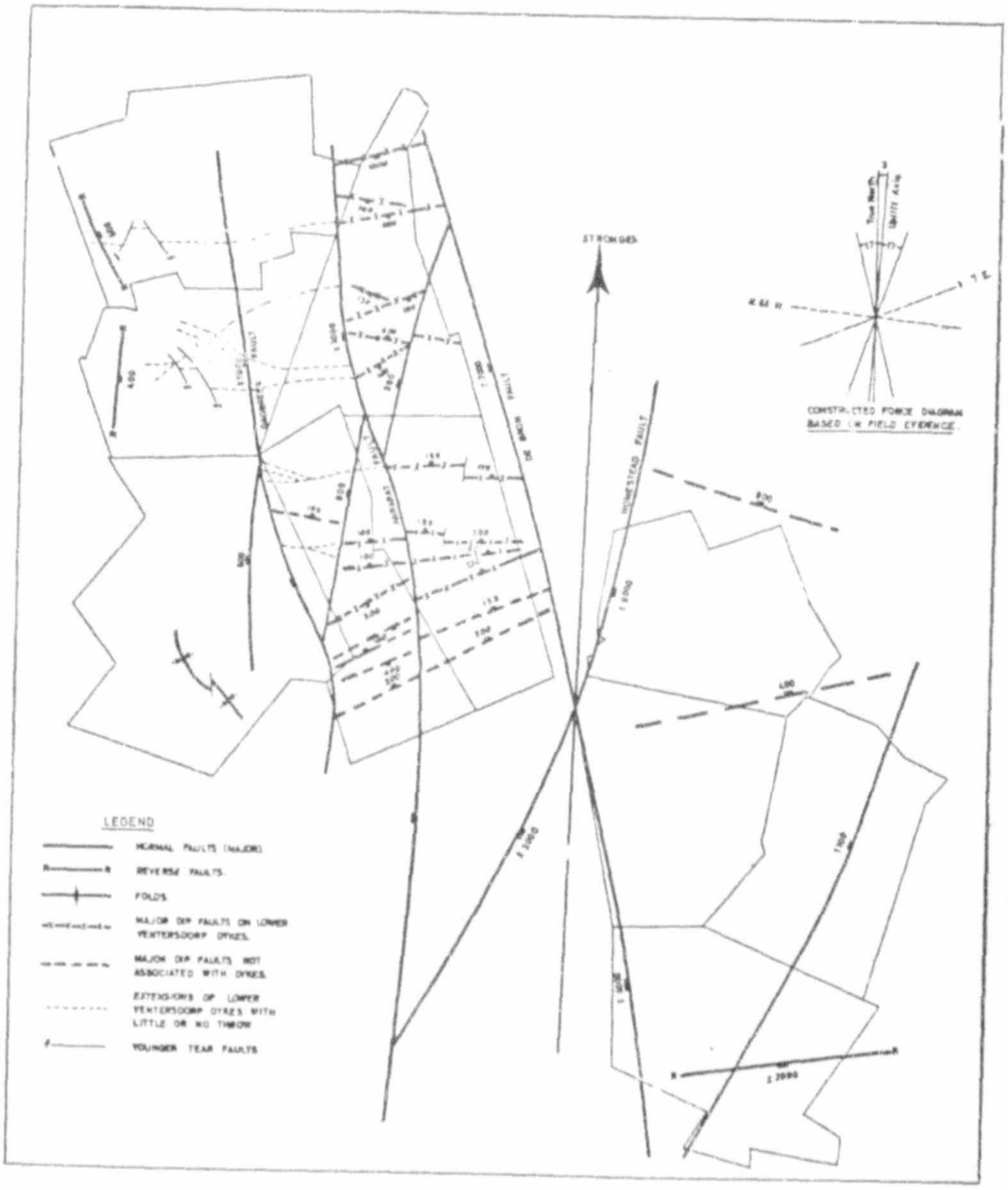


Figure 2.5 Traces of the initial stage faulting in the O.F.S. Goldfields

accompanying this major stress adjustment were secondary adjustments which led to normal faulting perpendicular to the principal uplift axis, thus creating an interblock structure on both sides of the central horst. In many cases, these faults followed the older Lower Ventersdorp dykes, thus having dips of between 70° and 90° and introducing displacements across these dykes of between 0 and 300 m. As uplift continued, the fault blocks adjusted individually as they butted against each other, the local compressional stresses being released by minor offsets in the form of numerous interblock normal faults, and some rotational faults adjacent to the major strike faults.

The western abutment to this activity was demarcated by a "hinge" zone, the western rim of the Witwatersrand Basin. Compressional features such as anticlines and reverse faults formed against this hinge zone in response to the overall lateral expansion (Figure 2.5). This then represented an initial phase of deformation. Additional phases of similar vertical movements followed, complicating and offsetting many of the structures of the first phase. The terminal stage, however, is represented by a set of strike slip faults, with strikes of N14E, N43E and N30W, dips of ± 70° and virtually no throw. This indicates a change in the maximum stress field compressive stress from the earlier east-west orientation to one with a N - S maximum horizontal compressive stress. It has been suggested that this was in response to the intrusion of the Vredefort Dome (Threader, 1963) however, this does not appear likely since the major thrust of the updoming was to the northwest and the resultant structure is situated north-east of the O.F.S. Goldfields. One other set of displacements occurred which represent a very late stage in the tectonism of the Witwatersrand Triad. They are a set of low angle thrust faults in the Khaki shales which transgress all other structures, possibly in response to lateral stress adjustments, (McKinney et al., 1964).

A major unconformity both stratigraphically and tectonically separates the Karoo Supergroup from the Witwatersrand Triad. After deposition of the Karoo, post-Karoo uplift and planation removed any of the upper series leaving only the Dwyka, Ecca and possibly small outliers of the Beaufort. In the Welkom area there is no evidence of any major tectonic disturbances associated with the Karoo except for some closely related dolerite dykes. The nearest structural feature is the Bloemfontein-Villiers fracture belt to the southwest of Welkom. In addition, landsat imagery shows an absence of drainage and lineaments converging on the Welkom area, thus suggesting the existance of a Karoo hinge zone.

2.2.4 Intrusives

The western graben intrusives are essentially all dykes, there being only a very small number of sills. The dykes can be grouped into three suites. Figure 2.4 shows the disposition of fissures which produced the andesites of the lower and upper Ventersdorp dykes, the Enkeldoorn is of particular interest, with a strike of $5^{O}N$ it passes through a fault block bounded by the Arrarat, Dagbreek, President Brand faults and Welkom dyke fault zone. For simplicity, this block will be termed the Enkeldoorn block in further discussions.

The petrography of these two sets is very similar and essentially the same as the Ventersdorp andesites. However, variations between different dykes in the ratio of sodic and calcic plagioclase produces an overall range of rocks from quartz diorite, diorite to diorite gabbro. This is further complicated by the absence of fresh samples because of the alteration of many diorite dykes to diabase. The composition and chronology of these dykes allows comparisons to be made with dykes in other Witwatersrand mines, such as ERPM. Here stress measurements have been made on Ventersdorp age tholeiitic quartz dolerite dykes (Gay, 1979), which have shown them to have very high compressive strengths and an ability to store residual stress. Structurally, only the Lower Ventersdorp dykes have received large offsets from subsequent faulting.

The third group of dykes is identified with the Karoo Supergroup. They are typically dolerites but there is one example of a lamprophyre and a small cluster of kimberlite intrusives. These minor occurrences do not present any major part in this present study because of their limited distribution and restriction to the perimeter of the study region.

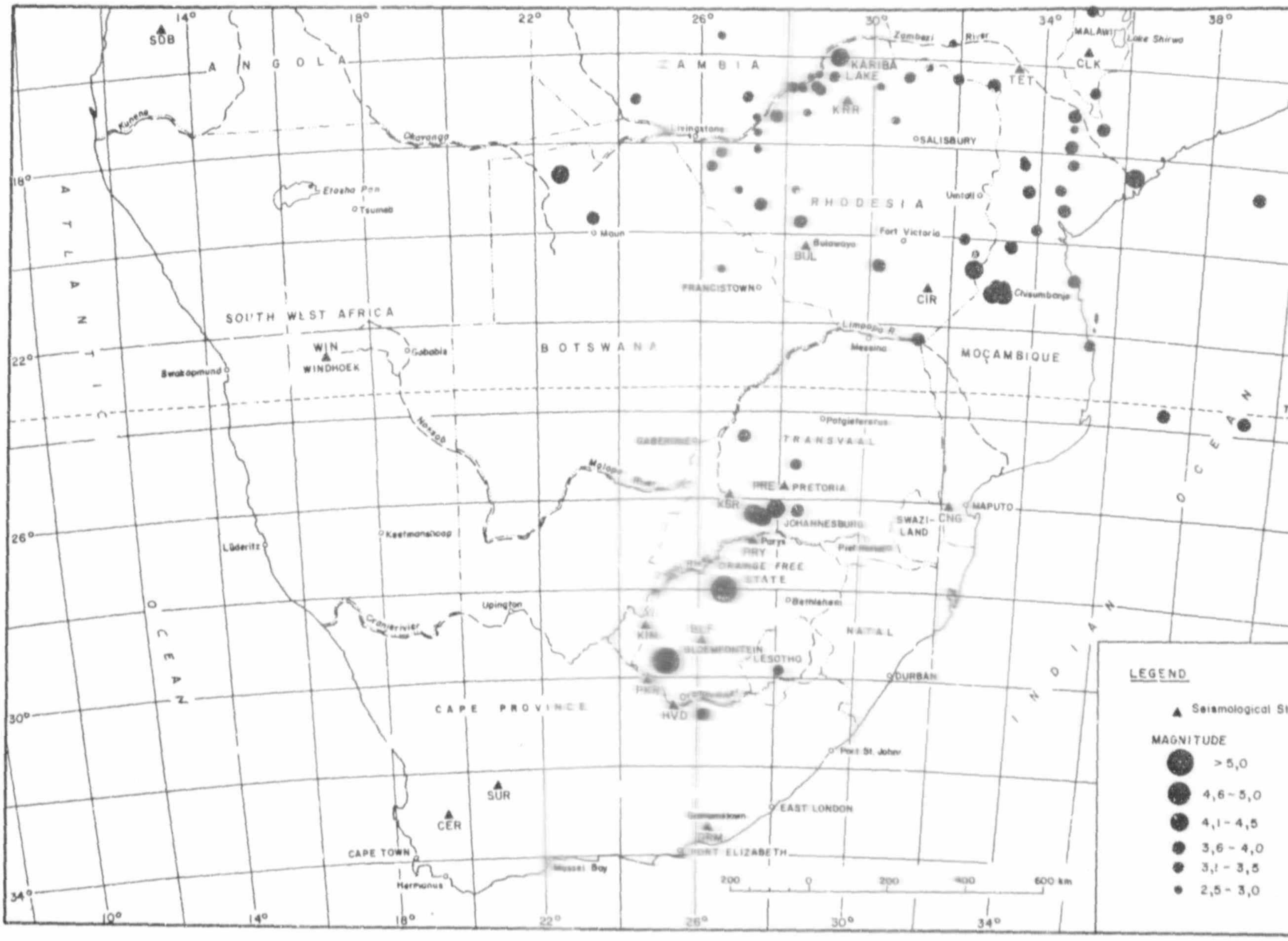


Figure 3.1 Earthquakes in Southern Africa and surrounding oceans for 1976 (S.A. Geological Survey (1979) Series 8)

3. SEISMIC HISTORY OF THE O.F.S. GOLDFIELDS (PRECEDING DECEMBER 1976)

Often when investigating the seismicity of localized regions historical records dealing with the level of activity are generally very scarce and limited. This situation is also applicable to the O.F.S. Goldfields. Even after mining had commenced with the sinking of the first shaft on St. Helena mine in 1947, reliable seismic reports were not available until the late 1950's. It is difficult to ascertain whether this implies there was little or no activity, or that documentation was of a poor quality or mislaid. Particularly, as there have been the usual handed-down accounts of activity from farmers and local residents and it was also unlikely that the early and rapid mining development did not have some disturbing influence on the geological structure. In addition, a comprehensive catalogue of probable natural seismicity for South Africa during the period of 1900 to 1970 (Fernandez and Guzman, 1979) further confirms the absence of documented natural activity for this area. The only noteworthy event that may have had a natural origin and possibly contributed to this region was on the 18th November 1954. This event was catalogued as having a location of 28.25°S and 27.25°E and a maximum intensity of V (M_L approximately 4.3) (Oliver, 1956). Therefore within the probable large location tolerances of that time, this event is well placed to be associated with the O.F.S. Goldfields.

In contrast the records of the region's seismicity from 1960 onwards are reasonably well established. Following the initial seismic investigations in the Central and East Rand Goldfields, Joughin (1966) made a comprehensive study of the seismicity of the Harmony Gold Mine in the southern O.F.S. Goldfields. His findings showed that there was extensive

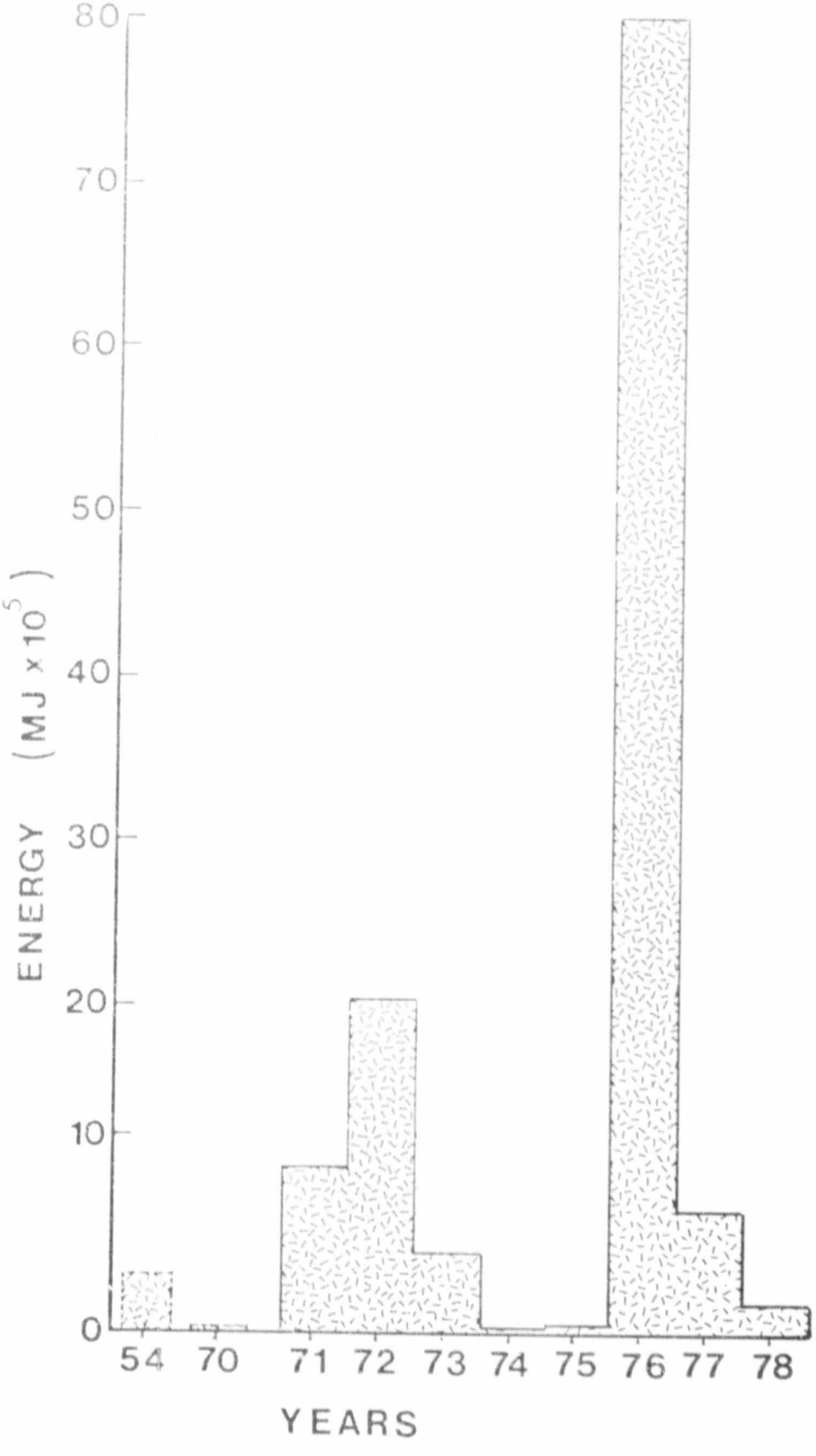


Figure 3.2 Annual seismic energy release for the O.F.S. goldfields. Data from the SAGS Seismic Catalogues

activity associated both in time and space with the mining; ninety-five percent of the events were situated above the active mine faces and the remaining five percent geologically controlled by a dyke, sill intersection approximately 800 meters above the reef. The log-frequency relationship for these events was determined as $\log N = 4.24 - 1.2M$ which is in agreement with the other Witwatersrand mining districts (McGarr, 1971b). After this initial investigation the local seismic network was discontinued, leaving only the national network operated by the South African Geological Survey (SAGS), (Figure 3.1), to monitor the O.F.S. Goldfields as part of a general coverage of South Africa. For the year 1971 a comparison was made of the level of activity between six different Witwatersrand mining districts (Fernandez, 1973). This report, besides confirming that most of the seismic energy was released in the larger events ($M_L = 3.5$ to 4.0), showed that the O.F.S. Goldfields contributed 28% of the total energy released for that year, second only to the Far West Rand Goldfields which contributed 39%. This is significant in that the O.F.S. Goldfields had the lowest frequency of recorded events, 5% of the annual total of 838 (Far West Rand 72%). This discrepancy can be accounted for by the biased disposition of the national network towards the northern mining districts (Figure 3.1).

To correct this bias and other weighting factors such as the improvement in the network and location techniques the magnitudes were converted to energy for a comparison of temporal and regional variation from 1970 to the present. The annual and monthly seismicity in terms of energy for the O.F.S. Goldfields is shown in Figures 3.2 and 3.3 respectively. The events were taken from the SAGS Catalogues and Bulletins and the energy was calculated using the corrected energy magnitude relationship of Gutenberg and Richter (1956), $\log E = 11.8 + 1.5M$ [illegible]s).

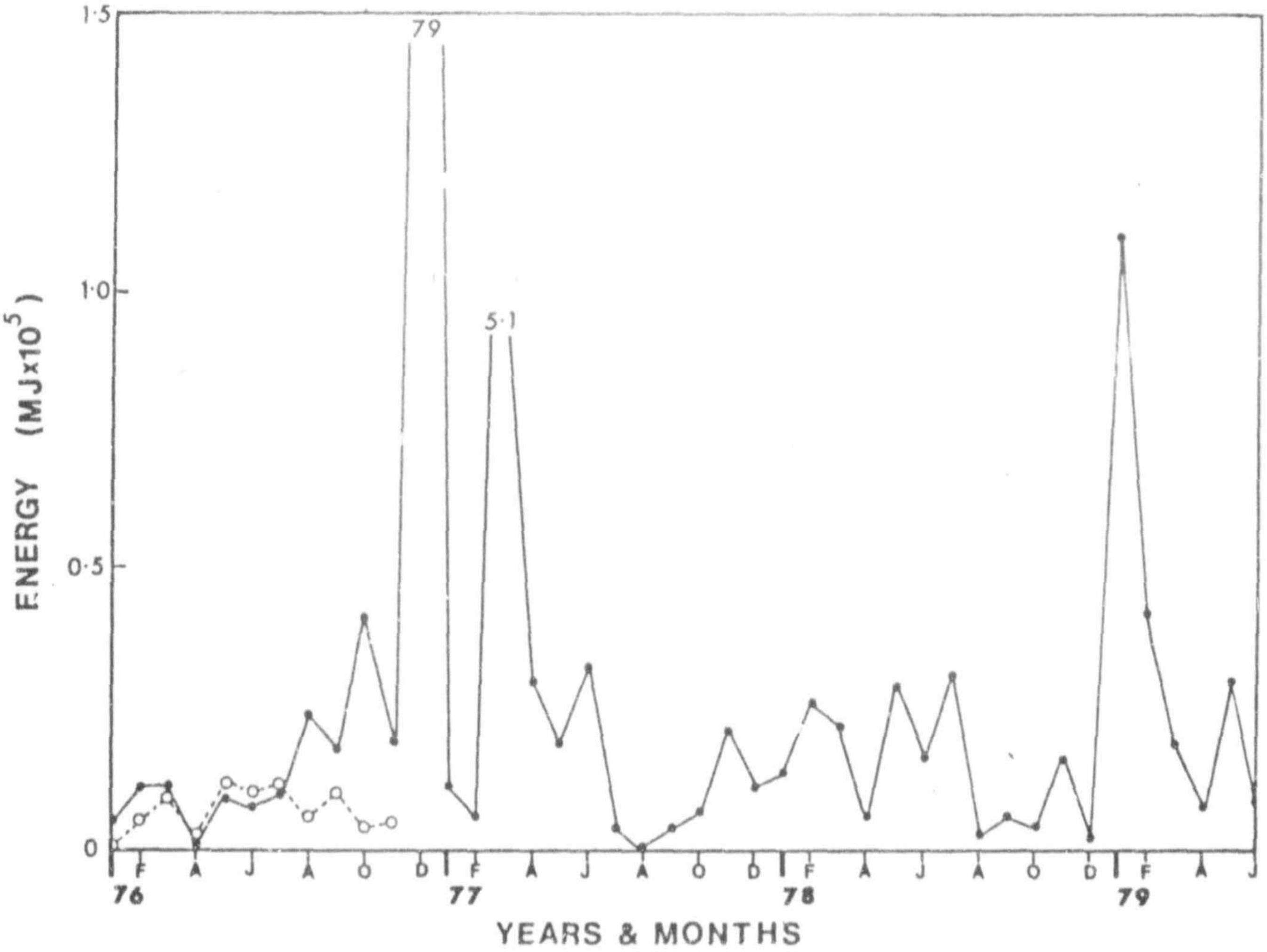


Figure 3.3 Monthly variation of seismic energy. Source of data for open circles S.A.G.S. catalogues of seismic events and for dots S.A.G.S. monthly seismic bulletins.

Note that since the introduction of an additional station at Welkom in July 1977 (Figure 3.3), there has been no major increase in the energy released. The annual seismic energy release shows two distinct maxima, the first in 1972 and the second associated with the principal event of this study in 1976. Preceding the 1972 maximum there appears to be an annual increase in activity, however, this increase is not well defined in the monthly rate. In contrast, by using the Bulletin records which list a higher proportion of the smaller events (M_L = 2.0 to 2.6) there is a very distinct increase in activity in the months preceding December 1976 (Figure 3.3).

In Summary therefore, there is no conclusive evidence to suggest that the geological structures of the O.F.S. Goldfields were either inactive or active prior to mining and since the advent of seismic data acquisition for this region there has been no general increase in seismicity, in fact, there is a tendency towards an oscillatory variation. It is however, almost certain that the recent high level of activity was not in evidence prior to the mining, since the town of Odendaalsrus preceded the mining by many years and the habitants had not recorded any major seismic activity prior to the mining.