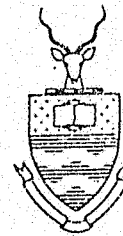


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I, Stewart Lloyd Fumerton do hereby declare
that this Dissertation is my own work and
has not been presented to any other
University for the purpose of obtaining a
Degree.

S.L. Fumerton

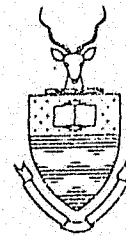
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THE FELSIC INTRUSIVES IN E.R.P.M., BOKSBURG.

Stewart Lloyd Fumerton

A Dissertation Submitted to the Faculty of Science
University of the Witwatersrand, Johannesburg
for the Degree of Master of Science

March 1975

ABSTRACT

This dissertation is concerned with ten en-echelon transgressive sills on the East Rand Proprietary Mines, which form part of a family of aplitic sills that occur in the Witwatersrand. The aerial extent of these sills varies from an estimated 125 square metres for the sills at the lowest known structural level, to 18×10^6 square metres for the sill at the highest structural level. The thicknesses of the sills are generally constant, but some sills have characteristic thicknesses, ranging from 0,5 - 6 metres. All the sills are zoned, having a narrow contact zone and a thicker central zone with a rapid transition between the two. Sometimes a chill zone is also present in the contact zone.

The sills appear to have formed by partial melting of 3,3 b.y. old crust at 35 kilometres below the surface. This anatexis took place at 2,1 b.y. ago and is probably related to the thermal activity of the Bushveld Igneous Complex. This thermal activity coincided with a strong horizontal compressive stress oriented north-south, which pre-determined the overall orientation and distribution of the sills at 9 kilometres below the surface.

The petrochemistry shows that the sills have a strong affinity to the peralkaline rocks but with major differences, especially in the mineralogy and petrology.

The uniaxial compressive strength of the aplite, varies from 530 MPa in the brittle central zone, to 230 MPa in the relatively weak and ductile contact zone. This contact rock produces Lüder's bands in testing, which have also been observed naturally within the sills.

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I would like to thank the members of staff of the Geology Department and the Economic Geology Research Unit of the University for comments and criticism, in particular Mr. T.S. McCarthy whose advice and assistance was invaluable in the analysis of the geochemistry samples, and who also read the chemistry section. Professors J. McIver and J. Ferguson read the petrology section.

I am grateful to the Geological Survey in Pretoria for the crushing of the majority of the geochemical samples; and the National Institute for Metallurgy for analysing the samples for various constituents.

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List of Symbols

b.y.	billion years (10^9)
m.y.	million years
ppm	parts per million
Peralkaline index	Molecular weights of Na_2O and K_2O over Al_2O_3
$r = K \cdot t / d^2$	K = thermal diffusivity
	t = time
	d = thickness of the body
	(defined by Jaeger '1968)
E	Young's modulus
kN	kilonewtons
MPa	megapascals (all compressive stresses are regarded as positive)
ν	Poisson's ratio
σ	Stress
$\sigma_1, \sigma_2, \sigma_3$	Principal stresses $\sigma_1 > \sigma_2 > \sigma_3$

1. INTRODUCTION

1.1 Introductory statement

This project is concerned with the structural geology, petrology, geochemistry, geochronology and rock mechanics of the felsic intrusives (known locally as the 'Chert Dyke') on the East Rand Proprietary Mines Limited. It was hoped that a detailed understanding of the nature of these intrusives would help overcome the problems caused by their presence during mining activities. These problems include unfavourable stope conditions, when the 'Chert' forms the hanging, and the apparent correlation between the presence of 'Chert' and the occurrence of severe rock bursts.

1.2 Regional Geology

E.R.P.M. lies some twenty kilometres to the east of Johannesburg at the town of Boksburg. It is the easternmost gold mine in the Central Rand Basin, which is part of the Witwatersrand Basin and is separated from the East Rand Basin by the Boksburg Gap. The mine exploits the auriferous conglomeratic horizons within the quartzites of the Main Bird series of the Upper Witwatersrand System. The reefs that are known to be present on the mine are:- North Reef (Angelo Leader), Main Reef, Main Reef Leader, South Reef-Composite Reef, Livingstone Reef, Bird Reefs, Kimberley Reefs and Elsburg Reefs, but of these only the Main Reef, Main Reef Leader and South Reef-Composite Reef are economical at present. The lower reefs in the sequence, i.e. North Reef, Main Reef, Main Reef Leader and South Reef form separate horizons at the west of the mine but merge in the centre to form the Composite Reef. According to Shipway (1972) it is the South Reef which is continuous across the mine and unconformably overlies the other reefs. Above the Witwatersrand System are the lavas and sediments of the Ventersdorp System, which are, in turn, overlain by the basal sediments of the Transvaal System, south of the mine.

DISTRIBUTION OF FELSIC INTRUSIVES ON THE WITWATERSTRAND

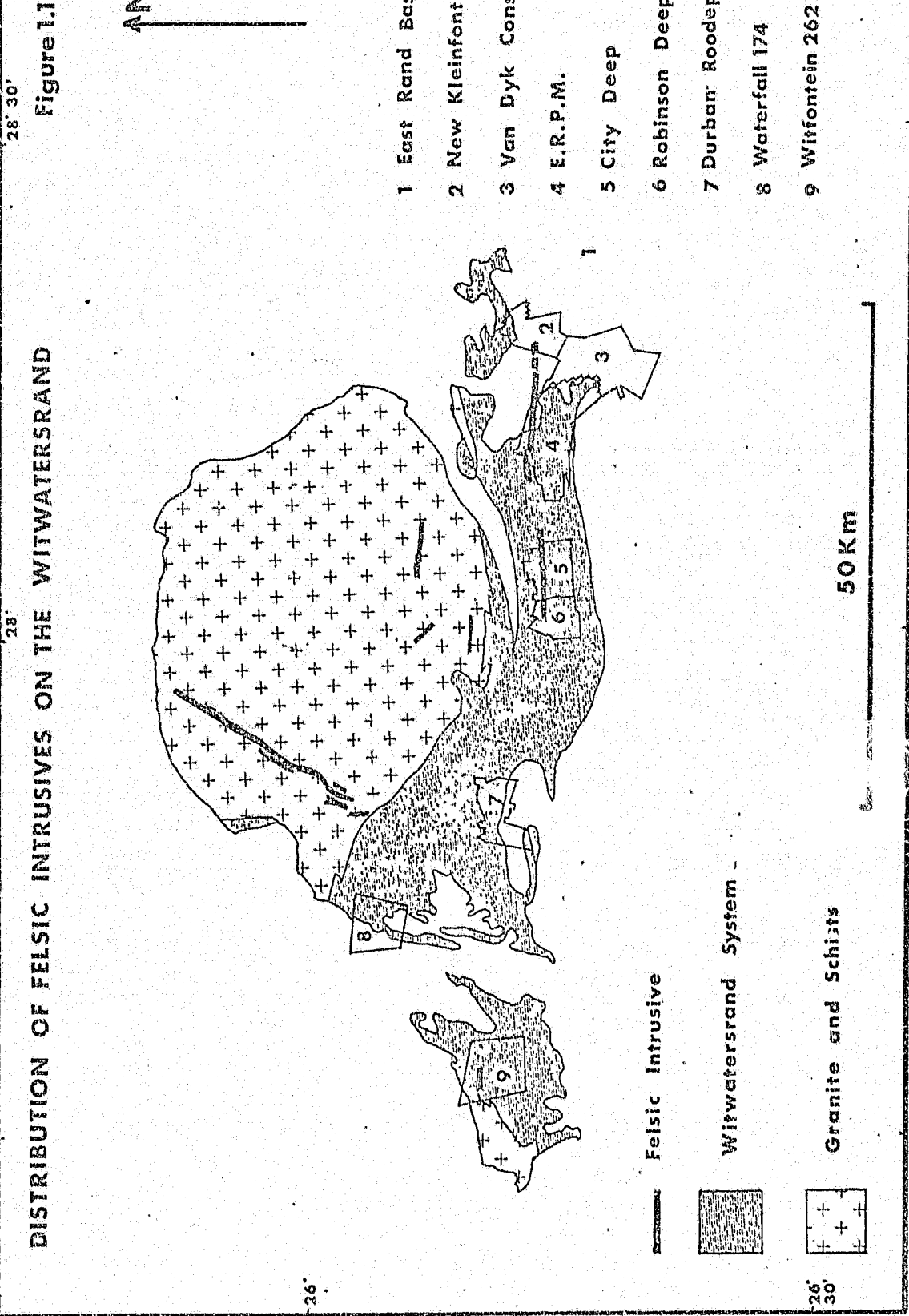


Table 1.1

Occurrences outside the E.R.P.M. of acid intrusives near the Central Rand

<u>No. on Figure 1.1</u>	<u>Locality</u>	<u>Description</u>
1	East Rand Basin	Quartz porphyries occur as sills, described as 'yellow flint-like rocks' with corroded quartz phenocrysts set in a fine grained matrix (Whiteside, 1950). Quartz 'nylonite' dykes and sills up to 12 metres thick, composed of 'euhedral quartz, plagioclase felspar and clots of calcite and epidote in a fine grained, spotted matrix of quartz, felspar chlorite and sericite'. There are β quartz phenocrysts (Whiteside, 1950).
2	New Kleinfontein	Aphanitic igneous rock, known only from hand specimens; similar to the rock on E.R.P.M.
3	Van Dyk Consolidated	A deep surface borehole (VS6) intersected an acid sill 10 metres thick above the Composite Reef. The log gives two descriptions of this sill, namely 'acid intrusive' and 'Old Lady type'. The Old Lady is a mafic sill in the East Rand Basin.
5	City Deep	The Rand Deep Level borehole sited at the N.W. corner of Rand Mines Deep now in the centre of City Deep (Curle, 1899), intersected three acid sills below the Main Reef, the top one is 18,3 metres thick (Weber, 1909). In two shaft sections a transgressive sill is marked as 'Chert Dyke'. This sill dips south at 35° - 40° and is 11 metres thick.
6	Robinson Deep	An acid sill intersected above the Main Reef in the Turf Club East borehole is reported by Weber (1909); the sill appears to be in the same plane as that in the City Deep lower levels.
7	Durban Roodepoort Deep	Weber (1909) reports an acid intrusive in the old Roodepoort Deep Mine.
8	Waterfall 174	A large outcrop of an acid intrusive is reported by Weber (1909) on this farm. The old farm number is 74.

Table 1.1 continued

<u>No. on Figure 1.1</u>	<u>Locality</u>	<u>Description</u>
9	Witfontein 262	A 75 - 90 metres wide outcrop of acid intrusive is reported by Weber (1909) on this farm. The intrusive contains abundant quartz veins which have been exploited for gold. The old farm number is 29.
	Johannesburg-Pretoria Dome	Wager (1907), Willemse (1933) and Anhaeuser (1973, 1974, personal communications) have reported a number of acid intrusives in the granitic rocks.

The eastern parts of the mine are covered by flat lying sediments of the Ecca Series of the Karroo System. Detailed lithologic descriptions of the Witwatersrand sediments, especially the reefs, are given by Shipway (1972), the general geology of the Central Rand is reviewed by Pretorius (1964).

The lower economic reefs dip southwards at 45° on outcrop but this angle decreases to 15° at three kilometres below surface. Higher in the stratigraphic sequence the dip is southwards at 25° on outcrop and again decreases with depth. The strike of the sediments varies over the mine area from 090° in the western section to 110° in the central and eastern sections. Further east on the Van Dyk mine the strike is approximately 180° . The strata therefore outline part of a basin-like structure. Faults and mafic dykes are very common within the mine area. These have been recently described by Jeffery (1975).

Prior to this investigation, the officials on E.R.P.M. believed that the 'Chert' occurred as one or two undulating sills. However the results reported here indicate that there may be as many as ten or more aplite sills which transgress the sediments. These sills have been intermittently recorded on the mine plans since the turn of the century as 'Chert Rock', 'Chert Dyke' or simply as 'Chert', but generally the 'Chert' is not differentiated from the more common mafic dykes.

1.3 Acid intrusives outside E.R.P.M.

Several occurrences of acid intrusives are known outside the mine area. These occurrences which extend for some hundred kilometres from the East Rand to the far West Rand are shown in Figure 1.1 and details of the rock type are listed in Table 1.1. Most of these occurrences are not accessible now, and so exact comparison with the E.R.P.M. bodies is not possible, but they do indicate that acid igneous activity occurred over a wide area of the Witwatersrand. Moreover with the exception of the

outcrops in the Archaean granite, the sill-like bodies are confined to a particular structural level within the sediments and some within the granite have a parallel strike.

1.4 Previous work on E.R.P.M.

The aplite sills on E.R.P.M. have been described by several people previously but the work reported here represents the first attempt to investigate the detailed nature of the bodies. Weber (1909) described a sill in the Cinderella section of the mine (see Figure 1.2), and concluded that it was a microgranite. Gold concentrations up to 4,4 p.p.m. were determined by fire assay, but were normally negligible. The same sill was described by McDonald (1911) from the Blue Sky section. He also classified it as a microgranite, and inferred from the mineralogy that it had been subjected to an intense metamorphism not seen in other dykes on the mine. Hence he concluded that the sill was the oldest intrusion. Shipway (1972) noted the lack of contact metamorphism and concluded that the sill was not igneous, but rather a low temperature secretion of the adjacent quartzites into pre-existing fractures giving a composition of $\approx 99\% \text{SiO}_2$. A tectonic origin was suggested by Pretorius (1964) who stated that "the so called 'Chert Dykes' are, in fact, zones of intense mylonitisation along lines of shear". However, this proposal was not applied to the occurrences on E.R.P.M. in particular. Because of its apparent association with rockbursts and other mining problems, the 'Chert Dyke' has been the subject of a number of investigations to determine its rock mechanical properties. These results are reported in a number of unpublished C.S.I.R. Special Reports, Brace et al. (1966) and, briefly, in Jaeger and Cook (1969 pp. 146, 147). The most striking property is the very high uniaxial compressive strength of the rock.

1.5 Scope of present work

The work reported here commenced with the detailed mapping of all the accessible footwall drives in the Angelo and Lower Hercules sections. Less detailed mapping was done in the stopes to confirm the mapping of the mine surveyors and check isolated occurrences. The determination of the mineralogy of the sills was done in considerable detail, principally using X-ray diffraction techniques, and a large number of petrological thin sections were examined. Some 76 samples were analysed for major elements, principally to study variations across the sills, but at least one sample of all but two sills was also analysed. Eight of these samples were used in the isotopic studies relating to the geochronology of the sills. Twenty-six samples were tested to ascertain some rock mechanical properties of the rock. The majority of the specimens for the above work were obtained by diamond drilling. This work was done during 1973 and 1974.

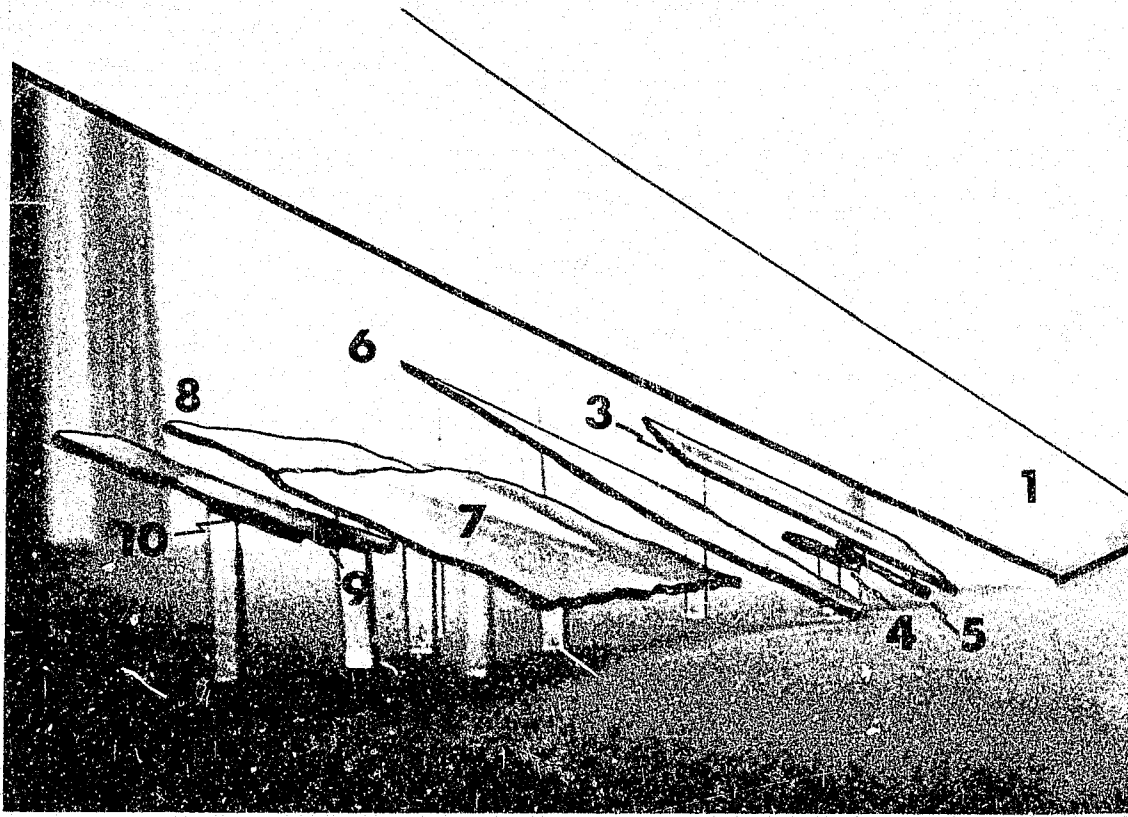


Plate 2.1

A photograph of a model showing the en-echelon nature of the sills

Table 2.1

Dimensions of the sills

<u>Sill No.</u>	<u>Average Thickness</u>	<u>Strike</u>	<u>Dip</u>	<u>Orthogonal Separation from No. 1 sill</u>	<u>Orthogonal Separation from next sill</u>	<u>Length of sill-reef intersection trace</u>
1	3 - 4 m	± 90°	50 upper levels 20 lower levels			6800 m, 1800 m
2	± 3 m	± 90°	50° S	± 24 m		Duplicated by faulting
3	2 - 4 m	± 90°	± 20° S	± 26 m		500 m
4	2 - 3 m	± 90°	± 20° S	± 33 m	± 7 m (No. 3)	None
5	3 m on 78 level	± 90°	± 20° S	± 41 m	± 15 m (No. 3)	None
6	± 4 - 6 m	± 90°	± 20° S	± 76 m	± 43 m (No. 4)	± 1300 m
7	Unknown	± 90°	Unknown	± 72 m	3 - 4 m (above No. 6)	Predicted to be greater than 2000 m although it has not yet been mined.
8	1,5 - 2 m	90° - 110°	30° S	± 106 m	± 30 m (No. 7)	Greater than 1100 m
9	0,5 - 1 m	80° - 100°	40° - 70° S	± 123 m	± 15 - 20 m (No. 8)	Greater than 300 m on both South and Main Reefs
10	0,5 m	± 90°	± 60° S	± 126 m	± 3 m (No. 9)	± 5 m on South Reef

2. MORPHOLOGY OF APLITE SILLS

The underground mapping revealed the presence of ten en-echelon sills which in general cut across the sediments at low angles. The distribution of the sills are shown in plan in Figure 2.1, and section in Figures 2.2, 2.3 and Plate 2.1. They are numbered from the highest in the east down to the lowest in the western area of the mine. The dimensions of all the sills are listed in Table 2.1. The boundaries of the sills were determined from underground exposure, their absence from expected localities as well as by diamond drilling.

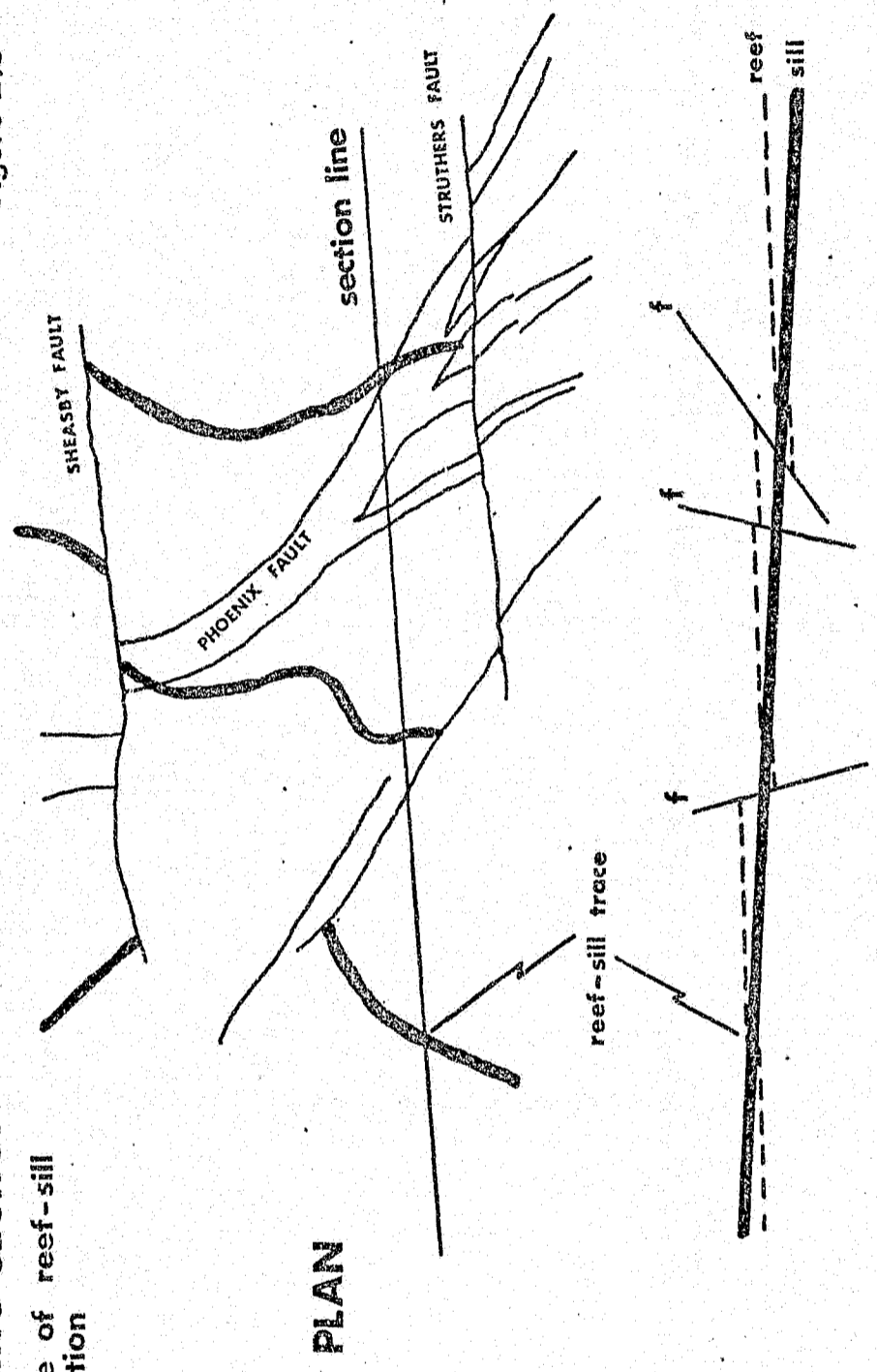
2.1 Dimension and distribution of the sills

2.1.1 Sill No. 1

This sill is thought to sub-outcrop near surface against the recent and Karroo deposits, as shown in Figure 2.1. The western termination is thought to lie to the west of the Central shafts. The reason for this is that there are a number of shafts between the Central shafts and the reef-sill trace of No. 1 sill, in which one aplite sill is present. Because of this, the aplite in the Central shafts is probably part ^{of} Sill No. 1, and not part of one of the lower sills which are present in the stopes of the Central section. The eastern limit is beyond the eastern boundary of E.R.P.M. and is thought to be in or beyond New Kleinfontein mine, possibly correlating with the occurrence of aplite in that mine. This sill strikes at a different angle from the strata and so it cuts through the Composite Reef from the hangingwall in the west to the footwall in the east. The trace of the intersection between the reef and the sill is shown from its termination in the lower stopes in Hercules Section to its sub-outcrop east of the Blue Sky shaft (see Figure 2.1). The trace is disjointed, not due to any disruption of the sill, but because of the faulting of the reef plane, which is the mapping plane. This is illustrated in a diagram-

Figure 2.5

DIAGRAMATIC SECTION
Showing style of reef-sill
trace duplication



PLAN

SECTION

atic E-W section (Figure 2.5) in the vicinity of the Phoenix fault.

Although Sill No. 1 is the biggest on the mine, access to it can only be had in the Lower Hercules Section, where it terminates, and in the vicinity of the main surface shafts that are still open.

2.1.2 Sill No. 2

This sill has only been mapped at one locality in the upper levels of Hercules (H22). Hence its extent cannot be fixed definitely, but it is known that it is not present in the developments on the lower level (H23). This exposure is a considerable distance into the hanging but a single occurrence of 'Chert' is marked in the Cason shaft section which is only a short distance into the hangingwall and therefore on a much lower plane than the Hercules locality. These two exposures have been very tentatively correlated to fix the attitude of the sill but may not be part of the same sill.

2.1.3 Sill No. 3

This sill is well-exposed in the footwall development in the Lower Hercules Section of the mine and so its morphology is well documented. Its dimensions were also fixed by occurrences in falls of hanging in the eastern Angelo section, as well as boreholes. The sill is absent in the H78 development where it was expected, suggesting that the edge of the sill runs south-east to pass between the H77 and H78 developments.

2.1.4 Sill No. 4

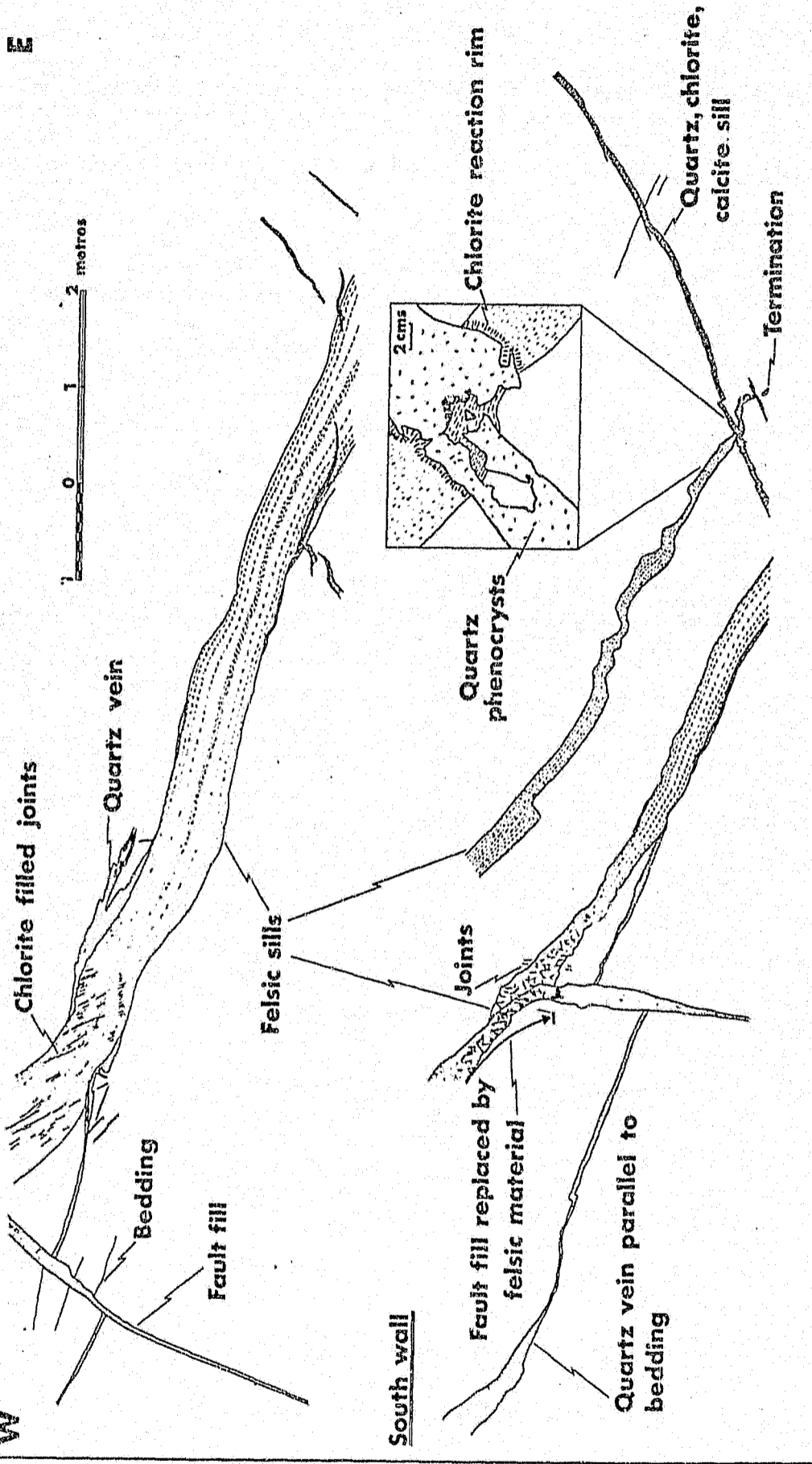
This sill is only known in the footwall development in the western parts of 76 and 77 levels in Hercules Section. No reef intersection trace has been mapped, but reports of its presence in H77 west stope suggest that it probably terminates near the expected reef intersection. Evidence for the termination of this sill is good, with one termination

SILL No5 IN H77 STATION DEVELOPMENT

North wall

W

Figure 2.6



Drawn from photographik mesale

visible on the eastern edge on 76 level while a borehole drilled on 77 level to intersect the eastern extension did not do so. The western edge is known to lie between two adjacent cross-cuts to the reef on 76 level, and between two adjacent box-holes on 77 level. This evidence indicates that the sill must be very small in area (see Figure 2.2).

2.1.5 Sill No. 5

This sill is also only known from two exposures in the footwall development on 77 and 78 levels in Hercules Section. The 77 level exposure is near the tip of the sill for it is not present in nearby station development to the west, where it was expected, and it was not intersected in a borehole drilled from 77 level to establish the eastern extent.

Figure 2.6 illustrates the sole spectacular exposure of the sill. In this section the only known faulting of the sills is documented with the fault

in the vicinity of the abutment of the sill replaced by aplite. Also associated with the aplite sills in this locality is a set of en-echelon mafic quartz-chlorite-calcite sills that post-date the aplite sill. This aplite sill occurs completely in the footwall below No. 3 sill, and so is not en-echelon to it.

2.1.6 Sill No. 6

This sill has an extensive reef-sill trace in the Angelo section of the mine. However, despite this long reef trace, the sill is not seen in the footwall development \pm 20 metres below the reef plane until the 76 level. This means that the sill terminates between the reef plane and the accessible development until some point between 75 and 76 levels. The aerial extent of the sill has been further fixed by a number of boreholes drilled in the hangingwall.

2.1.7 Sill No. 7

The existence of this sill was established by a borehole drilled mainly to intersect Sill No. 6 but which intersected two aplite sills. Subsequently this sill has been proved to be above Sill No. 6 by a number of boreholes starting in No. 6. Its eastern limit is tentatively fixed by two intersections in boreholes, and its absence in the 75 and 76 stopes; the western limit is not known at all. However, the reported occurrences of 'Chert' in the 'E', 'F' and 'D' pilot winzes (developed in the reef plane) probably correlate with this sill, and if this correlation is correct then it must be considerably larger than Sill No. 6. If so, the sill may well outcrop in the western portion of the mine, although it has not been reported in the South West vertical shafts. If the sill is smaller than No. 6 because of incorrect correlation with the exposures in the pilot winzes, the same problem of the absence of 'Chert' in the South West shaft section still exists.

2.1.8 Sill No. 8

This sill is only known in the Driefontein Section at present, but it will probably be encountered in the Angelo Section in the near future. It has been mapped in 69 and 70 level pilot winze stopes, and 67 South Reef stope. The reef intersection trace has only been partially mapped as there is doubt of the 'Chert's' presence in the area between 67 South Reef and 70 pilot winze stopes on the part of the mine officials. The NW trending intersection in Figures 2.1 and 2.4 has been constructed assuming that the sill is present in the old workings of 69 stope, which is ahead of the 69 pilot winze stope.

2.1.9 Sill No. 9

This sill occurs in the Driefontein section in the 64 level South Reef and Main Reef stopes (only the South Reef sill intersection is plotted on Figure 2.1). The reef-sill trace is not well mapped.

2.1.10 Sill No. 10

This, the structurally lowest sill is similar in appearance to No. 9, and occurs in 64 level South Reef stope in Driefontein Section. It is the smallest of the sills mapped and is confined within two stope face positions approximately 5 metres apart.

2.1.11 Clastic sill

Approximately 3 to 5 metres below Sill No. 10, there occurs a 0,5 metre thick sill which cuts across the reef and resembles a quartzite in hand specimen. The sill is parallel to No. 10 but is wider and extends into the footwall development where it cuts through a mafic dyke.

2.2 Other occurrences on the mine

There are two exposures in the far west section of the mine (see Figure 2.1), that are marked on the mine plan as 'Chert'. As this part of the mine is now inaccessible it is not known how these exposures correlate with the en-echelon distribution of the sills further east. Speculating on their correlation, as a disjointed reef-sill trace similar to Sill No. 1 in Figure 2.5, they might belong to one of the three sills whose western limit is unknown (Sills 7, 8 and 9). Wilder speculation would be to correlate these three sills to the three sills intersected in the Rand Deep Levels Borehole.

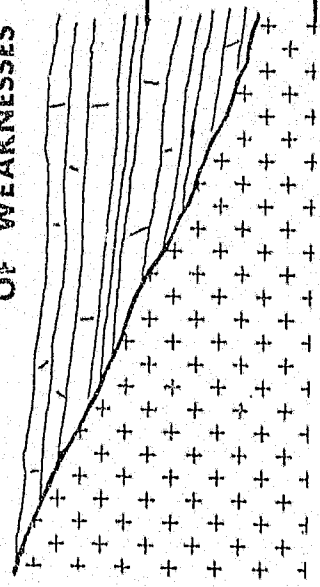
2.3 Structural relationship with adjoining sediments

On a large scale the sills are independent of the planes of weakness such as bedding and joints in the sediments. For example in the Hercules Cinderella Section, the angle between the bedding and Sill No. 1 is only $2 - 3^{\circ}$; this small but significant angle between the sill and the bedding planes suggests that parting planes parallel to bedding were not important, at the time of emplacement. Thus the orientation of the sills is probably tectonically controlled and the confining pressure during emplacement must

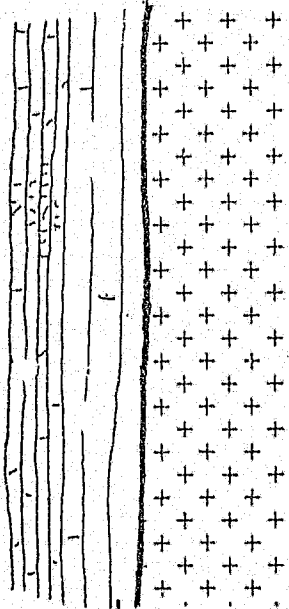
CONTACT RELATIONSHIPS

Figure 2.7

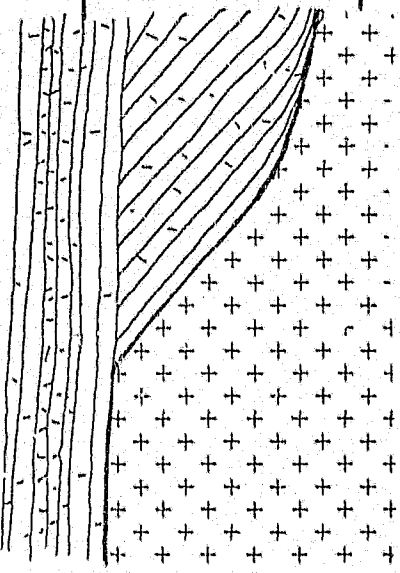
TRANSGRESSIVE CONTACT INDEPENDENT OF WEAKNESSES



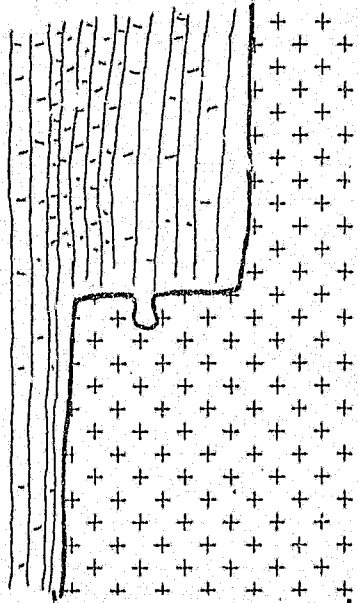
CONTACT CONFORMABLE TO BEDDING



CONTACT CONFORMABLE TO CROSS BEDDING



TRANSGRESSIVE CONTACT FOLLOWING A PRE-EXISTING JOINT



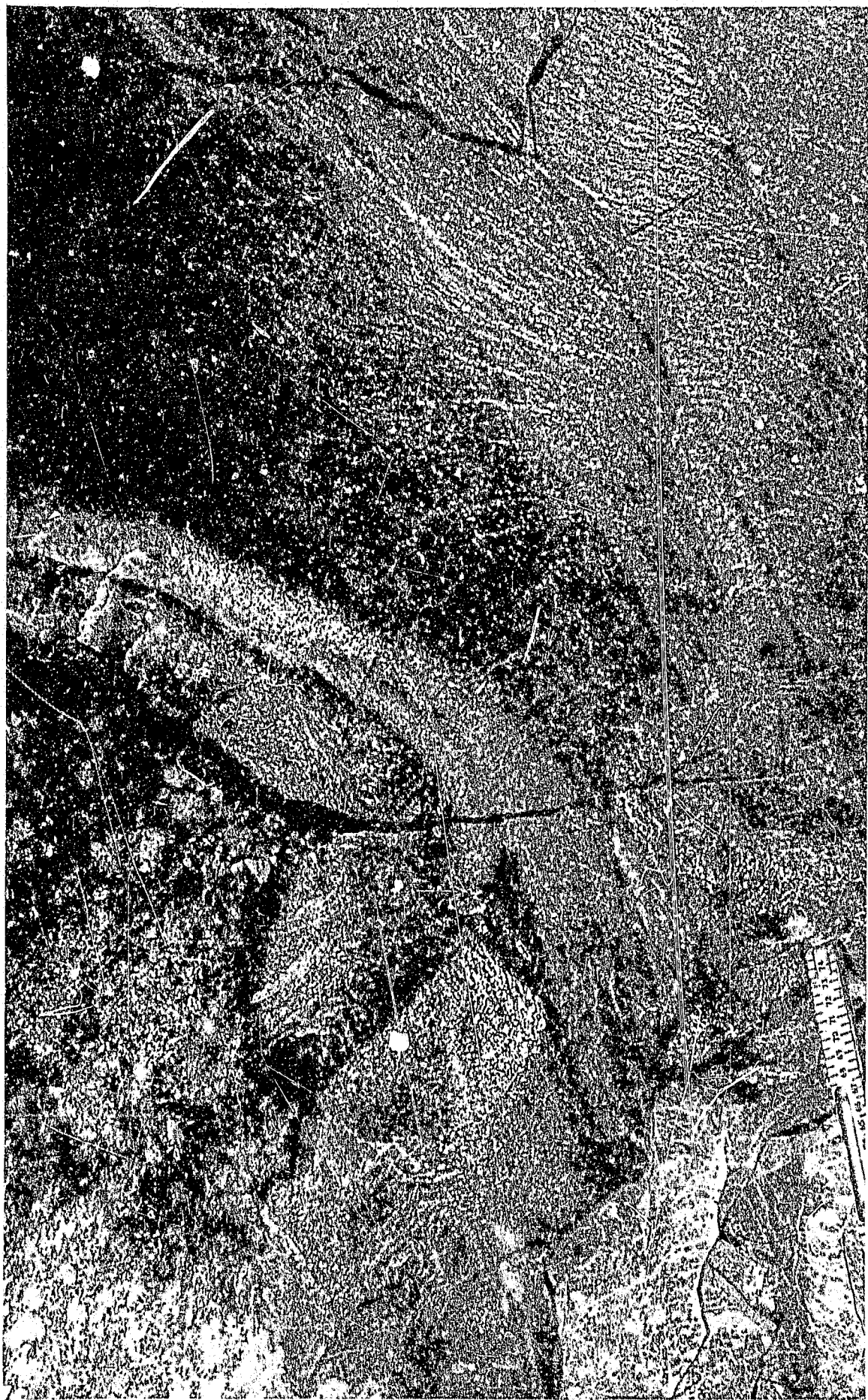


Plate 2.2

Contact of the aplite with the reef showing an abrupt change in the contact angle and a clear distinction between the contact and central zones.

have been sufficient to render the bedding plane weakness a negligible factor. However, there are frequent departures from this independence of sill attitude from control by sedimentary planes of weakness, and in particular, four styles of contact between the sediments and the sill were observed, namely:-

- (i) Complete transgression of the sill through the sediments, indicates a tectonic control. Well developed in Sill No. 1 (see Figure 2.3).
- (ii) A conformable contact with the bedding plane, indicates a bedding plane control.
- (iii) A conformable contact with the bedding plane of a foreset unit in a cross bedded sequence in preference to a bottom set. This has two possible interpretations: either the foreset bedding plane is weaker than the bottom set bedding plane, or the foresets and bottom sets have comparable weakness with the foreset plane being nearer to the tectonically preferred direction.
- (iv) Intrusion along a pre-existing joint perpendicular to the bedding plane.

These four styles are illustrated in Figure 2.7, and Plate 2.2,

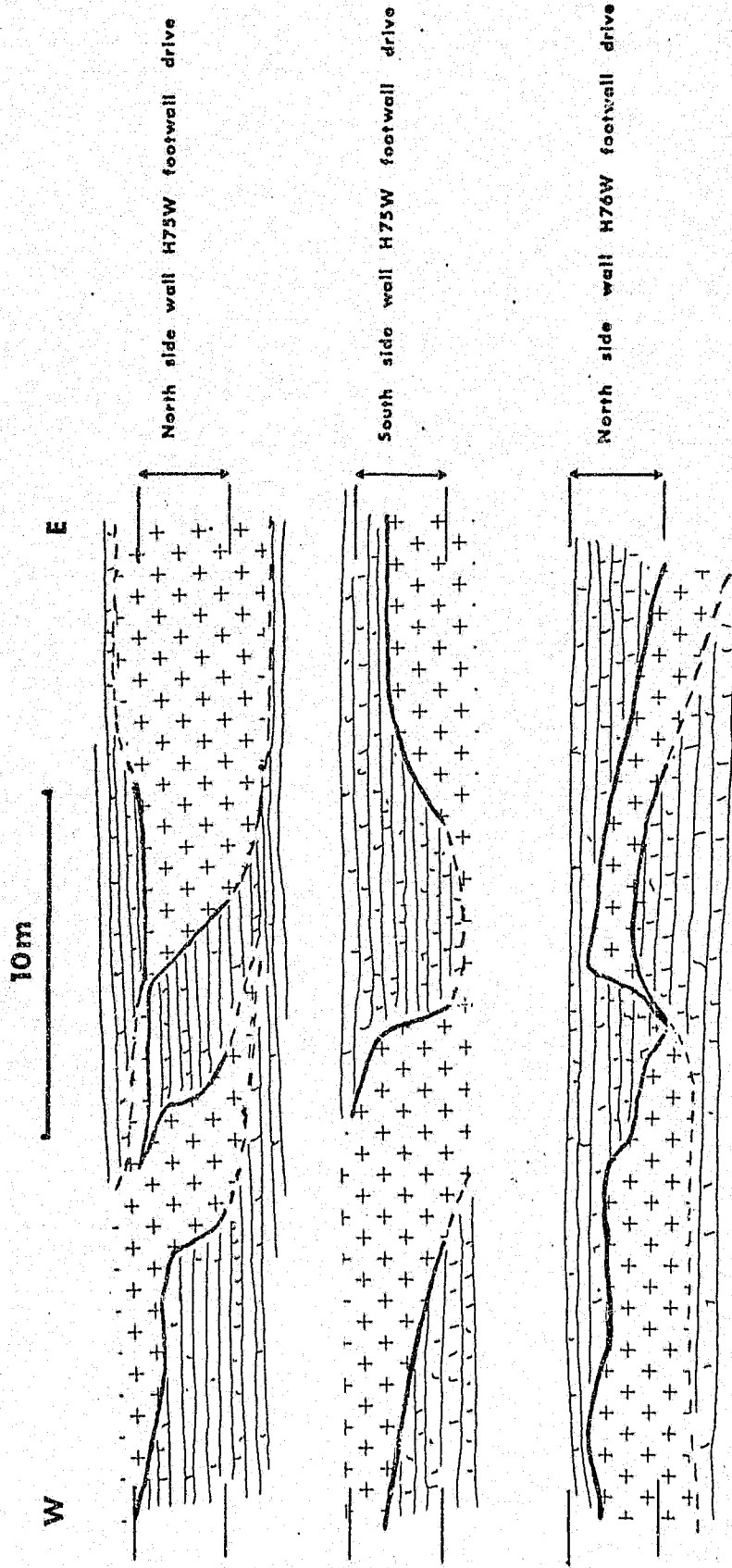
The first two are the most common, but they rarely persist over any great distance. Usually the mode of intrusion alternates between the two styles.

2.4 Constriction of the sills

By constriction is meant an abrupt reduction in the thickness of a sill for a short distance after which the sill carries on with its original thickness, usually on a different plane. Only two examples of constriction are known: in No. 3 and No. 8 sills. The largest occurrence

CONSTRUCTION IN No.3 SILL

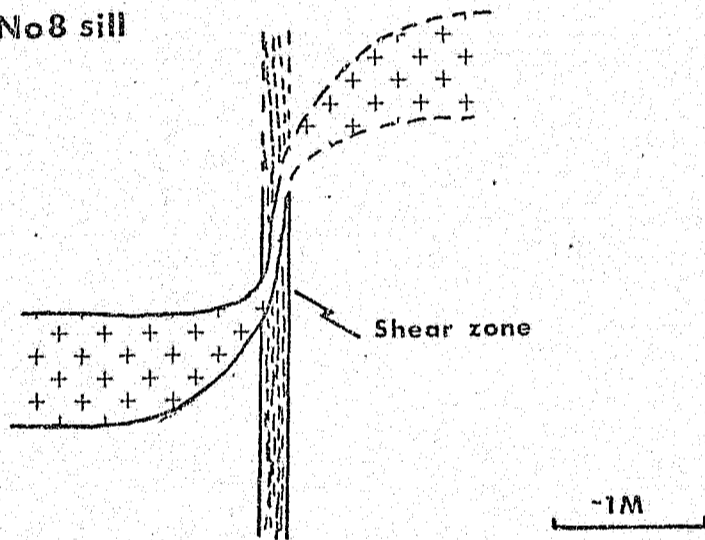
Figure 2.8



is in No. 3 sill where the structure can be observed for over 300 metres in a north-easterly direction. This constriction reduces the size of the sill from \pm 3 metres to 0,1 metre as shown in Figure 2.8. The shape of the constriction suggests that it might be a connection of two horns (as defined by Currie and Ferguson, 1970, and Pollard, 1974), the morphology of which, in part, is controlled by the jointing in the sediments. The constriction in Sill No. 8 cannot be traced over its full extent but it is obviously connected with a shear zone as shown in Figure 2.9.

Figure 2.9

Constriction in No8 sill



2.5 Branching and magmatic stoping

Three instances of branching and one of overhand stoping as described by Balk (1937 pp. 21) have been observed in the sills. Stoping occurs in Sill No. 1 where a small offshoot of magma intrudes up a joint and then follows the bedding to partially enclose a raft of quartzite, as shown in Figure 2.10.

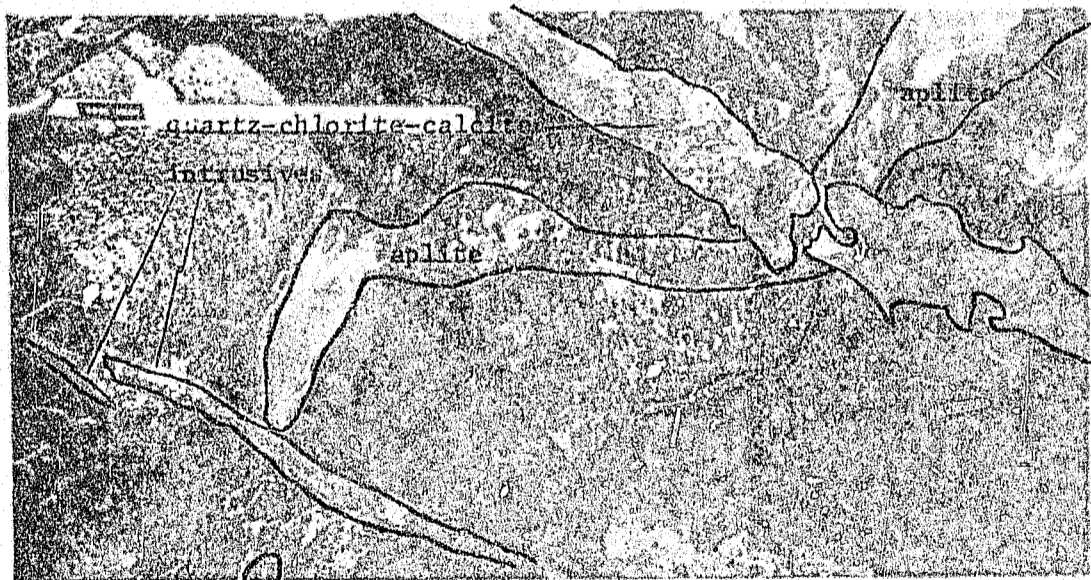
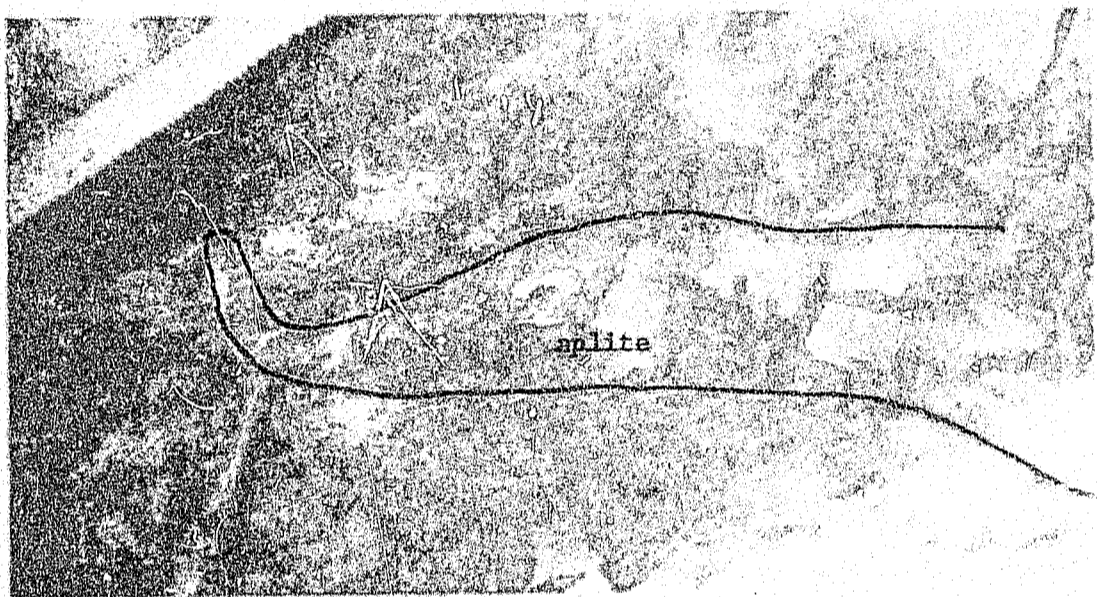
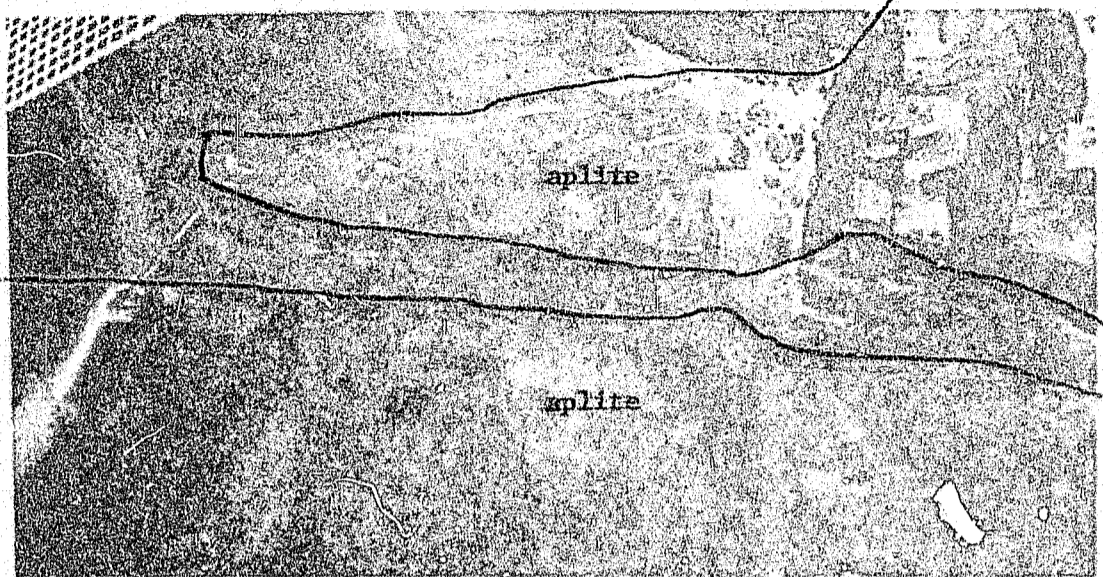


Plate 2.3

Horn occurring in No. 4 sill on H77 level.

Plate 2.4

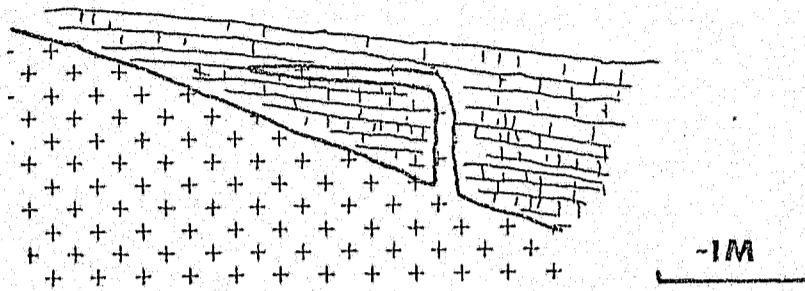
The termination on No. 1 sill on H76 level.

Plate 2.5

The termination of No. 5 sill on H77 level.

Figure 2.10

Overhand stoping in No1 sill



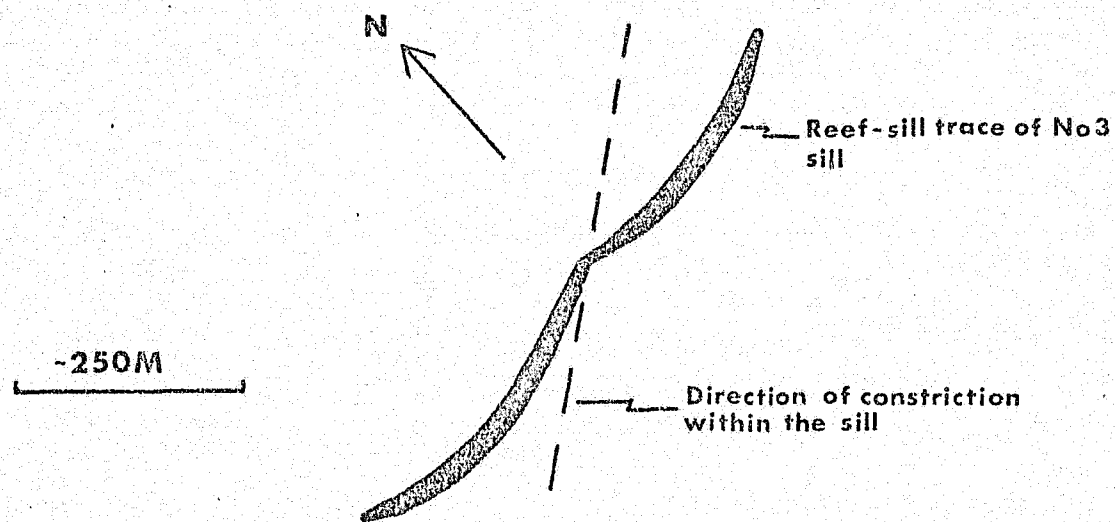
Branching occurs in Sill Nos. 3, 4 and 5. That in No. 3 sill is the longest but is only known from diamond drilling and mapping by A.M. Shipway in a now closed-off cross-cut. The branch is about 0,5 m compared to the 3 metres of the main body. Its length is estimated to be in excess of 25 metres. The branch in Sill No. 4 is fully exposed and shown in Plate 2.3 where the minor horn dies out rapidly. The branch in No. 5 sill is illustrated in Figure 2.6.

2.6 Termination of the sills

The large scale nature of a sill's termination can be deduced from the mapped reef trace. This shows that the edges of the sills are curved away from the general plane of the sill, as illustrated in the E-W section through the mine in Figure 2.3. In particular No. 3 sill has a double curvature in its reef trace as in Figure 2.11.

Figure 2.11

The double curvature in the reef-sill trace



The junctions of the two curved portions approximately coincides with the known region of constriction.

The terminations of Nos. 1, 4, 5 and 10 sills were observed during the underground mapping. Sill Nos. 1, 4 and 5 taper gradually down to a few centimetres before disappearing without any disruption of the sediments; this is shown in Plates 2.4 and 2.5. By contrast Sill No. 10 ends by changing laterally from a fine grained laminated sill into a coarse grained felspathic vein with no fabric. This lateral change will be discussed in the next chapter. This vein has the same attitude as the sill but is only \pm 10 centimetres wide.

Table 3.1

Mineralogy of the sills as determined by microscopic observations on thin and polished sections, refractive indices and diffraction X-Ray analysis

Phenocrysts

Quartz, bipyramidal Found in most specimens as crystals up to 3 mm in length near the contact. Pseudomorphs of α quartz after β quartz.

Felspar Occurs as anhedral grains in clusters, or as single crystals. The clusters are up to 3 mm in diameter. They occur in the central zone mainly as plagioclase, perthite, anti-perthite and minor amounts of orthoclase.

Magnetite Only found in the white areas of the central zone, as near perfect octahedrons up to a millimetre in size.

Pyrite Found in the contact zones adjacent to the reef as perfect cubes with sides up to 3 cm; mantled by radial growths of quartz and may also have inclusions of quartz.

Pyrrhotite Found only in the immediate contact zone with the footwall quartzites; occurs in anhedral grains 1 - 2 mm in diameter.

Calcite Commonly found as small anhedral grains.

Siderite Not as common as the calcite but is known to occur in two forms; small subhedral crystals or in clusters up to a centimetre in diameter.

Fluorite Small euhedral to anhedral crystals up to a millimetre in diameter have been found in all specimens investigated.

Biotite Anhedral crystals up to a millimetre long are sometimes found.

Table 3.1 continued

<u>Matrix</u>	Ubiquitous.
Quartz	Untwinned; occurs in all specimens.
Felspar	Predominantly near the contact, usually with a different grain size, larger or smaller than the average matrix.
Muscovite	As for muscovite.
Biotite.	Distributed uniformly across the sills; usually thuringite or aphrosiderite variety.
Chlorite	In trace quantities in all specimens.
Zircon	Found only in aplite with a red colouration.
Perovskite	Found only in one specimen.
Ilmenite	Found in a mica rich vein parallel to and within one centimetre of the contact.
Manganite	
<u>Joints, veins and breccia filling</u>	
Quartz	Usually euhedral with an α quartz crystal form; inclusions follow growth lines.
Chlorite	Subhedral blades of chlorite fill in the voids between quartz.
Fluorite	Only found in microscopic veins, often with calcite; or as euhedral crystals in breccia.
Calcite	As for fluorite.
Sphalerite	Only one vein known with good euhedral crystals. Distinguished from fluorite by X-Ray fluorescence.

Table 3.1 . continued

Haematite	Found in only one specimen; associated with magnetite.
Siderite	Found as irregular veins, 1 mm wide by 20 mm long.
Pyrite	Found in one specimen as massive euhedral crystals which terminated in a mass of pyrite on the contact.
Goethite	Found with subhedral form in one specimen.
Muscovite	Found in an irregular vein with calcite, chlorite and traces of pyrite. It is thought to represent a mechanical filling of a joint with material from an overlying fault fill of the same composition.

3. PETROLOGY

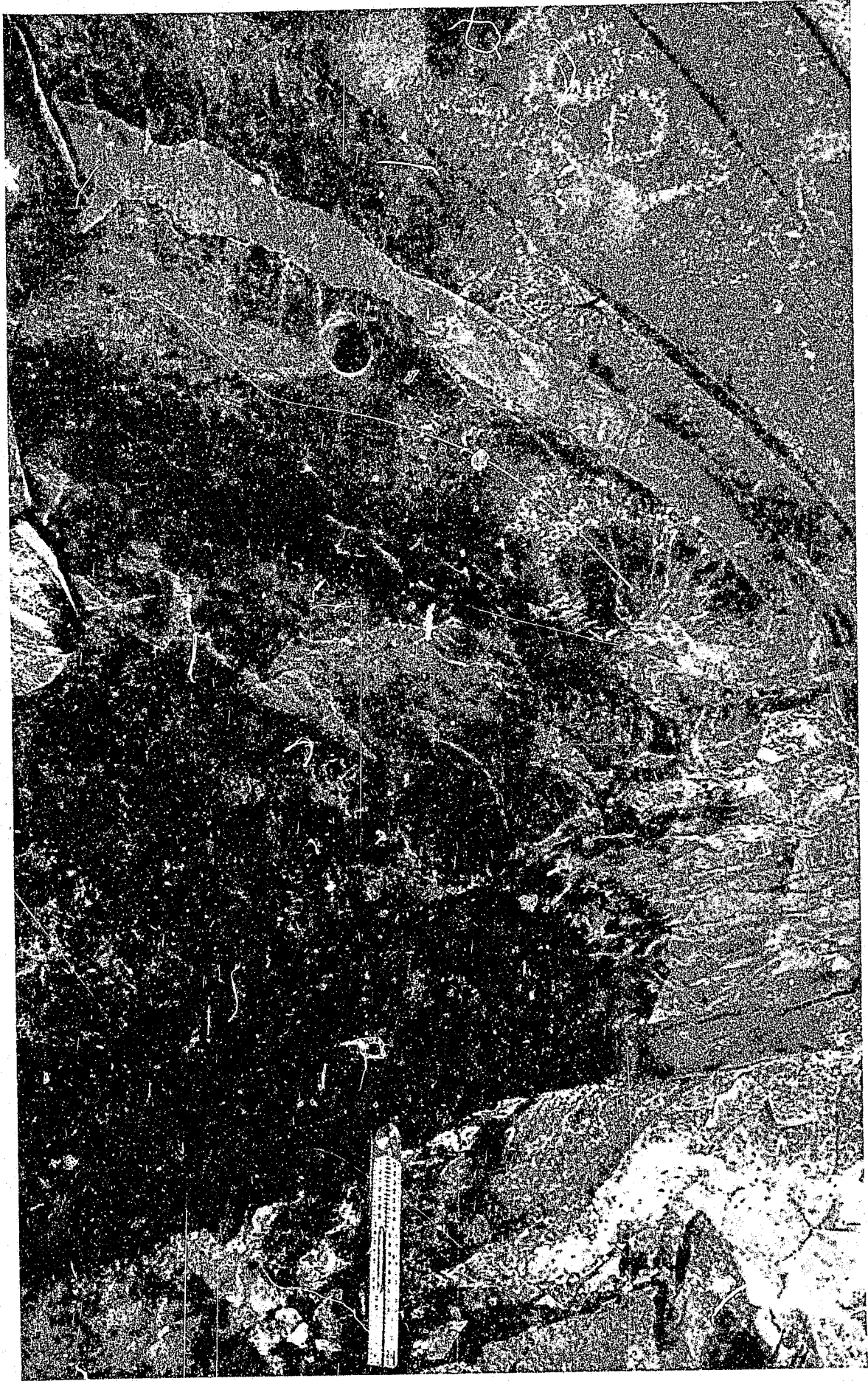
This petrographic description is primarily based on samples from sills 1 and 3; otherwise only the obviously different rocks were examined microscopically. Included in this description are similar rocks from City Deep Gold Mine and New Kleinfontein Gold Mine, which have not been previously described by other workers. The mineralogy determined in this work is presented in Table 3.1. Previous workers have reported a similar basic mineralogy, but in addition McDonald (1911) recognised sphene in No. 1 sill in the Cinderella Section, and Weber (1909) tentatively recognised this mineral in the top sill in the Rand Deep Borehole. The composition of these felsic sills corresponds to that of the plutonic alkali granite or alkali rhyolite for the extrusive phase in the new nomenclature (Strickeisen, 1973, Hyndman, 1972, pp. 38) but as the hypabyssal nomenclature is not published, the term andelite is used in this work.

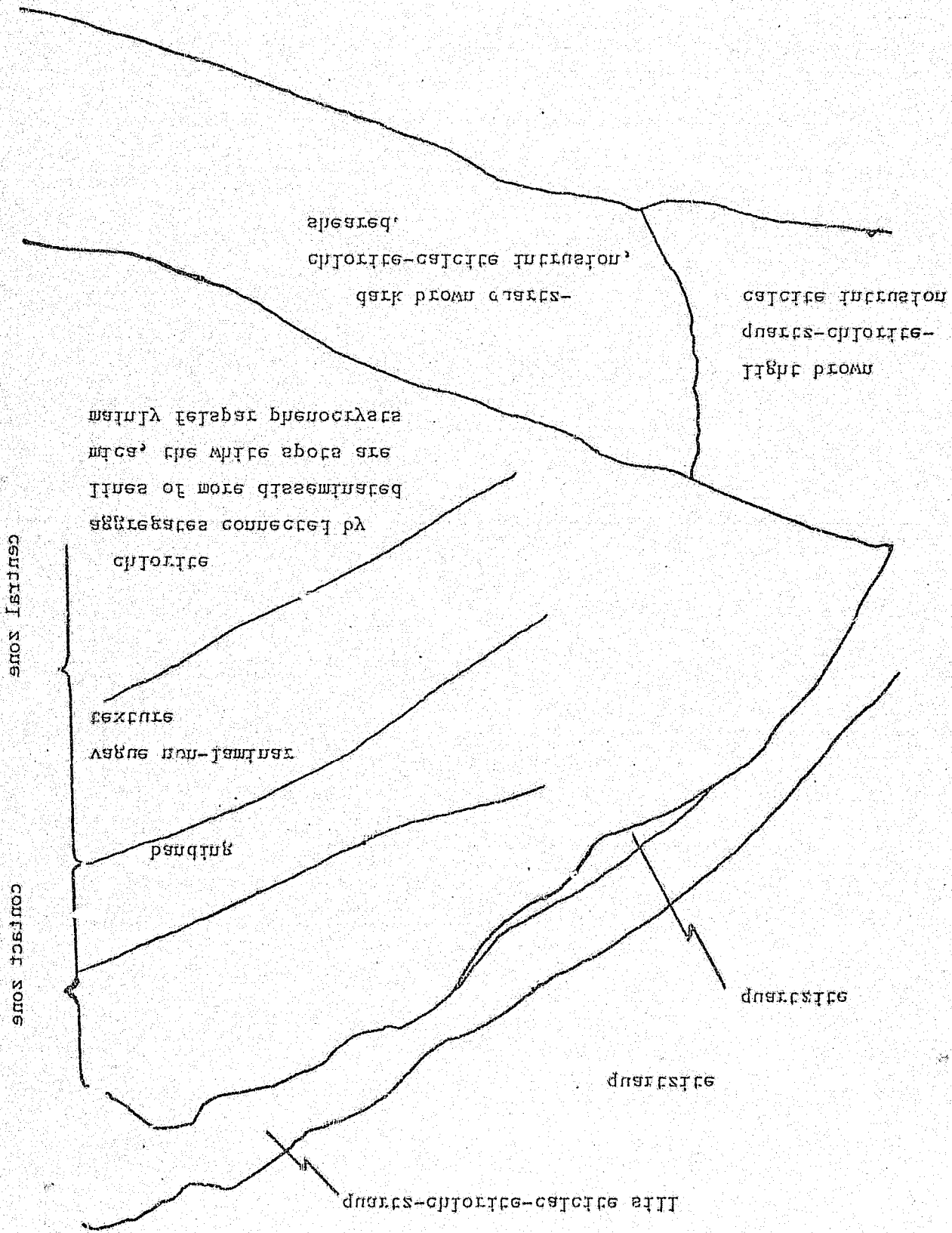
3.1 The sills

3.1. Microscopic description

3.1.1.1 Zoning and colour

All the sills are zoned parallel to the contacts. Typically, there is a dark green zone on the contact which changes rapidly in the thicker sills to a lighter colour in the central part of the sill. It is this distinction that is used to define the contact zone and the central zone (see Plate 3.1). In the thinner sills this light colouring is not fully developed in the central zone, and the centre is a pale green in colour or alternatively these sills have a very light colour for their complete thickness. The thickness of this contact zone in the thicker sills ranges from five to thirty centimetres. There is no precise line which separates the two zones; rather, the division is marked by the rapid change in





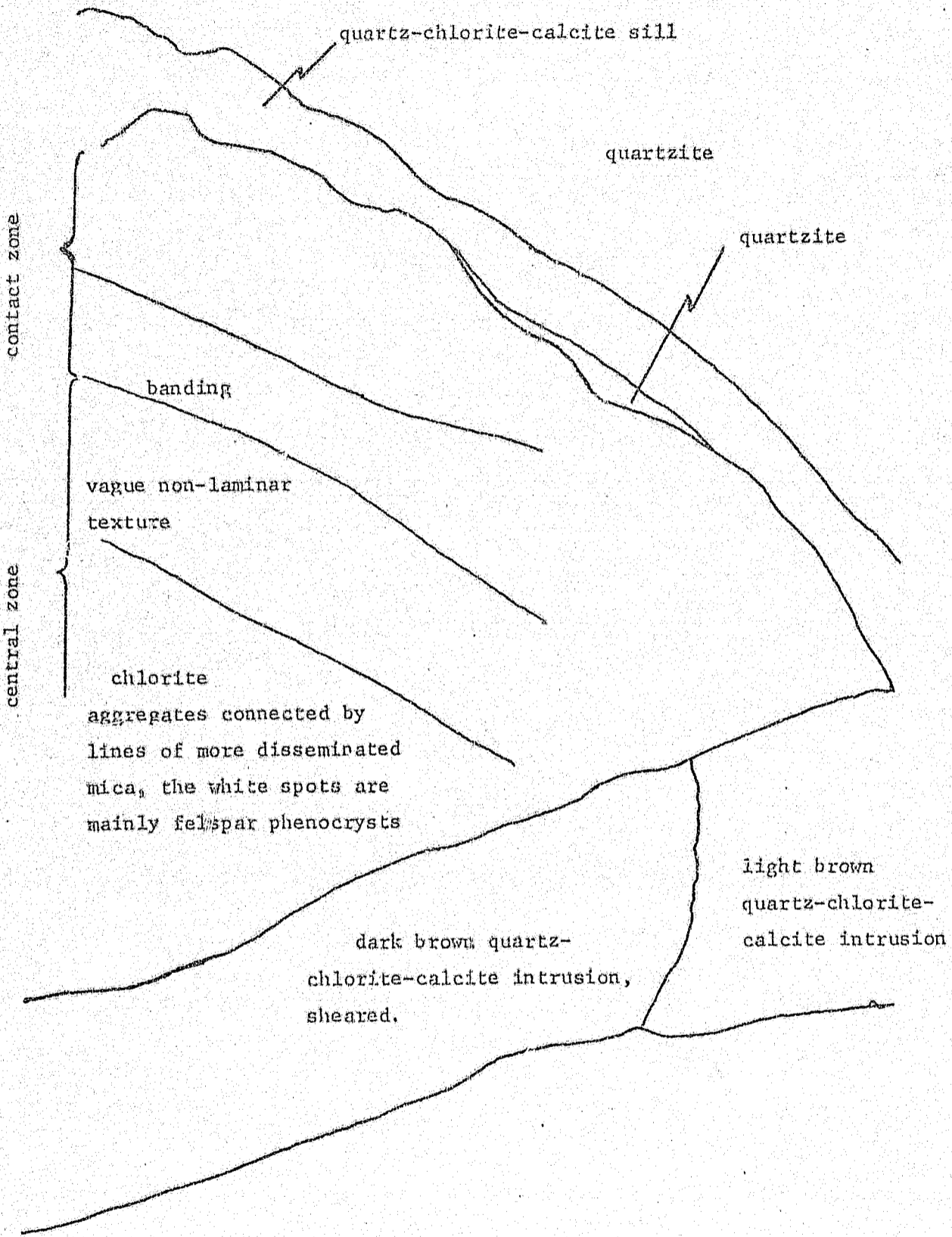


Plate 3.1

Some of the petrographic textures occurring in the sills are shown in this photograph of the top contact of No. 6 sill on G77 level.

They are:- zoning, banding, laminar texture, non-laminar texture and associated quartz-chlorite-calcite intrusions.

colour from the more uniform central zone outwards. In addition to this gross zoning, most sills display alternating diffuse bands of dark and light material which are parallel to the contact and about ten centimetres thick.

The colours found in the sills range from white through green or brown to black. In some rare cases the sills are a light brick red; this red colour occurs in patches up to six metres wide, with an abrupt transition into the more normal colouring. Besides red, black is also rare and only occurs occasionally in the contact zone when the sills cut through a mafic dyke. The brown colouring is restricted to the termination of the sills or when the sills are less than half a metre thick. In general the colour of the rock varies with the concentration of fine grained phyllosilicate aggregates, which vary in size from 0,5 to 3 millimetres.

3.1.1.2 Central Zone

The material in this zone is porphyritic, with an aphanitic matrix. The larger grains form white spots between one and two millimetres in diameter; of these, the bigger ones are roughly spherical in shape. In total, these felspar phenocrysts form less than one per cent by volume of the rock; they are supplemented by occasional fine grained quartz phenocrysts.

The mafic constituents in these rocks are euhedral phenocrysts of magnetite and ellipsoidal aggregates of chlorite. The chlorite aggregates are similar to the segregations or autoliths in the Sierra Nevada Coast Range, Idaho and Boulder batholiths described by Balk (1937, pp. 12), they have their major axis sub-parallel to the contact and are trailed by irregular lines of disseminated mica extending away from the ellipsoids parallel to the contact. These textures are illustrated in Plate 3.1.

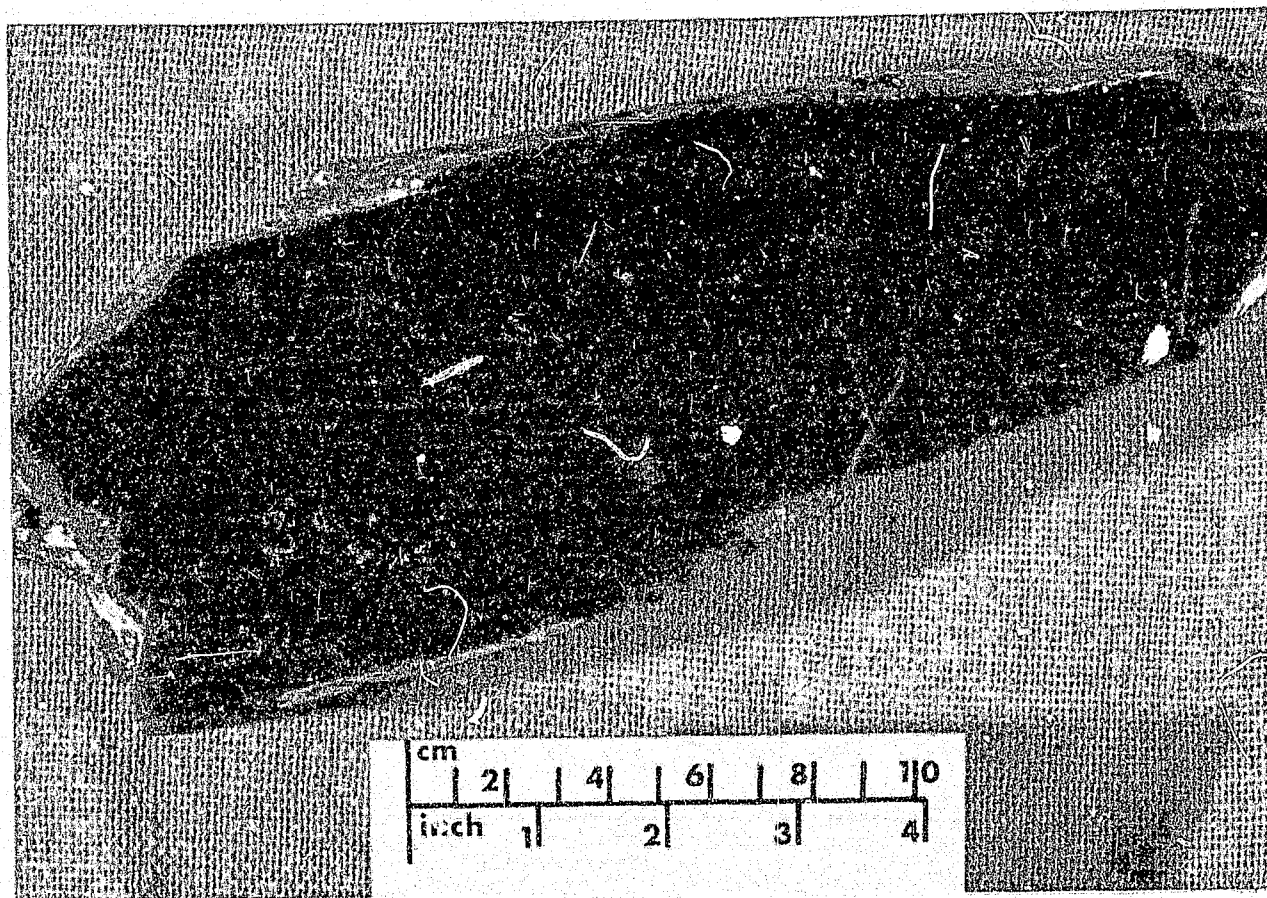
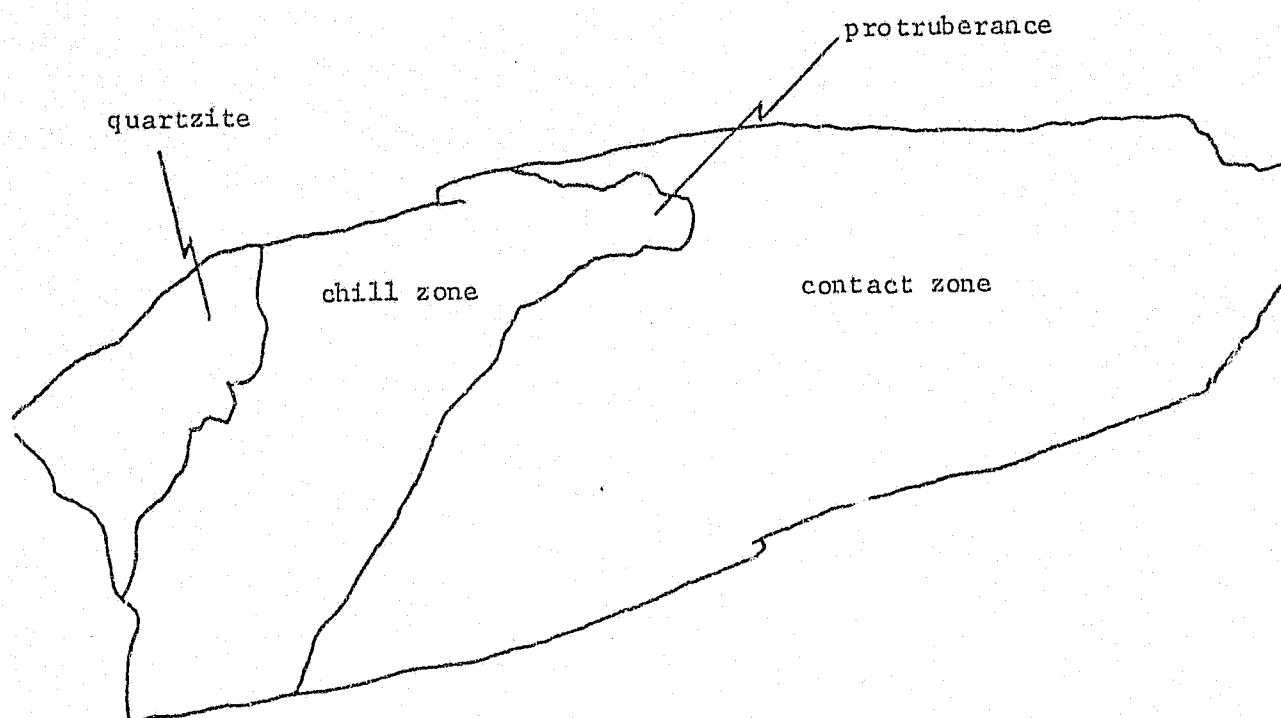


Plate 3,2

Non-laminar flow texture caused by a protruberance of chill zone material, which is also visible adjacent to the contact. (Photograph by M. Hudson).



3.1.1.3 Contact Zone

The rock is translucent with an aphanitic matrix but in some sections fine grained mica forms in bands parallel to the contact. Bipyramidal quartz phenocrysts are always present but felspar phenocrysts are rare. The quartz phenocrysts are larger than those in the central zone.

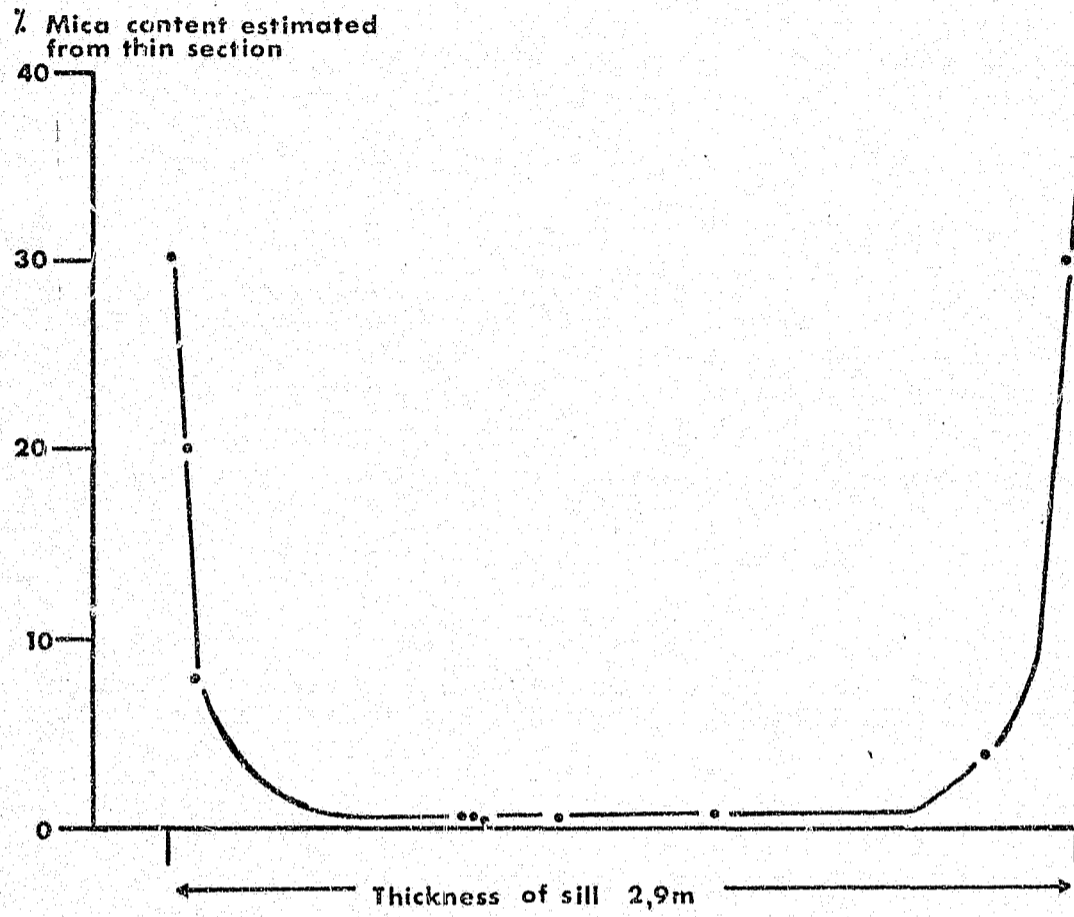
In the stopes, near perfect euhedral cubes of pyrite are found in the sills; these are mantled by radial growths of quartz up to 5 millimetres thick. The quartz that occurs as inclusions within the pyrite has an interface between the two minerals that is anhedral. These pyrite phenocrysts are associated with two types of matrix; the more common one is aphanitic and translucent and the other is less translucent than the normal contact zone because of the presence of fine grained, pale green mica crystals in the aphanitic groundmass.

3.1.1.4 Contact

The actual contact between the sill and the adjoining sediments is always sharp and occurs either as cusped indentations which are one to twenty centimetres wide and which intrude into the quartzite by as much as five centimetres; or as a rectangular castellated pattern, controlled by the bedding. In addition the aplice may have a ghost bedding demarcated by pyrrhotite bands which connect with the bedding planes in the quartzite. Besides this ghost bedding, there is frequently a zone on the contact, which disturbs the flow structure that is present towards the centre of the sill. This material protruding into the sill might be an early 'chill zone'; it contains euhedral phenocrysts of quartz but not felspar (Plate 3.2). There is always a sharp contact between the chill zone and the rest of the contact zone.

Variation in mica concentration
across a sill

Figure 3.1



3.1.2 Microscopic description

3.1.2.1 Zoning

The zoning as seen in thin section is marked by changes in composition of the matrix and in the form and abundance of the phenocrysts. The concentration of micaceous minerals in the matrix varies across the sills (see Figure 3.1) from being large at the contact to very small in the centre. Similarly, quartz phenocrysts are more abundant and have a better morphological form near the contact than in the central zone. By contrast, phenocrysts of felspar do not vary in form across the sills, but are more abundant in the central zone. However, gross banding seen in hand specimen cannot be correlated with these microscopic observations.

3.1.2.2 Central Zone

The matrix consists mainly of untwinned plagioclase, which forms about 60% of the rock, lesser amounts of quartz and traces of zircon and fluorite. Fluorite and carbonate also occur in microscopic veins with quartz and chlorite. The texture is heterogeneous, ranging from near perfect polygonal grains to interlocking elongated grains with all possible variations between these extremes. Where the grains are elongated there appears to be a preferred morphological direction but there is no similar optically preferred orientation. The maximum size of any grain in the matrix is 0,4 millimetre but most grains are about 0,01 millimetre in diameter.

The quartz phenocrysts in this central zone have experienced severe magmatic corrosion; they are mantled by matrix with a high concentration of mica in a zone about 0,1 millimetre wide. In sills 9 and 10 they may also occur as clusters of fine grained quartz.

Also in this central zone are granophyric pseudo-spherulites which have a diameter between 0,5 - 2 millimetres. These are formed of radially oriented grains of orthoclase which are anhedral in form with



0,01 mm

Plate 3.3

Pseudo-spherulite formed by the intergrowth of radially oriented
crystals of quartz and felspar.

intergrowths of ellipsoids of quartz. Also radially orientated and with major axes of about 0,2 millimetre in length (Plate 3.3). The abundance of these pseudo-spherulites is considerably less than the quartz phenocrysts.

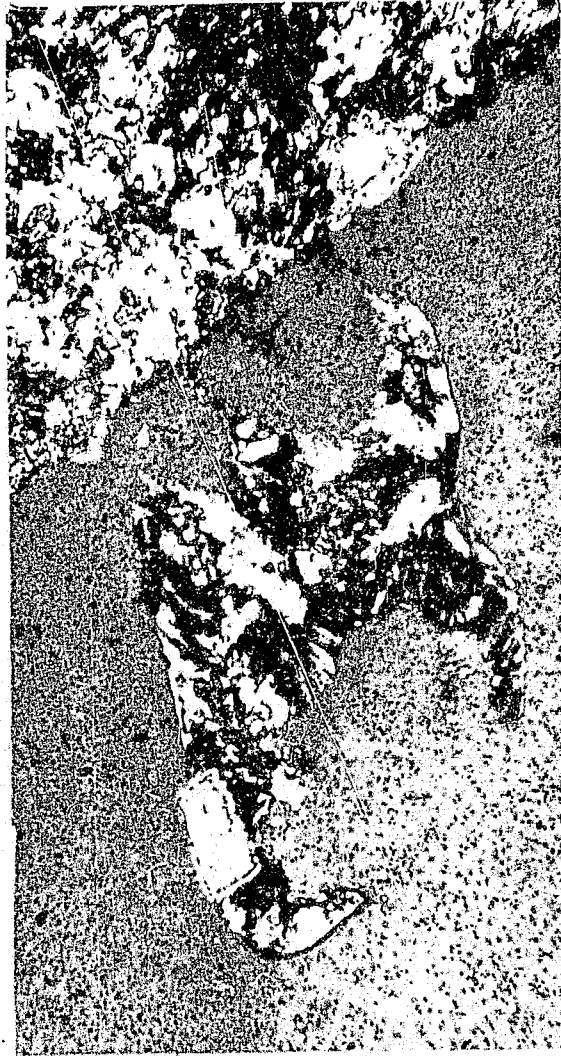
The felspar phenocrysts occur either as subhedral single crystals or as clusters of anhedral grains. The latter do not usually have a compositional zoning (see Plate 3.4), but they do show alteration to fine muscovite along the edges of the grains. Besides this alteration, most felspar grains are saussuritised and some are altered to carbonate, particularly those with polysynthetic twinning and stringlet perthite. This alteration is especially pronounced in sills 9 and 10, which contain opaques in the core of the felspar grains. Measurements of the optical angle ($2V_{\alpha}$) indicate that the untwinned felspar corresponds to 50 - 60% orthoclase and 40 - 50% plagioclase.

The single crystals of felspar show compositional zoning, with the core being altered plagioclase or anti-perthite. These cores are mantled by anti-perthite and orthoclase, or purely compositional plagioclase zoning. In detail, the zoning comprises a core of plagioclase, an inner rim of perthite, an outer rim of orthoclase and finally, a mantle of perthite. When the orthoclase is not mantled by perthite it is usually enclosed in a granophyric textured rim, where quartz exsolves from orthoclase to form a vermicular texture.

The compositions of the plagioclase in the central cores of the single crystals and the clustered grains were determined using the universal stage technique. The range in percentage anorthite for 23 measurements was from 1 - 34% An with a bimodal distribution of peaks at 1% and 22% An. These results fall on the high temperature curve for plagioclase twinned on the [010] crystal face.



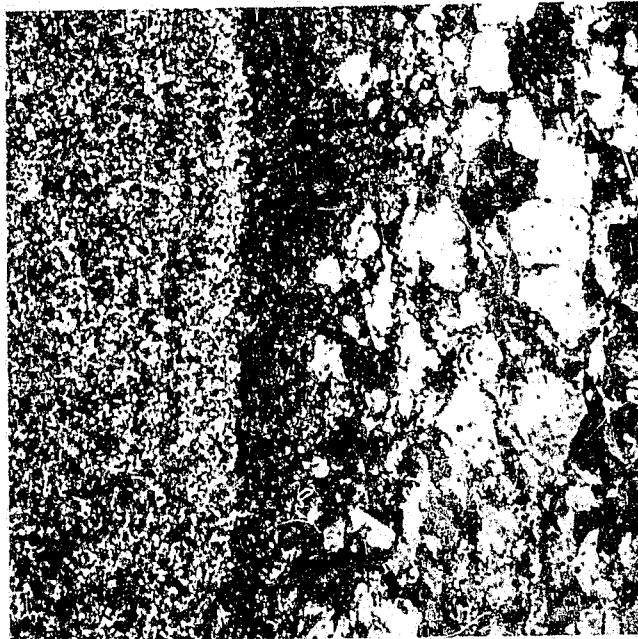
A 0,5mm



B 0,5mm



C 0,4mm



D 1mm

A Plate 3.4

Part of a cluster of feldspar grains devoid of compositional zoning, but showing saussuritization in the centre of the grains and alteration to sericite along the grain boundaries.

B Plate 3.5

An inclusion of matrix and some feldspar phenocrysts in a β quartz phenocryst. The inclusion abuts with the groundmass along a fracture containing sericite.

C Plate 3.6

A large number of plagioclase inclusions in a skeletal crystal of β quartz.

D Plate 3.7

The contact of the aplite with the adjacent quartzite. Phyllosilicates appear as the darker grains.

3.1.2.3 Contact Zone

Within the matrix the mineral components have various characteristic sizes with muscovite and biotite being either larger or smaller than the average grain size of 0,01 millimetre as defined by the quartz and feldspar grains. The exception to this is in the contact zone when it is adjacent to the reef, and also contains large crystals of pyrite, then the quartz and feldspar can have an average grain size of about 0,5 millimetre.

In the contact zone the quartz phenocrysts have the euhedral, bipyramidal form characteristic of β quartz (McIver, 1973, personal communication), the high temperature polymorph of quartz; although the crystal lattice as determined by X-Ray diffraction corresponds to low temperature α quartz. These pseudomorphs show magmatic corrosion, but some of the crystal facets are preserved. All the quartz pseudomorphs are mantled by rims of pure muscovite. The phenocrysts frequently contain inclusions of muscovite, anti-perthite, plagioclase, matrix and carbonate. The carbonate inclusions are always found with plagioclase or anti-perthite, suggesting that they are alteration products of the calcic component in the plagioclase (Plates 3.5 and 3.6).

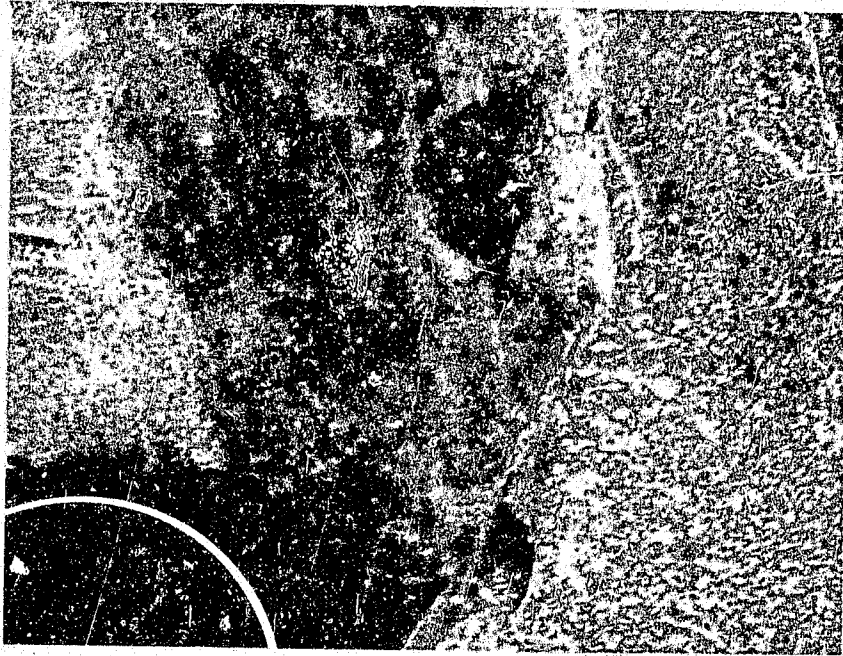
Feldspar phenocrysts are rare in the contact zone except as inclusions in the quartz phenocrysts.

The actual contact is microscopically sharp (Plate 3.7) with muscovite and pale green biotite, occurring in bands of high and low concentration. By contrast the remnant chill zone is not discernable microscopically from the rest of the contact zone.

3.2 Termination of sills

3.2.1 Macroscopic description

Generally the material in the terminations appears to be the same as that in the contact zone. However, one exception is known; namely the



4cms



0,2mm

Plate 3.8

One of the nodules in the aplite; it is marginally darker than the surrounding rocks, and also has a slightly bleached mantle adjacent to the nodule.

Plate 3.9

A felspar phenocryst occurring within a nodule, and arrested in the process of polygonization.

termination of Sill No. 10, which has a mottled white and light grey colour and a medium grained porphyritic texture with phenocrysts of quartz and felspar 1 - 2 millimetres in diameter. This termination is only about 10 centimetres thick and resembles a felspathic vein which is cut by quartz rich mineralised joints inclined at 70° to the edge of the sill.

3.2.2 Microscopic description

Only the termination of No. 10 sill has been examined microscopically. It is composed mainly of felspar with minor amounts of quartz: the felspar is altered to chlorite and epidote to such an extent that the chlorite is almost a pseudomorph which has, in places, recrystallised to form radial blades. The veins within the sample are principally composed of quartz and chlorite and again the chlorite appears with epidote and chloritoid alteration products of the original felspar. Subsidiary carbonate veins may cut through the chlorite grains. The rock has a metamorphic appearance unlike that of the normal contact zone.

3.3 Nodules within the sills

3.3.1 Macroscopic description

Nodules of a similar colour to the host rock are found in Sill No. 3. These nodules are aphanitic and may have a whorl-like pattern marked by thin lines of mafic minerals (Plate 3.8). Only three of these nodules have been observed, with diameters of 1.5 - 7 centimetres. They are rarely seen because of the slight colour contrast which is difficult to detect; thus they may be more common than suggested by the present observations.

3.3.2 Microscopic description

The nodules have the same mineralogy as the sills but there is a decrease in average grain size of the matrix to half that of the host

Author Fumerton S L

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