THE PATCHWAY GOLD MINE

A mineragraphic and petrographic examination of ore from the Patchway Gold Mine, Rhodesia, and an appraisal of the relationship between gold mineralisation and geological structure.

by

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ABSTRACT

A remarkable correlation between hydrothermal gold mineralisation and geological structure is discussed. The mineralisation occurs in vein quartz which occupies a fissure in Archaean greenstones of the Basement Complex in Rhodesia. It has been determined that gold which is silver-rich is typical of low-grade ore, and is associated in space with sulphides that crystallised early in paragenesis. Silver-poor gold is characteristic of high-grade ore which is concentrated along the crestal zone of anticlinal warps in the fissure. It is suggested that the local pattern of fracturing and folding is related to fundamental wrench faulting.

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1. INTRODUCTION

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1.1 GENERAL SETTING

Situated 18°14' south of the equator on meridian 29°48' east, Patchway Gold Mine is 85 miles west-south-west of Salisbury, Capital of Rhodesia, and some 11 miles north-west of the Rhodesian agricultural and mining centre of Gatooma. At an elevation of 3,600 feet above mean sea level the mine location is transitional between Highveld and Lowveld, the local vegetation consisting of deciduous and semi-deciduous trees and thorn scrub set in coarse grassland covering gently undulating terrain. The area forms part of the Zambesi drainage system, with local annual streams meandering south-westwards to the Umniati tributary of the Zambesi. Where it flows near the mine the Little Mazoe River shows a degree of control by the underlying structure in that it trends parallel to the local north-easterly strike of shearing and appears to follow a shear zone for this part of its course.

Reference to the Provisional Geological Map of Southern Rhodesia, compiled on a scale of 1:1,000,000 and published in 1961, shows that on a regional basis the host rocks of the Patchway mine are classified as part of the Bulawayan System, and, as such, form part of the Basement Complex. A more detailed provisional compilation of the Geology of the Gatooma Mining District was completed by the Geological Survey in March, 1967, and published on a scale of 1:100,000. On this map the Patchway host rocks are designated by the symbol (yB) as greenstones (meta-basic lavas) forming the upper member of the Mafic Formation of the Bulawayan Group.

Of these Archaean greenstones, Swift (33, 1961) has written the following:

".... In the larger gold belts they are mostly fine-grained and light in colour, being altered largely to chlorite and carbonate minerals. The original texture, which is very often variolitic, may be seen easily with a hand-lens on a ground surface, but near mineral veins where there is much carbonate a thin section often shows nothing ...."

The Patchway greenstone host is Archaean pillow lava which has been intruded, at different times, by a series of dolerites. Some fractures in the greenstone have been filled by andesine porphyries and by mineralised vein quartz. The economically important auriferous vein strikes just east of north and dips westwards at approximately 30 degrees. Reference to Figure 1, which is a plan of the mine workings as at January, 1967, will confirm that underground development extends along a total strike length of 4,800 feet, and at that time, the vein had been developed down-dip to a vertical depth of 1000 feet. The mine is divided by a major shear into what are termed the North Ore Body and South Ore Body sections, in which development levels are generally spaced at vertical intervals of 100 feet, giving a stoping back of slightly less than 200 feet per level.

1.2 HOST-ROCK PETROGRAPHY

Despite Swift's comment that near mineral veins, where there has been much carbonatisation, a thin section often shows nothing, examination of thin sections of specimens of the Patchway greenstones did not prove to be worthless. The specimens were chosen from diamond borehole core and underground cross-cut exposures and are believed to be representative of the different types of rock exposed in the mine. In these greenstones the recognition of different types is largely subjective, and is based on the detection of marked differences in the colour, granularity, and fracture displayed by hand specimens between one underground exposure and the next.

As an aid to the determination of the minerals present in the thin slices examined, adjacent sections of the specimens were finely ground in an agate mortar and the resulting powder was spread evenly onto glass slides, using acetone as a lubricant. These prepared mounts were examined by means of a Philips X-ray Diffractometer incorporating a PW 1010 generator and a PW 1050 wide-angle goniometer. Using $CuK\alpha$ radiation, a nickel filter, and a scanning speed of 2 degrees 2 θ per minute the specimens were irradiated between 4 degrees and 60 degrees 2 θ. The resulting recording strip charts were indexed by noting the value of 2 θ for each distinct peak of X-ray diffraction intensity, and these values were translated into values of the spacing of the structural planes, or (d), by reference to Parrish and Irwin's charts for the solution of the Bragg equation. Comparison of the (d) values so obtained with those listed in the KWIC Guide to the Powder Diffraction File, 1966, and A.S.T.M. cards resulted in the identification of the major minerals present in the specimens examined. This was found to be a most useful diagnostic aid.

Listed in decreasing order of age, the recognised types of host rock exposed in the Patchway Mine are the following:

(a) Pillow lava
(b) Doleritic greenstone
(c) Quartz dolerite
(d) Andesine porphyry
(e) Dolerite

These will now be described in sequence:

(a) <u>Pillow lava</u>:

Commonly termed 'greenstone' because of its metamorphosed appearance, this Patchway host is a fine-grained grass-green coloured rock displaying pillow structure. Underground development exposures show that the pillows are between twelve and eighteen inches in diameter, ovoid in shape, and have no apparent preferred orientation. In hand specimen the one to two inch wide inter-pillow zones are a pale greeny-yellow in colour and resemble a clastic breccia in appearance.

The most striking feature of this rock, when examined under the microscope, is the well developed pilotaxitic texture formed by highly saussuritised plagioclase feldspar laths measuring less than 1 mm in length which are set in a matrix of secondary chlorite and calcite. Small maximum symmetrical extinction angles place the feldspar as oligoclase. The rock is ubiquitously veined by secondary calcite and hydrothermal quartz, and some magnetite may be observed in thin section. The inter-pillow zones comprise segregations of epidote, quartz, and cryptocrystalline material surrounded by marked reaction rims and enclosed in allotriomorphic granules of hydrothermal quartz.

The pillow structure and sodic plagioclase suggest that this lava is a metamorphosed spilite, which, according to Turner and Verhoogen (36, 1960), consist principally of highly sodic plagioclase and augite or its altered equivalent. On the other hand, the pilotaxitic texture is more typical of andesites.

Listed in order of decreasing peak-intensity, the following minerals were determined in a specimen of this pillow lava by X-ray diffraction:

1. Quartz
11. Chlorite
111. Calcite
1V. Plagioclase

(b) Doleritic greenstone:

In hand specimen this rock is grey-green in colour, possesses a mottled fine-grained appearance and exhibits the blocky fracture typical of hypabyssal rocks in the area. As exposed on the 1100-foot level of the north ore body the indistinct and sheared contact between this rock type and the pillow lava can be seen to strike on a bearing of approximately 055^{o} with a steep north-westerly dip.

Under the microscope the rock is seen to be composed of a feltwork of highly altered plagioclase feldspar laths which measure up to 1.5 mm in length and are surrounded and enclosed by colourless fibres of tremolite. Palimpsest ophitic texture hints at dolerite parentage. The feldspar crystals exhibit maximum symmetrical extinction angles in the andesine range.

Chlorite is a major constituent of the matrix, and some quartz is present as well as minor quantities of magnetite and ilmenite. The latter is largely altered to leucoxene. Due to the highly altered state of the rock no modal analysis was attempted, but a visual estimation suggested the following constituent percentages:

Plagioclase	Tremolite	Quartz	Chlorite	Other
30%	40%	10%	15%	5%

Listed in order of decreasing peak-intensity, the following minerals were determined in a specimen of doleritic greenstone by X-ray diffraction:

1 Chlorite
11 Tremolite
111 Quartz
1V Calcite

(c) Quartz dolerite:

These are medium-grained intrusives which, from initial diamond drilling information, appear to strike on a bearing of 040^{0} and dip towards the north-west at angles of up to 70 degrees. The precise relationship between these rocks and pillow lava has been obscured by shearing, but from their texture they are thought to be intrusive dykes rather than intercalations of more basic lava. As the contact is approached the pillow lava becomes progressively more sheared and alters to a quartz-chlorite schist before giving way over a highly sheared transition zone to typical quartz dolerite.

The quartz-chlorite schist consists of fine-grained allotriomorphic-granular quartz and secondary calcite enclosing wisps and schlieren of chlorite and magnetite, with associated porphyroclasts of plagioclase feldspar up to 3 mm in length. Idiomorphic pyrite crystals rimmed by 'flame' textured quartz and some calcite are typical of the rock.

The quartz dolerite, more commonly described as epidiorite, comprises hypidiomorphic-granular laths of green hornblende measuring up to 7 mm in length and turbid crystals of altered plagioclase feldspar. The hornblende is markedly pleochroic (γ blue-green) and commonly twinned, while palimpsest albite twinning in the feldspar exhibits maximum symmetrical extinction angles in the andesine range. Much of the hornblende has been altered to chlorite. Anhedral and micrographic quartz is fairly abundant, and accessory minerals include ilmenite, represented by skeletal crystals much altered to leucoxene, and pyrite, prehnite, calcite and apatite.

A modal analysis (1000 point) of quartz dolerite gave the following constituent proportions:

Plagioclase	Quartz	Hornblende	Chlorite	Ore	Other
29.5%	15.0%	23.0%	24.5%	4.0%	4.0%

Dykes of this nature have, so far, only been detected in the southern section of the mine where two are known. They trend roughly parallel to each other and are between 50 and 100 feet in width. Concerning the effect of similar altered dolerites or epidiorites on gold deposition, Phaup (28, 1964) has commented that in the Bulawayo area of Rhodesia, where quartz veins are common in greenstone schist, many gold reefs terminate where the fissure passes into massive greenstone or epidiorite.

Describing the host rocks of the Dalny Mine, situated in a similar geological environment some twelve miles due north of Patchway, Leigh (18, 1964) described what he termed the Brown Dyke Series which are poor hosts for gold mineralisation from the depositional aspect. Members of this series he described as having the following mode:

Plagioclase	Quartz	Amphibole	Chlorite
5%	5-10%	40%	30%

In distinguishing dykes of this series from younger dolerite dykes, Leigh made the observation that, inter alia, the presence of graphically intergrown quartz is typical of the former. The logical inference is that the quartz dolerites or epidiorites in the Patchway Mine, which are characterised from younger dolerites by the presence of micrographic quartz, are similar to the Brown Dyke Series in the Dalny Mine.

Listed in order of decreasing peak-intensity, the following minerals were determined in a specimen of quartz dolerite by X-ray diffraction:

1 Chlorite
11 Quartz
111 Tremolite/Hornblende
1V Calcite

(d) Andesine porphyry:

These intrusives occupy fissures having strike directions of 055^{0} and approximately due north. The former dip at about 40 degrees to the northwest, strike parallel to the locally dominant shear direction, and are probably older than the gold mineralisation although they transgress the quartz vein. The northerly trending porphyries occupy the same fissure as the auriferous quartz vein. In places these porphyries roll away from the vein and are then seen to be identical in appearance to the porphyries which strike in a north-easterly direction, however, within the vein fissure this intrusive has been sheared and altered to a honey-coloured pyritic quartz-sericite schist.

In hand specimen the unaltered intrusive is seen to be porphyritic in texture and is greenish-grey in colour. Under the microscope the phenocrysts are found to be hypidiomorphic-granular crystals of andesine and anhedral grains of quartz measuring up to 2 mm across. The phenocrysts comprise 15% of the rock, the remainder being composed of an allotriomorphic-granular groundmass of quartz, plagioclase, and sericite less than 0.1 mm in grain size.

The honey-coloured porphyry is basically the same rock which has undergone extensive recrystallisation accompanied by the development of abundant sericite in the rock adjacent to the quartz vein. This alteration effect suggests that the phase of porphyry intrusion preceded the introduction of the vein quartz, a conclusion that gains support from the observed occurrence of thin ribbons or laminae of altered porphyry within the vein quartz.

Determination of the composition of the plagioclase phenocrysts by the Rittmann zonal method resulted in a variation in anorthite content between 32 and 45 per cent, while the plagioclase in the groundmass indicates a more sodic composition in the albite-oligoclase range.

Listed in order of decreasing peak-intensity, the following minerals were determined in a specimen of andesine porphyry by X-ray diffraction:

1 Quartz
11 Plagioclase
111 Sericite
1V Chlorite

(e) Dolerite:

Comparatively young dolerite dykes vary in size from stringers only three inches in width to major intrusions measuring more than 100 feet across. They strike in a northerly direction, with local variation in strike imparted by rolls, and dip westwards at high angles. In hand specimen they are deep-green in colour and, in underground exposures, their contacts are marked by an extremely fine-grained chilled margin with evidence of minor assimilation of the host by the intrusive. Thin slices through specimens collected from the contact between dolerite and pillow lava confirm the observation that assimilation of the host by the intrusive has been on a minor scale.

The grain size of these dykes varies from cryptocrystalline margins to medium-grained cores where individual feldspar and pyroxene crystals are commonly 3 mm long. Other obvious features are the occurrence of idiomorphic pyrite and disseminated pyrrhotite near the periphery of these intrusive rocks and an increase in the percentage of interstitial quartz towards the core of the dykes. A modal analysis (415 points) of a specimen from the core of one of these intrusives gave the following constituent percentages:

Plagioclase	Quartz	Pyroxene	Chlorite	Ore	Other
48.0%	11.0%	21.5%	6.5%	9.0%	4.0%

The texture of the rock is sub-ophitic, with laths of andesine penetrating crystals of augite but rarely being surrounded by the pyroxene. All of the thin sections examined showed moderate to extreme alteration of the pyroxene and plagioclase, the former being partially or completely uralitised to a green fibrous tremolite and the latter showing varying degrees of saussuritisation. The quartz occurs interstitially, and in contrast to the quartz dolerite and to the Brown Dyke Series in the Dalny Mine, is not micrographic. Accessory minerals include ilmenite and leucoxene, magnetite, epidote, and clinozoisite.

A feature of these dykes is the occurrence of sub-horizontal veinlets and veins measuring from less than 1 mm to more than 3 mm in width. In hand specimen the larger veins are seen to be filled with slip-fibre and cross-fibre which, under the microscope, is observed to be tremolite. These fissures or veinlets also contain quartz and calcite, and some pyrrhotite and chlorite.

Listed in order of decreasing peak-intensity, the following minerals were determined in a specimen of dolerite from the Patchway mine by X-ray diffraction:

1 Chlorite
11 Quartz
111 Plagioclase
1V Amphibole (Tremolite)

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2.1 UNDERGROUND WORKINGS

Gold-bearing quartz veins exposed in the Patchway mine occupy an irregular fissure of varying size that is generally between five and ten feet wide, with a maximum width of some thirty feet in flatter sections of the south ore body. The principal vein strikes just east of north and dips towards the west at an angle varying from 20 to 40 degrees. As a rule the vein is widest where the dip is less than 30 degrees.

In the northern section of the mine the vein dip averages 34 degrees, whereas in the southern section the average dip is 28 degrees. In part this difference is related to post-mineralisation normal faulting which is more evident in the northern section, and in part may be related to a major shear zone separating the two portions of the mine. However, in the absence of 'marker' horizons, the latter possibility must remain speculative.

Mapping of the geology exposed in the underground workings has been plotted onto a master plan on a scale of 1:500, and examination of this plan creates the impression that the auriferous quartz vein has been highly contorted by folding whilst in a plastic or semi-plastic state and that it has been dislocated by faulting while in a relatively brittle condition. Reference to Figure 2 will enable the reader to assess the aptness of this impression. This figure shows a plan view of the quartz vein exposed in development drives on the 900-, 1000-, and 1100-foot levels in the north ore body. The host rock is predominantly highly sheared pillow lava and doleritic greenstone, the shear or cleavage directions trending parallel to the dominant fault direction.

2.2 FAULTING

An analysis of the strike direction of 455 fault planes mapped in underground exposures is shown in Figure 3 in which, it will be noted, the dominant strike of faulting approximates a bearing of 055°, with a conjugate set of faults trending towards a bearing of 155°. In this analysis the dips of the individual fault planes were not considered for these commonly change attitude markedly on approaching the quartz vein. The dip of the most prominent of these faults, which was developed on a strike of 055° for a distance of 500 feet on the 1000-foot level of the mine, averages 40 degrees from the 400- to the 1000-foot levels. Accordingly, for the purpose of evaluating the dominant fracture pattern, a strike of 055° and a dip of 40 degrees towards the north-west has been assumed for the major shears. The dips of the conjugate faults or shears, which strike on a bearing of 155°, are not so well known and where these faults intersect the quartz vein their dips vary from 30 degrees towards the north-east to vertical, with a tendency towards a frequency maxima at 40 degrees to the north-east.

2.3 FOLDING

Comparatively minor folding of the quartz vein is encountered on all levels. Invariably this is associated with an increase in gold values, whether the amplitude of the fold concerned is measurable in inches or in tens of feet. Mapping of the most prominent of these folds has revealed that the axis of the fold plunges at 35 degrees on a bearing of 260°. This fold is illustrated in Figure 4 B.

2.4 THE VEIN FISSURE

Figure 4 A is a plan of a portion of the quartz vein exposed on the 500-foot level of the north ore body showing that the vein fissure is, in parts of the mine, partially filled by andesine porphyry which is locally termed felsite. Quartz vein material has been emplaced on either side of the felsite, and, in this particular instance, both the hangingwall and footwall portions of the vein carried payable gold values, although this is by no means the rule.

Zealley and Lightfoot (40, 1918) have observed that in the Patchway-Golden Valley area the gold-bearing quartz veins are apparently all fissure veins and are generally found near a body of felsite, in some cases actually at the junction between the felsite and the greenstone. In a description of the association of gold deposits with acid igneous rocks in Rhodesia, Maufe (23, 1913) commented on the frequent occurrence of these rocks in the neighbourhood of auriferous quartz bodies and suggested that the gold-bearing solutions probably accompanied and followed the intrusion of acid rocks. Maufe concluded that these felsites were probably derived from the same magma as the granite batholiths and that they were intruded at intervals during a period in which crustal movements and the intrusion of the granite batholiths also took place. Wiles (37, 1957) reported that small felsite dykes and sheets are found in many mines in the Hartley district, which adjoins the Gatooma district to the north-east, and frequently occur along reef channels where they may be highly altered, sheared, and also highly mineralised.

A classical example of an association between auriferous quartz vein and an acid hypabyssal rock is to be found in the Kolar gold-field of India. Bichan (4, 1947) described this "dogger" as pale buff in colour with distinct flakes of biotite aligned in the cleavage direction. He commented that two quartz veins are found respectively near the footwall and the hangingwall of the dyke-like masses of dogger, and his conclusion was that this previously emplaced rock of pegmatitic or aplitic composition had the effect of bifurcating the plane of fracture when a renewal of fissuring and introduction of the quartz veins took place. In this regard there is a striking similarity between the Kolar gold-field and the Patchway mine.

Reference to Figure 5 will show the typical relationship between host rock, felsite and quartz vein in cross section. It will be noted that in this figure the dip of the fissure is of the order of 30 degrees and that where the dip flattens the quartz vein is generally wider and vice versa.

Newhouse (26, 1940), in a consideration of the openings that result from movement along a curved or irregular fault plane, made the observation that as a rule in normal faulting a likely place for openings is where the dip steepens and in reverse faulting where the dip flattens. Extending this generalisation, Thornburg (35, 1945), in a description of Tertiary silver deposits associated with widespread faulting and fracturing of eruptive rocks, mainly andesites, in the Pachuca district of Mexico, showed that secondary footwall and hangingwall splits are typical of tension cracks formed as a result of normal faulting.

McKinstry (19, 1948) publicised Thornburg's findings under the heading of 'cymoid loops', and, more recently, Anhaeusser (2, 1965) has drawn attention to the development of the cymoid loop fracture pattern in the Barberton mountain land. These fractures, which are intimately related to gold mineralisation, he interpreted as second-order structures related to right lateral wrench or strike slip reactivation of pre-existing regional thrust faults.

Figure 6 illustrates diagrammatically the hypotheses of Newhouse and Thornburg. A comparison of their findings with the idealised sectional pattern of fracturing observed in the Patchway mine suggests that the latter pattern is related to minor overthrusting resulting in the development of footwall tension fissures in steeper sections of the vein. In suggesting that movement on the fissure was of a small order it is well to refer back to Newhouse who commented: "... many people have emphasized the relatively slight displacement along most of the faults in which ore bodies are found ...". Considering both a comparatively steeply dipping (40 degrees) portion and a flatter (25 degrees) section of the Patchway vein fissure in cross section, movement of the order of a 25-foot overthrust would produce an 84-inch wide opening in the less steep part of the vein. Widening by replacement would further increase such an opening, however, from the regular nature of the contact between the quartz vein and enclosing host rock which commonly breaks clean on blasting, it is apparent that replacement of the host rock by the quartz vein played a very minor part in the emplacement of the vein which is essentially a fissure filling.

2.5 INTRUSIVES

Another cross section through the mine is shown in Figure 7 illustrating the effect that the emplacement of post-mineralisation dolerite dykes has had on the attitude of the quartz vein. As has been noted earlier, these dykes strike roughly north and dip towards the west at high angles. The fact that their introduction has displaced the vein in a horizontal sense indicates that these dolerites occupy tension fissures and that very little assimilation of the host rock or quartz vein accompanied this phase of intrusion.

The strike of older quartz dolerite or epidiorite dykes varies from north to north-east with steep westerly dips. These intrusives were emplaced prior to the development of the Patchway vein fissure, and where it transgresses these dykes the fissure steepens markedly to a dip of 40 degrees or more. With this steepening in dip there is a narrowing of the fissure and a drastic diminution of gold values in the vein. Two of these epidiorites have so far been located in the lower section of the southern ore body where the vein dip has steepened to 40 degrees and the gold content of the vein is negligible in economic terms.

Considering the Gatooma district as a whole, it is illuminating to discover that epidiorites have been reported as poor host rocks for gold deposition in both the Cam and Motor mine at Eiffel Flats and the Dalny mine at Chakari. Leigh (18, 1964), in a description of the Dalny mine host rocks, commented that what he termed the Brown Dyke Series decrease the percentage of payable reef in the mine from the aspect of non-deposition rather than displacement. Similar hypabyssal rocks in the Cam and Motor mine have been described by Collender (6, 1964) who commented that these intrusives do not rupture, but rather crack unevenly under stresses and are poor host rocks to gold mineralisation.

In a description of gold mineralisation in the Bulawayo area, Phaup (28, 1964) has pointed out that massive greenstone or epidiorite has proved to be a poor host to gold mineralisation, and yet south of Bulawayo, in the Gwanda district, the gold mineralisation in the Freda mine is confined to massive epidiorite. One may conclude that in some cases, but not all, epidiorites encountered in Rhodesian gold mines prove to be unfavourable host rocks for gold deposition.

2.6 FISSURE RECONSTRUCTION

Before considering any possible relationship between the attitude of the vein fissure and economic concentrations of gold in the vein it is necessary to counter the effect on the fissure of the post-mineralisation dolerite dyke invasion.

Such a reconstruction was undertaken by treating the northern and southern sections of the mine as separate structural units. A tracing of the geology of each section of the mine was made from the 1:500 scale master plan and the post-mineralisation dolerites were excised from the tracings. Treating the fissures so exposed as tension fissures with a horizontal component of movement the tracings were re-assembled to the best fit. This reconstruction assumes as a basic premise that the dolerites occupy simple tension fissures and that there was little or no assimilation of the host rock during their emplacement. The plan of the underground workings obtained by this method of reconstruction is shown in Figure 8.

2.7 CONTOUR DIAGRAMS

Development ends in the Patchway mine are sampled after each round of blasting, which commonly advances the face of the drive by six feet, and the assay result of the gold content of the quartz vein determined by this sampling is plotted on transparent overlays to a surveyed plot of the underground workings on a scale of 1:250. These values, expressed as pennyweights of gold per ton (dwts/ton), were meaned over 50-feet long sections of all development drives and raises in the northern section of the mine. From the arithmetic mean values so obtained a contour diagram of the sampled gold content of the quartz vein in this section of the mine was prepared and is reproduced in Figure 9.

In an endeavour to determine any relationship between the attitude of the vein and the gold payshoot a structural contour diagram was prepared, following the method outlined by Conolly (7, 1936). A datum plane was assumed in the footwall of the two reconstructed sections of the mine. For both sections the strike of this datum plane was on a bearing of 011°, but in the case of the north ore body the dip chosen was 34 degrees and in the case of the south ore body 28 degrees.

It is important to stress here that the reconstructions of the two sections of the mine were undertaken independently of each other; similarly, in preparing the structural contour diagrams the two sections of the mine were treated as separate units.

In examining the relationship between the tin content and the structure of lodes at Geevor mine, Cornwall, Garnett (12, 1966) pointed out that in the construction of a Conolly diagram an unrealistic contour trend may develop in the direction of dip of the ore body, with corresponding suppression of horizontal trends, if measurements from the reference plane to the lode (or quartz vein) are made at intervals which are considerably less than the vertical interval between levels. In practise he recommended that a factor of 2:1 should be regarded as a maximum; for example, the measurements from the assumed datum plane to the vein or lode may be made at 50-foot intervals along each level if the levels are 100 feet apart vertically. In the case of the Patchway mine the levels are 100 feet apart vertically and roughly 180 feet apart in the plane of the reef, and for the purpose of preparing a structural contour diagram measurements were made in the horizontal plane between the footwall reference plane and the footwall contact of the vein at intervals of 50 feet along each level.

In a discussion of Garnett's paper, Williams (38, 1966) concluded that: "... the Conolly contour method is obviously best suited for the geometrical analysis of ore shoots formed by the infilling of spaces created by simple fault movement along curved or irregular fractures ...". The result of such a geometrical analysis of the Patchway vein is reproduced in Figure 9 A. An appraisal of the contour pattern discloses that each ore body or payshoot is associated with a broad anticlinal warp having a westerly plunge on a bearing of 263°. Secondary axes striking across these upwarps on a bearing of 006° and having a southerly plunge may be related more to the reconstruction than to folding for they trend roughly parallel to the dolerite-filled tension fractures.

It is surely more than coincidence that the two major payshoots in the mine are associated with anticlinal warps which plunge westwards on a bearing of 263°, while localised improvement in gold values in the vein may be seen to be associated in space with comparatively minor folds in the vein which plunge in a westerly direction on a bearing of 260° (see Section 2.3 and Figure 4 B).

2.8 FRACTURE PATTERN

In examining the pattern of fractures exposed in the underground workings at Patchway, cognisance was taken of the direction of strike of the dominant faults in the mine and the strike of the vein fissure. The subsequent dolerite-invaded tension fractures were ignored. A diagrammatic representation of the fundamental pattern of fracturing exposed by development on the 400-foot level in both the northern and southern sections of the mine is reproduced in Figure 10.

It will be noted in this figure that the vein fissure is roughly sigmoidal in plan, and is divided into several distinct units by shears which strike on a bearing of 055°. Development along the most prominent of these shear zones on the 1000-foot level disclosed that this zone is some 40 feet in width and in the core were encountered small lenticles of auriferous quartz, which, from their unfractured appearance and surrounding alteration aureole, appear to have crystallised in situ rather than to have resulted from fault drag. From this one may infer that opening of the sigmoidal tension fissures to receive vein material was the direct result of movement along these shear zones. It is possible that had these shear zones been less regular then more vein material would have been emplaced in openings along them as well as within the tension fissures. The overall pattern of fracturing suggests that the tension fissures resulted from regional compression about meridional axes which gave rise to torsional stresses of sinistral sense within the inter-shear zone lithological units.

Figure 11 is a stereographic presentation of the Patchway mine fracture pattern and includes an hypothetical strain ellipsoid indicating possible moments. The attitude of the axis of vein folding is shown in relation to the S 1 shear direction on the same stereogram. It will be noted that while the strike of the Patchway tension fissure corresponds to the strike of the BC plane, in three dimensions there is no correspondence.

2.9 STRESS PATTERN

In a consideration of the possible stress pattern released by shearing and fracturing in the Patchway area, note has been taken of the findings of workers in similar lithologically homogeneous fields elsewhere.

Shainin (32, 1950) has pointed out that many tension fractures in the Ordovician argillaceous limestone at Riverton, Virginia, exhibit what he termed "anomalous" curvature at either end. That is to say, the en echelon aligned fractures curve terminally in directions opposite from those that would result from frictional drag.

Roberts (29, 1967) has drawn attention to the fracturing of an Upper Ordovician meta-sandstone in Norway where he found that tension gashes, many of them filled with quartz or quartz and calcite, are particularly well developed in coarser sandstone and fail to penetrate the finer grained siltstone or shaley horizons. He attributed the development of these tension gashes to the imposition of a shearing couple acting along the top and bottom contacts of individual lithological units. Figure 12 is reproduced after Roberts, and it is of interest to note that these tension fractures exhibit "anomalous" curvature at their extremities, that they are associated with drag folding, that they may assume sigmoidal form and that major tension gashes may be divided into a number of smaller units. Comparing Roberts' figure to Figure 10 permits the observation that the Patchway mine fracture pattern is remarkably similar, albeit on a much larger scale. The inference that such a pattern of fracturing may develop in comparatively homogeneous Precambrian greenstones by the imposition of a shearing couple acting upon individual lithological units is entirely valid.

In the Patchway case, lithological control of the shear pattern may be surmised but is difficult to prove. Certainly, development exposures on the 1100-foot level of the north ore body indicate that doleritic greenstones in the Patchway sequence strike parallel to the S 1 shears. The dip of the greenstones, however, appears to be steeper than the 40 degree average inclination of the major north-south ore body shear.

After enquiring into the facets of wrench fault tectonics, Moody and Hill (25, 1956) proposed that large scale wrench faults may be a dominant type of failure in the earth's crust, and pointed out that large areas, probably continental in dimensions, appear to have been subjected to rather uniform stresses for extended periods of time. In fact, they suggested, exact dating of these deep and fundamental flaws in the crust is a difficult problem arising from the continuous activity of many of these faults throughout geological time. Moody and Hill made the point that many wrench faults are associated with low angle thrusts which are probably near-surface manifestations of the wrench faults.

Pertinent to any discussion of the structural pattern at Patchway is Moody and Hill's examination of the association between wrench faults and related drag folds. They found that the angle made by the axis of these folds with the strike of wrench faults in California, Texas, and Oklahoma varied between 4 and 29 degrees. At Patchway the angle between the S 1 shears, which strike on a bearing of 055°, and the anticlinal warps or folds, which plunge in a westerly direction on a bearing of 260°, is 25 degrees and well within their range. Further, in a consideration of the strain ellipsoid in Figure 11 it will be noted that the azimuth containing the plane of the principal stress direction in the Patchway area is 014°. Moody and Hill concluded from their investigation that the observed structural relations of wrench faults indicate that, in most instances throughout geological time, the principal stress direction relating to wrench faulting has been orientated approximately meridionally and that the azimuth varies between 340° and 20°; again, the Patchway angle falls within this range.

The close parallel between phenomena associated with wrench faulting and the structural relationships observed in the Patchway mine suggest that the fracture pattern is related to wrench faulting. Against this supposition is the fact that the S 1 and S 2 shears have dips in the 40 degree range while, by definition, wrench faults are vertical or sub-vertical fractures. Bearing in mind that low angle thrusting is commonly associated with wrench faulting it is not inconceivable that fundamental vertical wrench faults may flatten into shallow angle strike slip faults near the surface; nor is it impossible that there may be minor rolls in the plane of the wrench fault giving an overall impression of near-vertical dip that in localised sections may vary from vertical to 40 degrees or less. Examination of the strike extension of the major S 1 shear separating the two sections of the mine discloses that some 10,000 feet to the south-west of Patchway are two gold prospects named March Hare and Erin which strike on a bearing of 055° and dip towards the north-west at between 60 and 65 degrees. The gold mineralisation in these prospects is associated with isolated lenticles of quartz contained within a shear zone that is 40 feet wide. This suggests that within the space of two miles a major shear zone may vary from 40 degrees of dip at Patchway to 65 degrees of dip at Erin, and possibly near-vertical at other points along the strike.

Be that as it may, the temptation to associate the Patchway structural pattern of fracturing and folding with wrench fault tectonics is strong. This is by no means unique, and, in describing the Kolar gold-field, Bichan (4, 1947) has shown that gold is preferentially concentrated along both anticlinal and synclinal structures in the veins. These veins are found in a persistent fracture zone which extends north-south for nearly ten miles, and Bichan concluded that the most logical explanation for the development of these openings is that they are tension fissures produced by torsional stress resulting from "large scale and powerful strike thrust displacements". Similarly, the fracturing, with which is associated gold mineralisation in the Barberton mountain land, was related, by Anhaeusser (2, 1965), to second-order structures resulting from wrench or strike slip reactivation of pre-existing regional thrust faults. Likewise, McKinstry (20, 1955) concluded that in many parts of the world mines and mining districts are dotted along well defined lines, most of which are major structural lineaments.

2.10 REGIONAL LINEAMENTS

From the foregoing discussion it seems reasonable to suggest that the Patchway fracture pattern and vein folding are related to the application of stress on a regional scale. At Patchway this stress has been released in a left lateral or sinistral sense along wrench or strike slip fracture zones which may be fundamental in nature and pre-determined in space by the strike and dip of the affected Precambrian lithological units.

Goldberg (14, 1964) has pointed out that many of Rhodesia's gold ores appear to be directly related to structural influences, probably produced by regional deformation. On the evidence he collected from a large number of Rhodesian gold deposits, Goldberg suggested that their lineaments resulted from deformation due to the action of compressive forces acting about a northerly trending axis, and that in most instances, there is a marked spatial relationship between the lineaments in respective districts.

If it is correct to suggest that the Patchway fracture pattern is related to fissuring which is fundamental in character, then it may be expected that the locally evident lineaments will be of some significance on both a district-wide and a regional scale. Examination of mines and prospects in the Patchway area shows that they may be related to shear zones which strike on a bearing of 055° and to which they bear the same relationship as the Patchway vein. Reference to Figure 13 will clarify this point. Here the Patchway north and south ore body fissures are shown in relation to neighbouring gold deposits. Of these ore deposits, the vein of the Golden Valley mine crops out some 2000 feet to the west of the Patchway vein and dips in a westerly direction at approximately 28 degrees. The parallel with the Patchway vein is striking and the axis of elongation of the underground workings of the Golden Valley mine, which are over 2000 feet deep, plunges westwards on a bearing of 260^{o}. Further to the west the veins of the Easter Gift and Hamburg mine crop out. These mines are no longer in operation, but the former was mined to a depth of 100 feet below the surface along a strike length of 220 feet. Again the gold mineralisation was associated with a quartz vein which fills a tension fissure striking in a northerly direction and dipping westwards at 33 degrees. South of this the Hamburg mine was worked to a depth of approximately 150 feet below the surface along a strike length of more than 600 feet. Apart from the northerly strike and shallow westward dip, the Hamburg mine vein emulates Patchway in that it is offset by 'cross reefs' which strike on a bearing of 055^{o}. The other prospects shown in the close vicinity of the Patchway mine were largely rubble workings along the strike of quartz veins which have a comparatively low content of gold.

The lineaments displayed in Figure 13 are based partly on the knowledge of the Patchway fracture pattern, partly on the evidence of structural control of the local drainage along conjugate lineament directions, and partly on the geological sketch map of the country around the Dalny mine reproduced by Leigh (18, 1964).

The outline of the Lion Hill granite, which crops out of the footwall of the Patchway, Big Ben and Glasgow groups of mines, suggests that it may have been a diapiric pluton and that the concentric arrangement of mines about the pluton could be related to fracturing resulting from such a mode of emplacement. However, the obvious affinity between tension fissures, filled with auriferous quartz, and shear zones striking on a bearing of 055^{o} at Patchway and 155^{o} at Big Ben, and the stream course lineament which strikes on a bearing of 055° through the Glasgow group of mines, suggests that the introduction of these quartz veins was connected to a shearing on a regional scale rather than to localised diapirism; to some extent the location of the tension fissures and emplacement of acid hypabyssal felsites may have been controlled by the earlier diapiric dome fracturing.

Also shown in Figure 13 is the Arlandzer - Dalny group of mines in the Chakari shear belt. In a description of the Dalny mine, Leigh (18, 1964) stated that the Chakari shear belt has a width of some 2000 feet and a known strike length of 10 miles. From his text figures, measurement of the general strike of this major zone of shearing shows it to be on a bearing of 055°. The main shear zone comprises a number of separate shear zones, and within the area covered by the Dalny claims lie at least six individual shear units which vary in width from 5 to 50 feet and in strike length from 1000 to 5000 feet. The shear unit within which the Dalny mine is located has a maximum developed strike length of 5000 feet. Again, from Leigh's text figures, the strike of this shear is found to bear 060°, and Leigh reported that the shear zone, which varies between 10 and 100 feet in width, dips towards the north-west at between 60 and 85 degrees. The displacement along this shear in a horizontal sense, as determined by boreholes, is greater than 100 feet and less than 500 feet, and the footwall of the shear has been displaced to the north-east relative to the hangingwall. In other words the sense of movement along the Dalny shear was left lateral or sinistral, and identical in sense to the movement along the Patchway shear.

The gold mineralisation, occuring as replacement deposits and quartz vein filling, is, in the Dalny mine, associated with arsenopyrite and occurs in shear zones which strike in a north-easterly direction. Twelve miles to the south the gold mineralisation at Patchway, which is associated with pyrite, galena, chalcopyrite, sphalerite, and pyrrhotite, occurs in quartz vein material filling tension fissures which strike in a northerly direction and which are intimately related to shear zones which strike in a north-easterly direction. So far the laws of chance may still be operating; however, localisation and control of the gold mineralisation at Patchway is intimately connected to anticlinal warps and minor folds which plunge westwards on a bearing of 260°. Concerning Dalny, Leigh has related that major drag folding pitching west is convincingly demonstrated underground and he suggested that the Dalny shear is the dragged-out and sheared minor limb of a major regional drag fold. Again by measurement from Leigh's text figures, these drag folds plunge westwards on a bearing of 258°. It is suggested that these folds are not so much regional drag folds, but that they resulted from shearing or wrench faulting on a regional scale, and, in commenting on the Chakari shear belt, Leigh wrote: "... a regional shear belt of such intensity can only have been produced by widespread and major structural disturbances ...".

2.11 SUMMARY & CONCLUSIONS

For convenience, the salient structural features of the Patchway mine which have been discussed in this section are summarised in point form:

(a) The auriferous quartz vein, which is a fissure filling rather than a replacement body, strikes in a northerly direction and dips towards the west at approximately 30 degrees.

(b) Dominant faults in the mine strike on a bearing of 055° and dip towards the north-west at 40 degrees. A conjugate set of faults strike on a bearing of 155° and dip towards the north-east.

(c) Minor folds in the vein, which are associated with an increase in gold values, plunge at 35 degrees on a bearing of 260°.

(d) Structural contour diagrams of the vein reveal that the major ore shoots are associated in space with anticlinal warps which plunge towards the west on a bearing of 263 degrees.

(e) Epidiorites, or altered quartz dolerites, are unfavourable host rocks for gold deposition in this mine.

(f) Sigmoidal tension fissures, subsequently filled with auriferous quartz, developed between major shears which may have been pre-determined in space by the attitude of doleritic greenstones in the host rocks.

(g) The close parallel between phenomena associated with wrench faulting and the structural relationships observed in the mine suggest that the fracture pattern and mineralisation is related to fundamental wrench faulting.

(h) Several other gold mines in the Golden Valley and Chakari district evidence a similar relationship between mineralisation and structure.

It is apparent that gold mineralisation in the Patchway mine shows a remarkable degree of control by both the structure and texture of the enclosing lavas and intrusives of the Basement Complex. The structural control is shown by the formation of suitable tension openings between shear zones for the introduction and deposition of hydrothermal quartz, and by the formation of both minor and comparatively major folds or warps in this quartz vein with which concentrations of gold are associated. The texture of the host rock is important from the non-depositional aspect in that certain epidiorites are poor host rocks for gold mineralisation.

FIGURE ONE

Being a plan of the underground workings of the Patchway Gold Mine as at January, 1967. Development drives and raises are shown, together with the areas of reef that had been stoped-out at that time. The lowest level shown is 1000 feet below the surface.

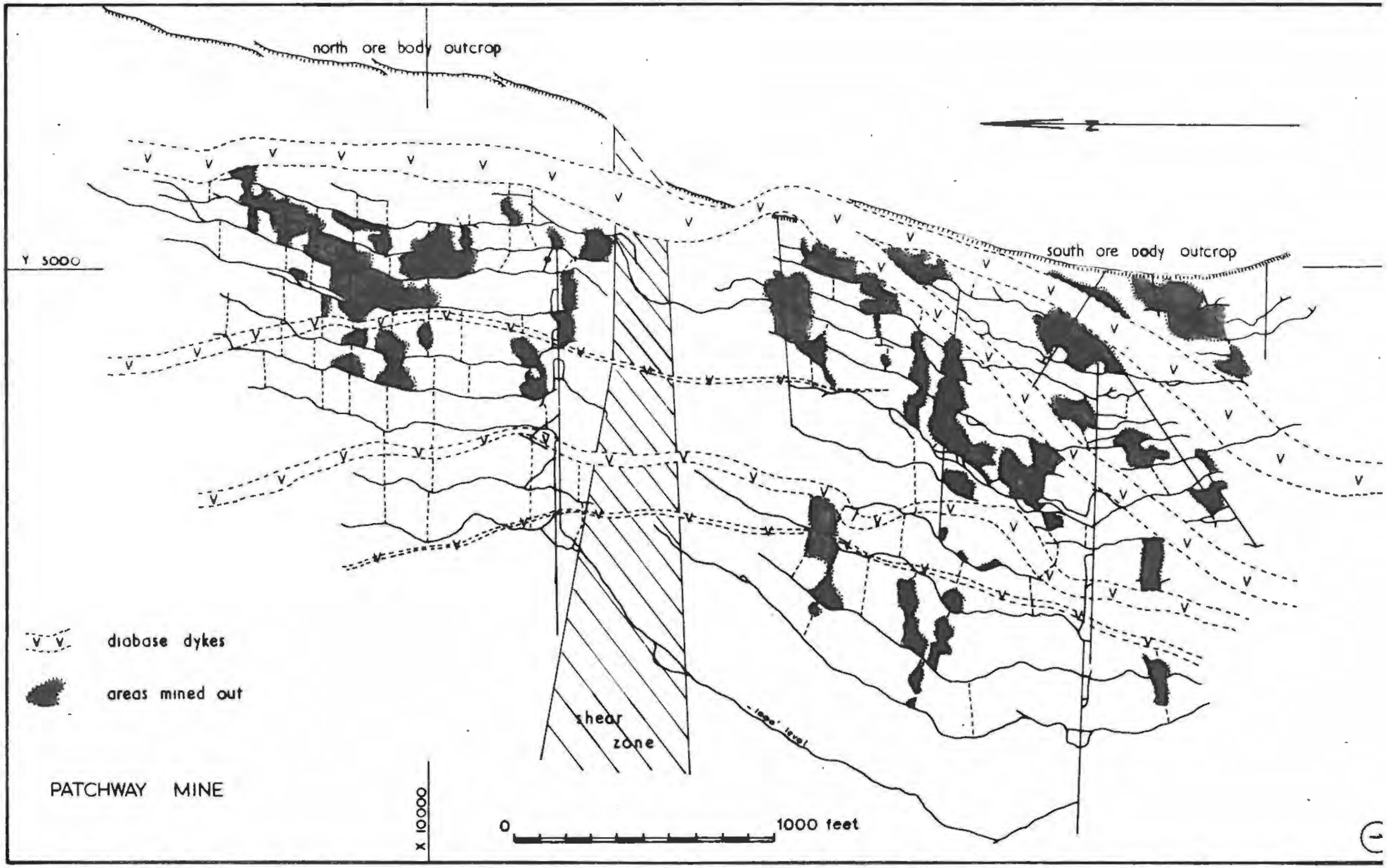
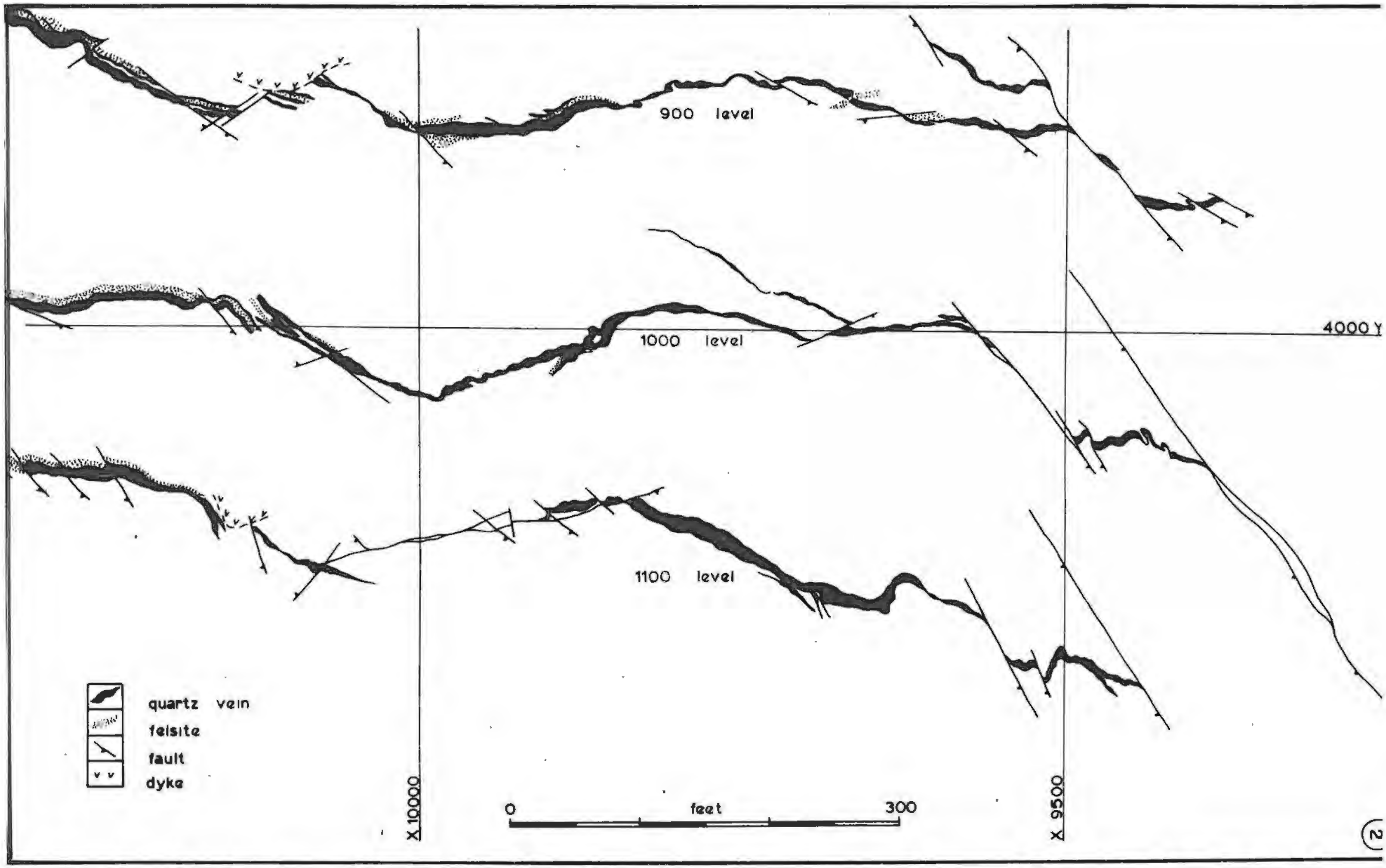

north ore body outcrop
N
south ore body outcrop
Y 5000
X 10000
diabase dykes
areas mined out
shear zone
0
1000 feet
PATCHWAY MINE
1

FIGURE TWO

Being a plan of the quartz vein exposed by development in a section of the north ore body. Note the sinuous nature of the vein and the degree of faulting.



900 level
1000 level
1100 level
4000 Y
X 10000
X 9500
0
feet
300
quartz vein
felsite
fault
dyke
2

FIGURE THREE

Being a rose diagram which indicates the direction of strike of 455 faults exposed in the mine.

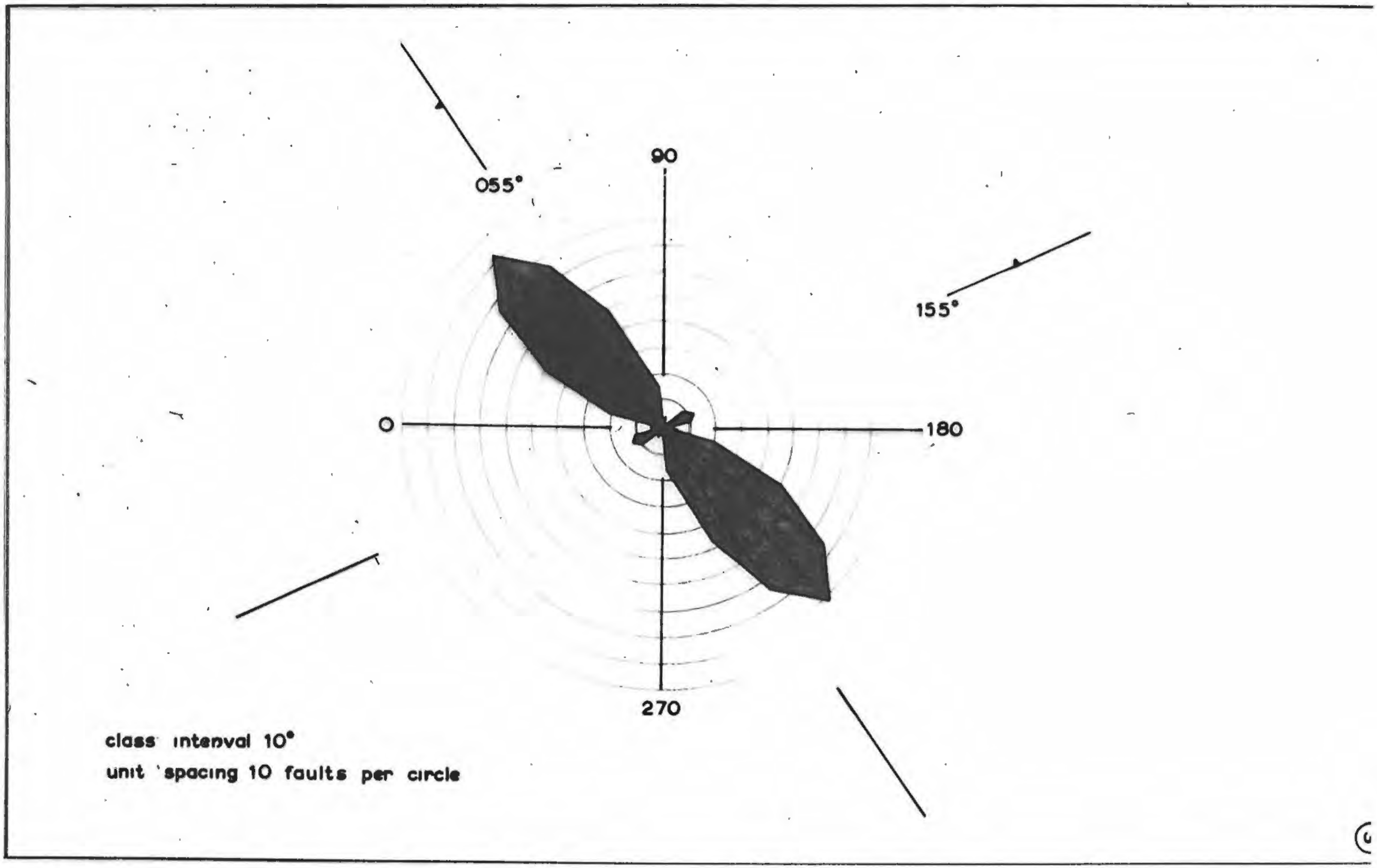

055°
90
155°
0
180
270
class interval 10°
unit spacing 10 faults per circle

FIGURE FOUR

A. Being a plan of a section of the quartz vein illustrating the size of the fissure and the relationship between hydrothermal quartz and felsite or andesine porphyry.

B. Being a plan of a section of the quartz vein that has been folded. Note the bearing of the axis of this fold.

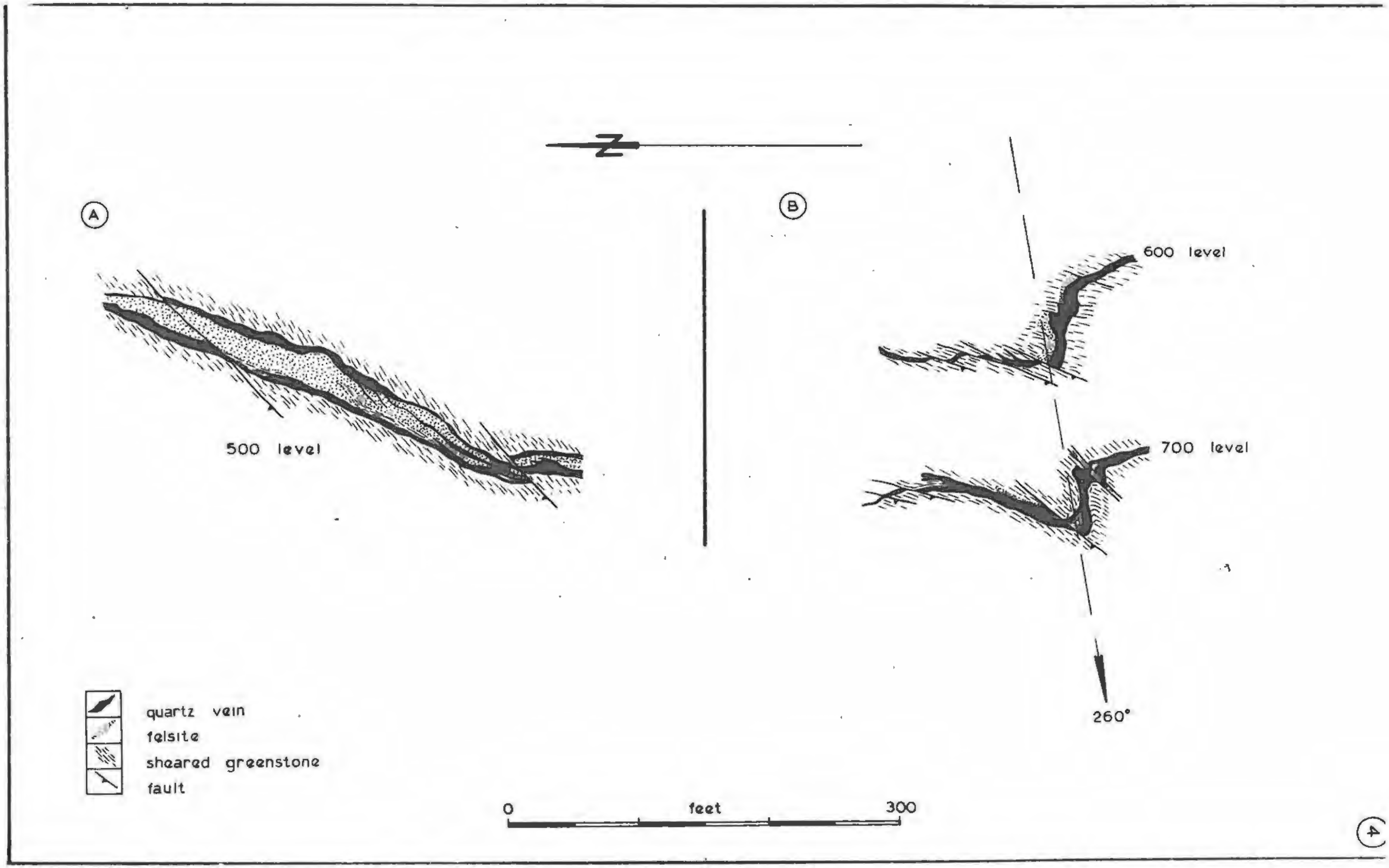

N
A
500 level
B
600 level
700 level
260°
quartz vein
felsite
sheared greenstone
fault
0
feet
300
4

FIGURE FIVE

Being two dip-sections illustrating the relationship between hydrothermal quartz and felsite. Note the footwall spur vein and the fact that quartz has been emplaced on both sides of the felsite.

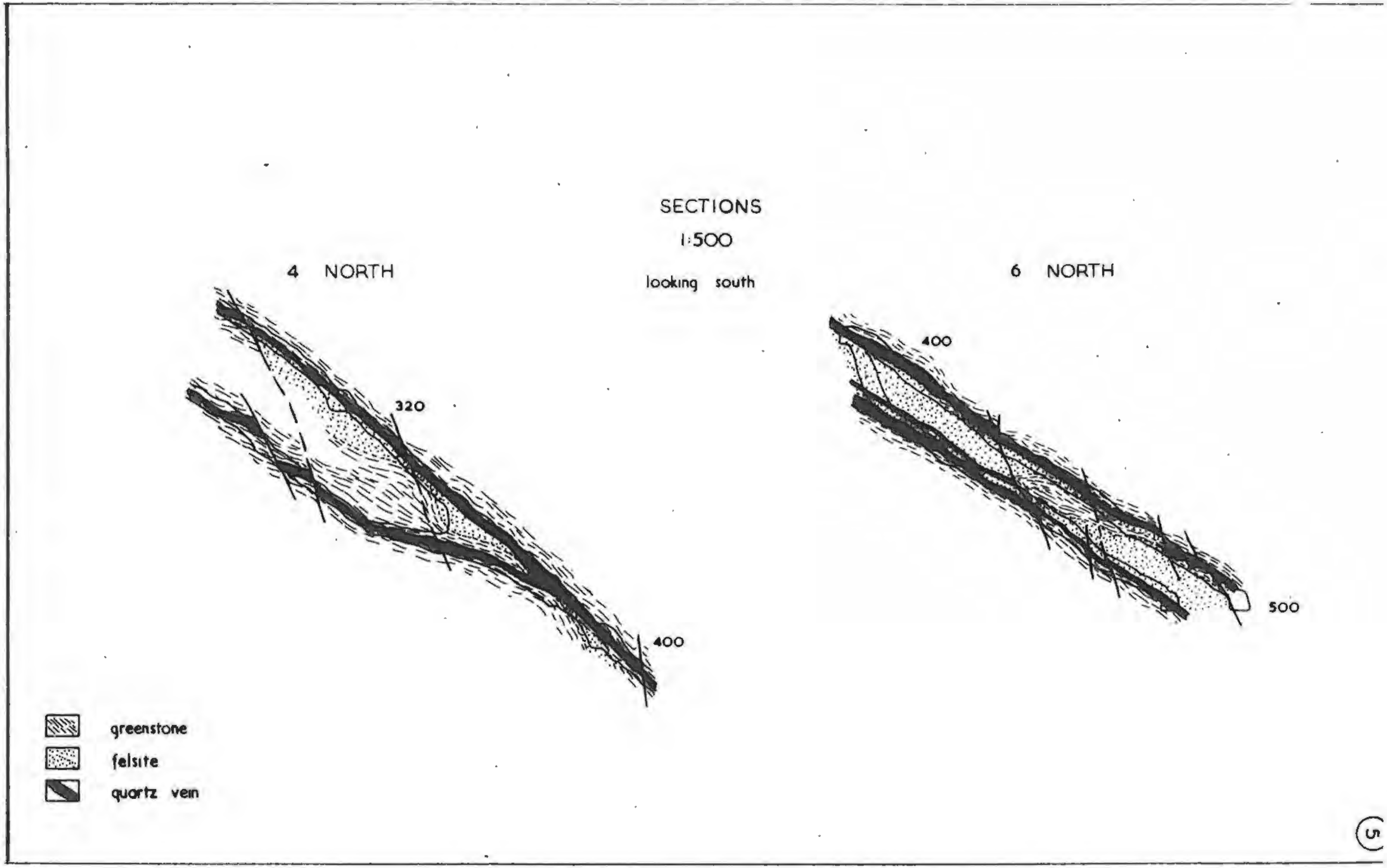
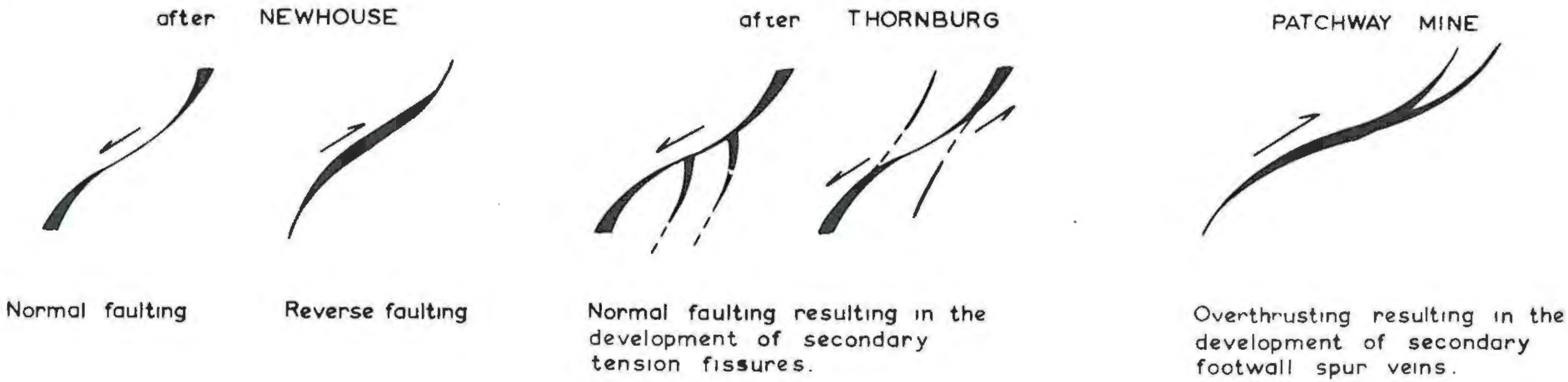

SECTIONS
1:500
looking south
4 NORTH
320
400
6 NORTH
400
500
greenstone
felsite
quartz vein
5

FIGURE SIX

Being a series of diagrammatic dip-sections showing the relationship between different types of faulting and the openings resulting from such movement.

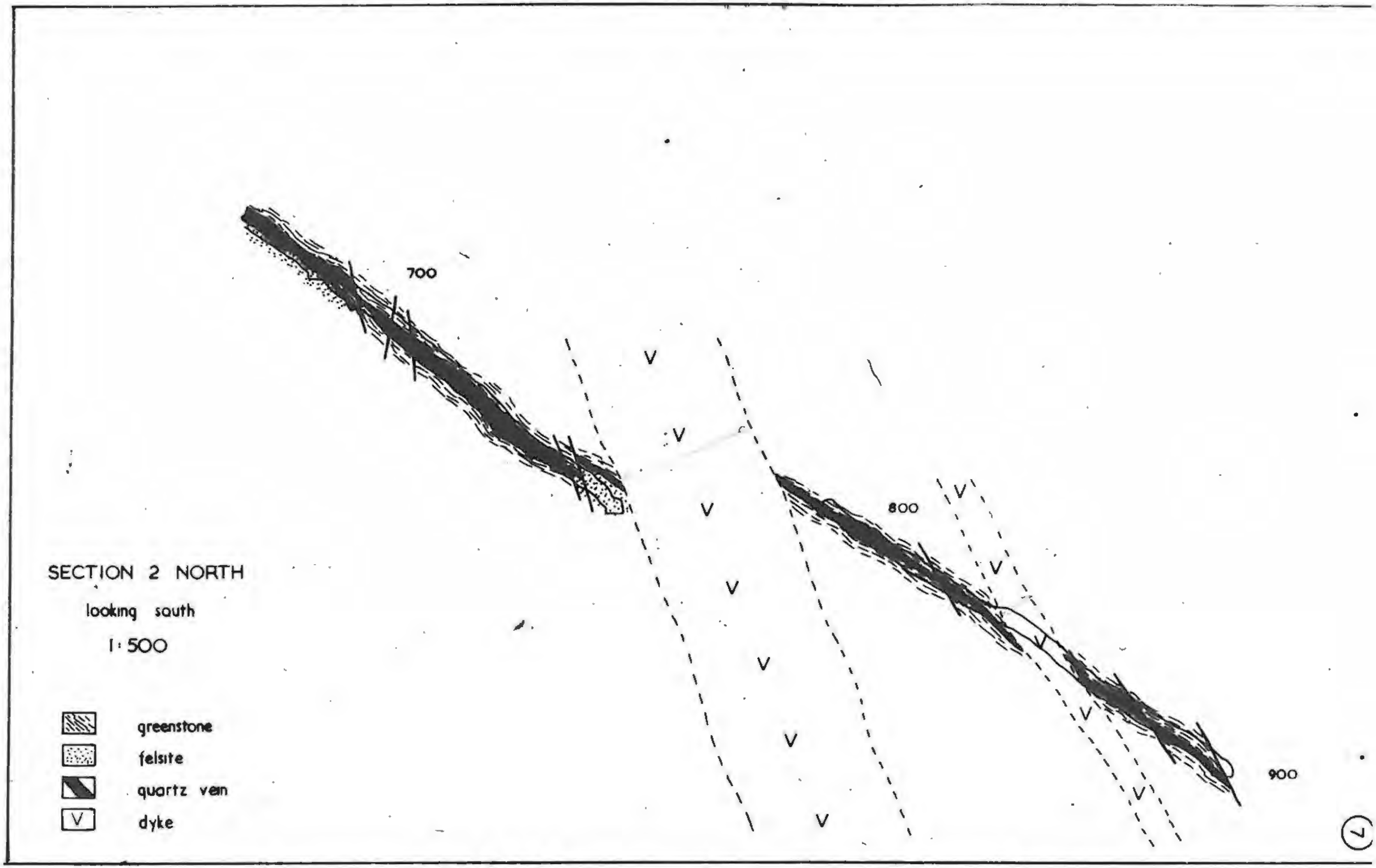


SECTIONAL REPRESENTATION OF VEIN OPENINGS

9

FIGURE SEVEN

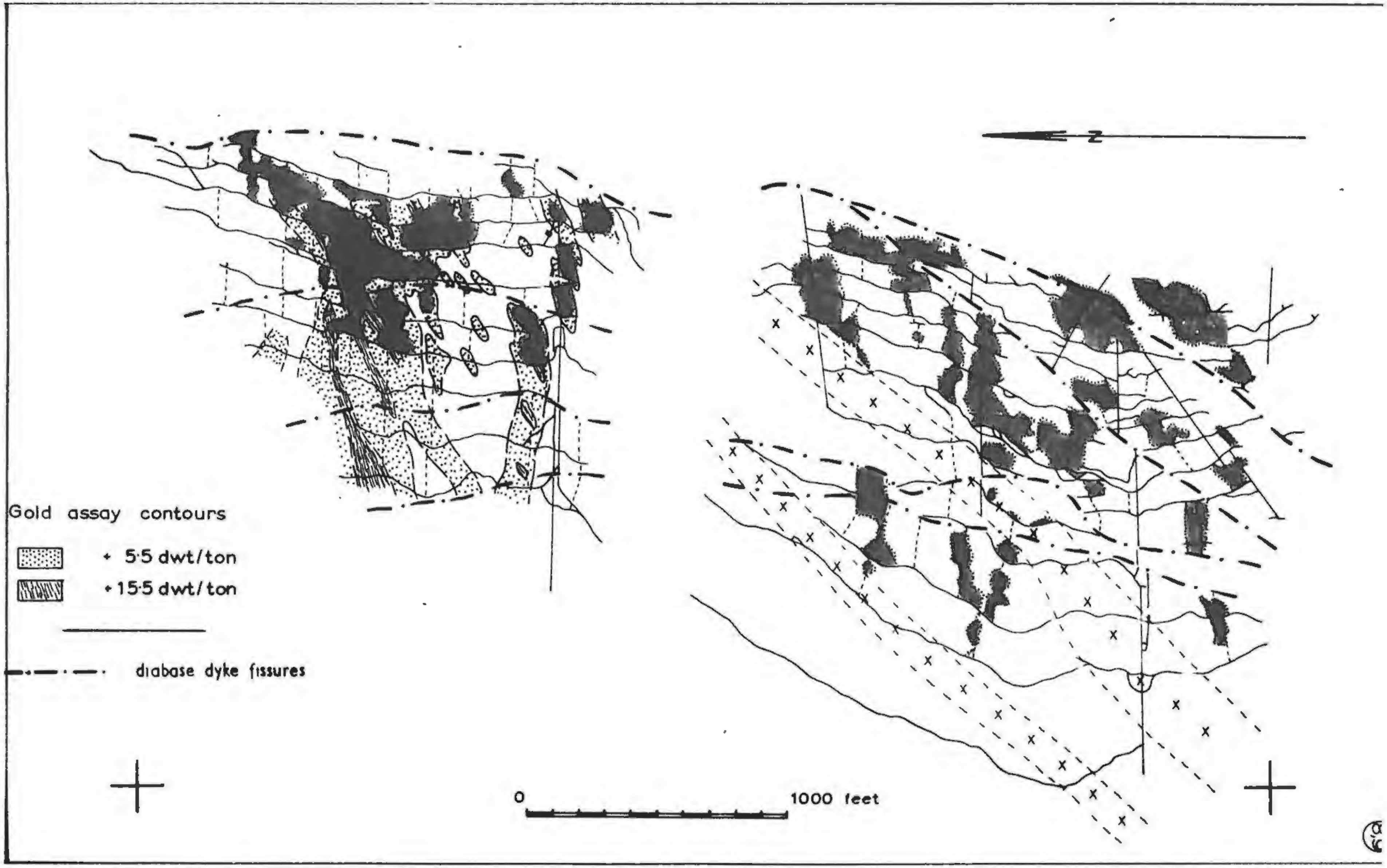
Being a dip-section showing the displacement of the vein caused by the intrusion of dolerite dykes.



700
800
900
SECTION 2 NORTH
looking south
1:500
greenstone
felsite
quartz vein
dyke

FIGURE EIGHT

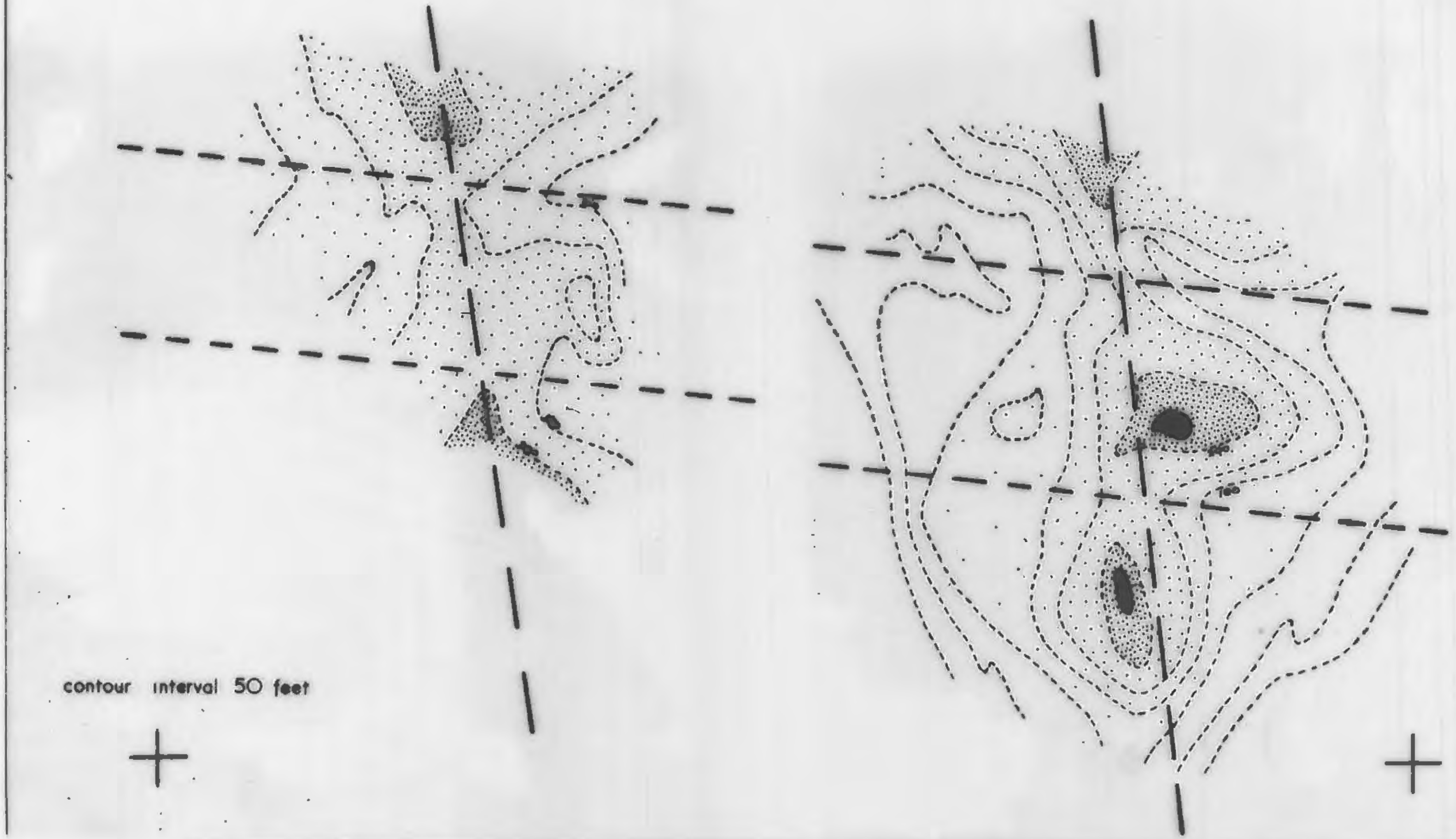
Being a reconstruction of Figure One, after excising the post-mineralisation diabase dykes. The symbol X denotes the apparent position of epidiorite dykes in the southern section of the mine.



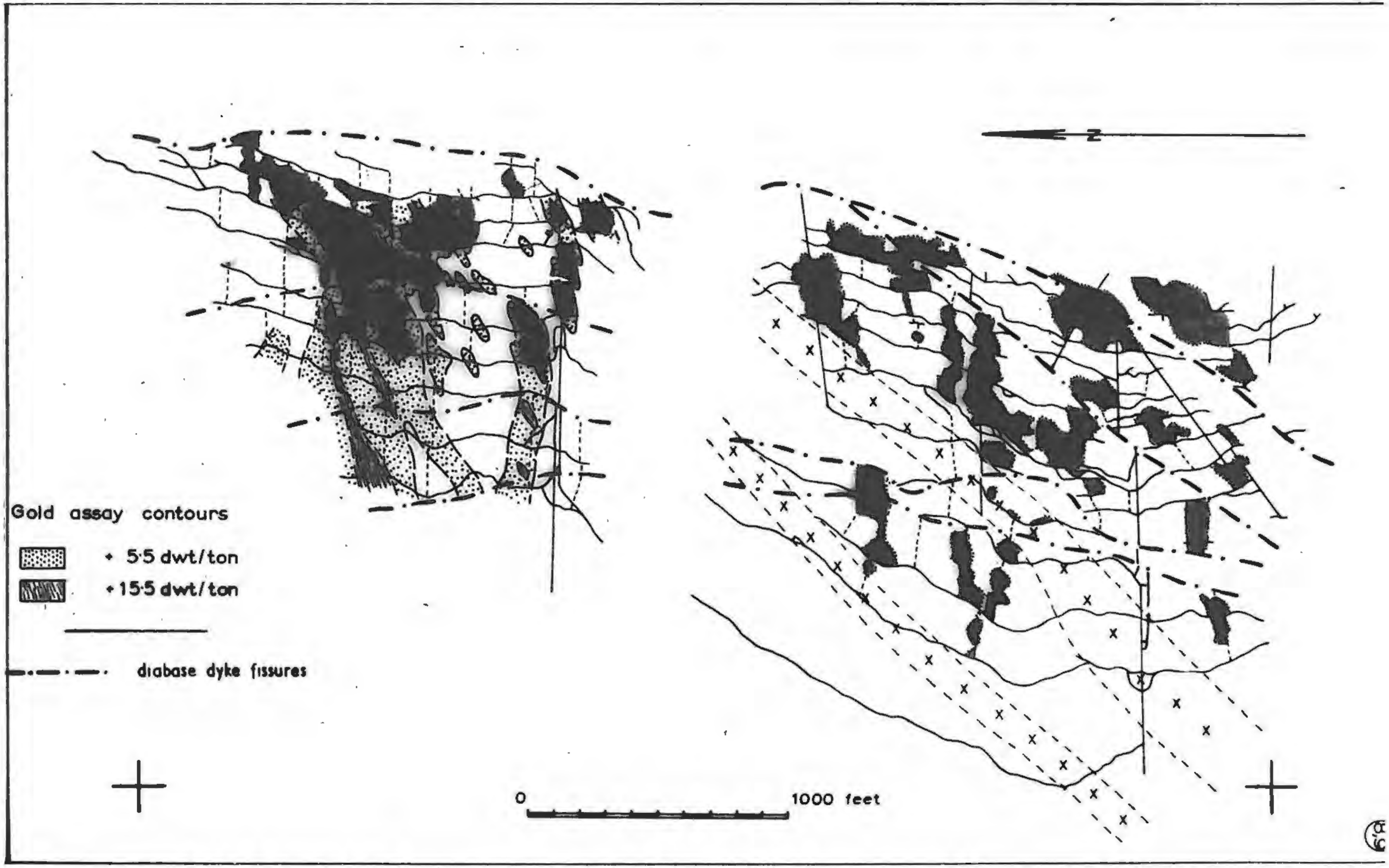
N
Gold assay contours
+ 5·5 dwt/ton
+ 15·5 dwt/ton
diabase dyke fissures
0
1000 feet

FIGURE NINE

Being a Conolly structure contour diagram showing the attitude of the Patchway vein. Note the correlation between the axis of folding affecting the vein in the northern section of the mine and the gold value contours.



9A



Gold assay contours
+ 5·5 dwt/ton
+ 15·5 dwt/ton
diabase dyke fissures
N
0
1000 feet

FIGURE TEN

Being a diagram representing the pattern of the fracturing exposed along the 400-level of the mine.

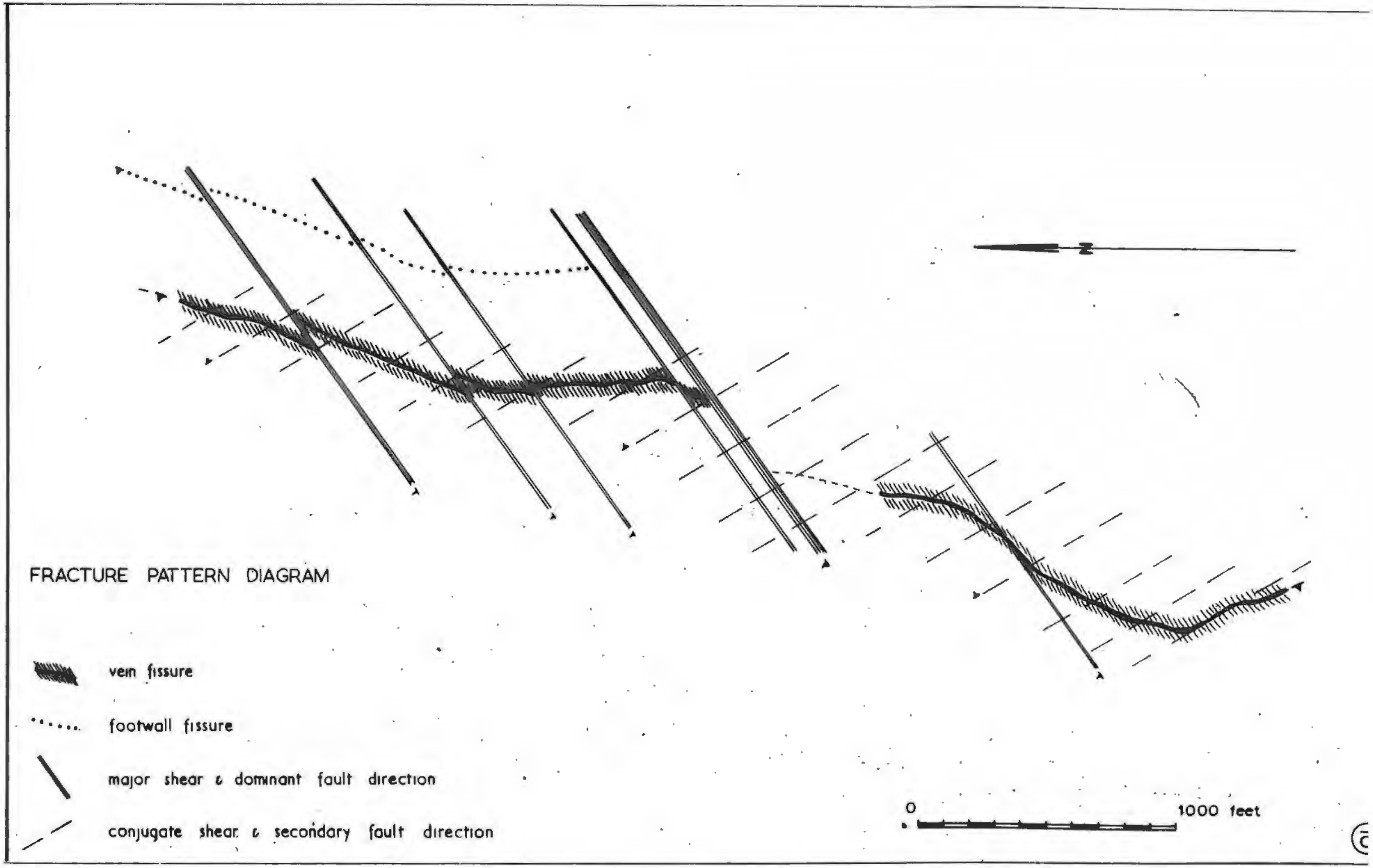
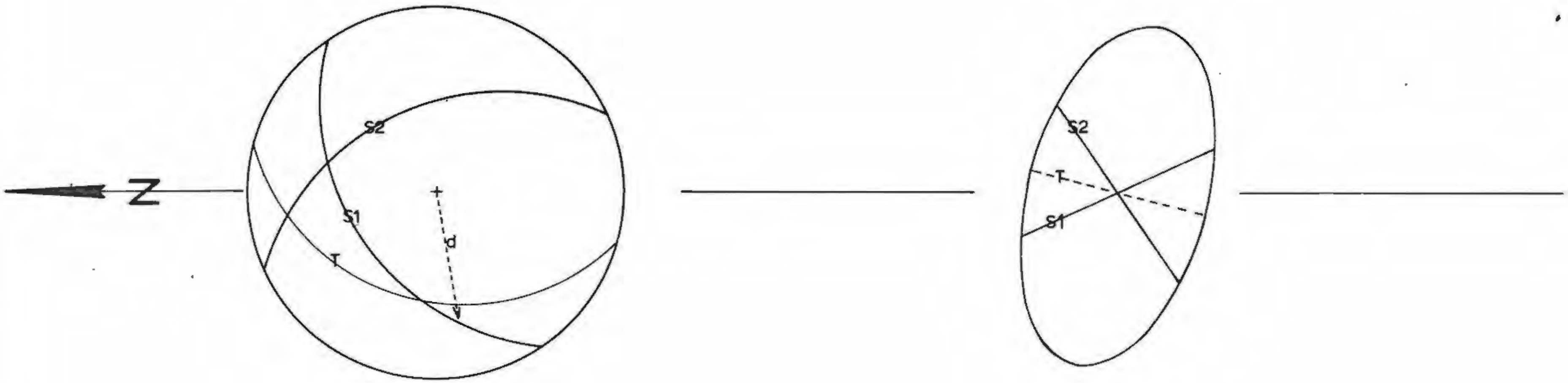

FRACTURE PATTERN DIAGRAM
vein fissure
footwall fissure
major shear & dominant fault direction
conjugate shear & secondary fault direction
0
1000 feet
N

FIGURE ELEVEN

Being a stereographic presentation of the major structural elements exposed in the mine.

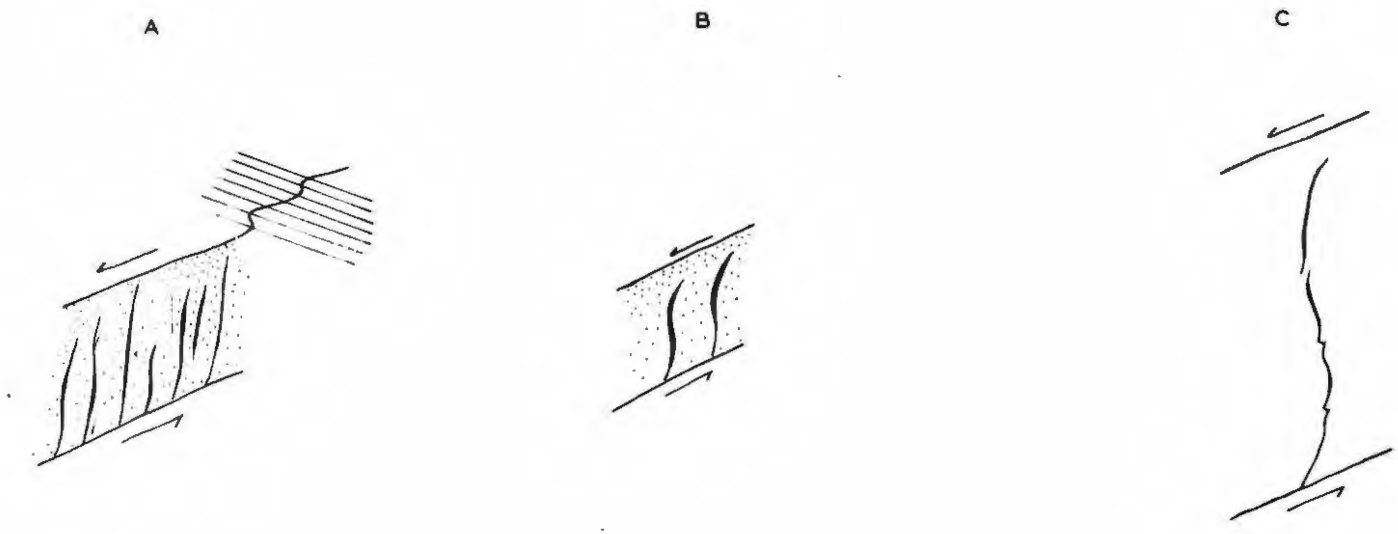


lower hemisphere

		Strike azimuth
S1	primary shear	055°
S2	complementary shear	155°
T	vein fissure	014°
d	axis of anticlinal folding	260°

FIGURE TWELVE

Being an example of the relationship between the development of tension gashes and shearing. Compare this with Figure Ten which displays a remarkably similar relationship.



diagrammatic representation showing probable stress distribution

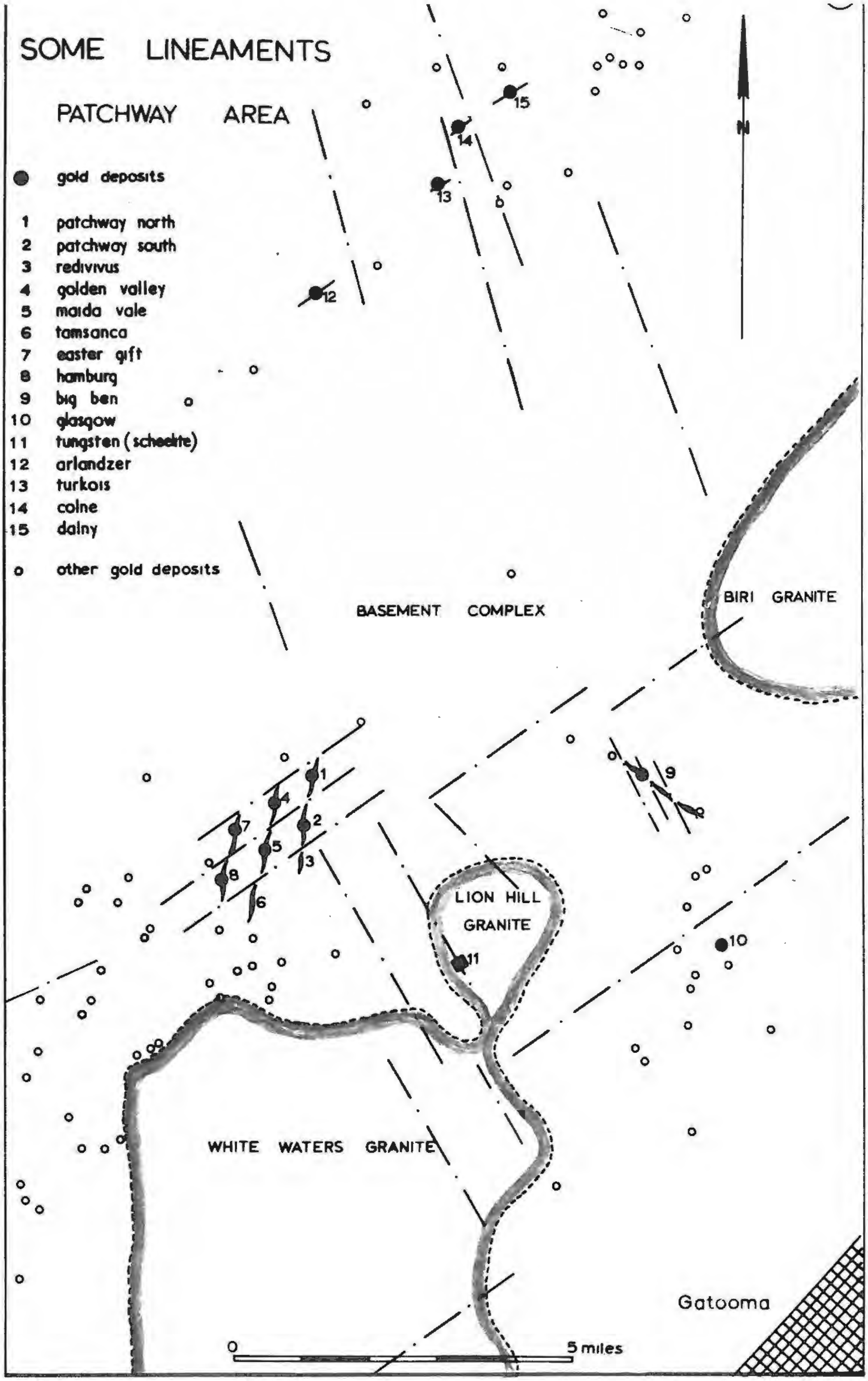
sigmoidal fractures

division of curved tension fractures into smaller sigmoidal gashes

TENSION GASHES IN PSAMMITE (after Roberts)

FIGURE THIRTEEN

Being a regional plan illustrating the relationship between structural lineaments and gold mines in the Golden Valley and Chakari areas of the Gatooma mining district.


SOME LINEAMENTS
PATCHWAY AREA
gold deposits
1 patchway north
2 patchway south
3 redivivus
4 golden valley
5 maida vale
6 tamsanca
7 easter gift
8 hamburg
9 big ben
10 glasgow
11 tungsten (scheelite)
12 arlandzer
13 turkois
14 colne
15 dainy
other gold deposits
N
BASEMENT COMPLEX
BIRI GRANITE
LION HILL GRANITE
WHITE WATERS GRANITE
Gatooma
0
5 miles

3. THE MINERAGRAPHY OF THE PATCHWAY MINE ORE

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3.1 INTRODUCTION

A partial analysis of ore concentrates from the Patchway mine, utilising spectrographic and X-ray techniques, suggests that the ore mineralogy is relatively simple, ~~for~~ the major sulphides in the ore being limited to pyrite, galena, sphalerite, chalcopyrite, and pyrrhotite.

This conclusion has been supported by the examination under the ore microscope of a number of polished sections of the gold-bearing ore. These specimens were subjected to micrometric analysis in an endeavour to obtain quantitative or semi-quantitative statistical data concerning the distribution and manner of occurrence of the gold and sulphides in the ore. Particular attention was paid to the textural relationships between sulphides and gold in the specimens, with a view to determining their paragenesis and to defining any genetic affinity between the gold mineralisation and the deposition of any particular sulphide.

3.2 ANALYSIS OF ORE CONCENTRATES

Ante-cyanidation concentrates of Patchway mine ore were sampled on several occasions during October and November 1967 by removing a portion of the concentrates from the Gallagher strakes table in the mine mill. These samples were bulked to form one composite sample.

A portion of this sample was submitted to the Rhodesian Geological Survey Department in Salisbury for spectrographic analysis. The spectrographer subsequently reported that the concentrate contained the following proportions of nickel, copper, and lead:

0.01 % nickel
0.02 % copper
0.05 % lead

The undermentioned elements were sought but not found: Arsenic, antimony, bismuth, cobalt, mercury, molybdenum, platinum, selenium, tellurium, tungsten and zinc. It is unknown why zinc, which is present in the ore in the form of sphalerite, was not determined.

Another portion of the concentrate was examined by the writer in the following manner. The portion was finely pulverized by hand using an agate pestle and mortar and treated with a powerful magnet to remove any highly magnetic particles. The powder was then separated into five fractions by means of a Frantz Isodynamic Separator, and a portion from each of the five fractions was smeared evenly onto a glass slide, using acetone as a lubricant. The five slides so prepared were examined in turn by means of a Philips X-ray Diffractometer following the procedure outlined in Section 1.2. By this means the following minerals were identified in the concentrate examined:

Quartz
Chlorite
Pyrite
Galena
Sphalerite
Chalcopyrite
Scheelite

Pyrrhotite was not detected in the concentrate by this method of examination, and was no doubt removed when the sample was treated with a powerful magnet.

3.3 MICROMETRIC ANALYSIS OF POLISHED ORE SPECIMENS

Representative specimens of Patchway ore collected from different stopes on all levels of the north ore body between the 250 and 1200-foot horizons were worked up to a fine polish on nylon laps dressed with Norton E266 alumina followed by 3 micron diamond paste.

Of the specimens so prepared, 27 were seen to contain gold and were subjected to the following analysis under the ore microscope at a magnification of 96 x. Each specimen was traversed under the microscope along lines at intervals of 300 microns, and the gold or sulphide observed under the intersection of the ocular cross-hairs at each interval of 300 microns along the individual traverse lines was noted. In other words, the gold or sulphide particles encountered at each intersection point on an imaginary 300 micron grid covering the surface of the specimen were counted. The results of this number-frequency analysis are shown in Table 1, and, in brief, out of a total particle count of 7640 the following proportions were obtained:

Mineral	Percentage	Number-frequency
Pyrite	43.4	3315
Galena	25.3	1934
Sphalerite	9.7	742
Chalcopyrite	8.7	661
Pyrrhotite	1.8	140
Gold	11.1	848
	100.00	7640

At first glance the proportion of gold present in the specimens examined may appear to be disproportionately high, and to put this into perspective it would be well to note that, in the Patchway ore, minerals having a specific gravity greater than 2.88 (bromoform) amount to less than one per cent by weight. This figure is based on the fact that approximately 4 tons of concentrates are recovered by the Gallagher strakes table from a daily auxilliary mill feed of some 40 tons of ore. Therefore the concentrates represent approximately 10% of the mine ore, and when 158 grams of concentrate was treated with bromoform only 14 grams, or 8.9% by weight, remained when the bromoform was decanted. This indicates that minerals in the ore having a specific gravity greater than 2.88 (notably gold, sulphides, and scheelite) amount to only 0.89% by weight of the ore.

To continue this semi-quantitative reasoning in round figures, it is reasonable to state that the total gold and sulphide content of the Patchway ore does not exceed one per cent. From micrometric analysis, the number-frequency proportion of gold in specimens of ore amounts to approximately 10% of the total sulphide and gold content, suggesting that the total gold content of the ore is of the order of 0.1%. Actually this figure is some sixty times greater than the average tenor of the ore which, at a grade of slightly less than half an ounce of gold per ton, contains approximately 0.0017% gold. It must be realised, however, that these specimens were selected for their apparently high gold content, and it is submitted that although they suggest a gold content that is some sixty times greater than the average for the reef as a whole, they are, in fact, typical of highly mineralised portions of the vein.

In appraising these statistics for trends indicating any relationship between the tenor of ore and the extent and nature of sulphide mineralisation, notice was taken of the distribution of gold in the northern section of the Patchway mine. Ore reserve calculations illustrate that high-grade ore invariably is associated with three stopes on any one level in this section of the mine, and that these three stopes are closely associated in space with the axial region of anticlinal flexures in the vein. High-grade stopes in this section of the mine are to be found on profile lines 1, 5, and 6. At the end of June, 1967, stopes on these index lines contained 63.8% of the total ore in reserve with an average gold content of 9.9 dwts/ton, while stopes on the 2, 3, 4, 7, and 8 profile lines contained only 36.2% of the total ore in reserve with an average gold content of 7.6 dwts/ton.

In explaining what is meant by these profile lines, it should be stated that, in plan, the northern section of the mineralised quartz vein, which strikes roughly north-south, is divided into a series of hypothetical west-east trending profile or boundary lines that are positioned approximately 150 feet apart. These profiles are used as an index for mining purposes, and are numbered from 1 to 10 as one proceeds north along any one level from the southern margin of this section of the mine. Raises connecting levels are so positioned as to coincide with these profile lines, and as each raise is the central axis of a potential stope these stopes are numbered according to the relevant profile. Thus the 4 north profile stope on the 400-foot level of the mine is on the same profile line as the 4 north profile stope on the 1000-foot level.

Furthermore, as the structural axis of the north ore body plunges westwards on a bearing of 263^{o}, or just south of west, the 400/4/North stope is in roughly the same position with reference to the margins and centre of the payshoot as is the 1000/4/North stope. That is, in relation to the mineralisation in the mine these two stopes are in virtually the same lateral position although their vertical separation is some 600 feet.

In view of this, polished specimens of ore from the northern section of the mine were classed according to whether they were obtained from the higher- or the lower-grade stopes. The gold and sulphide content of these specimens, determined by micrometric analysis on a number-frequency basis, are tabulated below:

<u>Profiles 2,3,4,7,8</u> - 8 specimens analysed

	Pyrite	Galena	C/pyrite	Sphalerite	Pyrrhotite	TOTAL
No.	163	90	53	339	49	694
%	23.5	13.0	7.6	48.9	7.0	100

<u>Ratio</u>

Gold	:	Sulphides
377	:	694
1	:	1.8

<u>Profiles 1,5,6</u> - 16 specimens analysed

	Pyrite	Galena	C/pyrite	Sphalerite	Pyrrhotite	TOTAL
No.	3142	1828	605	230	91	5896
%	53.3	31.0	10.3	3.9	1.5	100

<u>Ratio</u>

Gold	:	Sulphides
421	:	5896
1	:	14.0

Were these results not so remarkably different the paucity of the data might mitigate against any valid conclusions. However, the fact that an obvious difference in grade can be correlated with such a marked empirical variation in the gold : sulphides ratio, which varies from 1 : 14.0 in specimens from high-grade stopes to 1 : 1.8 in specimens from lower grade stopes, suggests that such a correlation is significant. Also, specimens from lower-grade stopes are characterised by a greater percentage of sulphides which commonly crystallise earlier, in para-genetic order, than galena. In other words, in the specimens from the lower-grade stopes, pyrrhotite, sphalerite, and chalcopyrite amount to 63.5% of the total sulphide particles counted, whereas in specimens from high-grade stopes these particular sulphides amount to only 15.7% It will be noted that the total gold content of the specimens from the lower-grade stopes appears to be greater than that of the high-grade specimens, the former giving a particle count of 377 for 8 specimens and the latter a particle count of 421 for 16 specimens. Subjective support for the validity of the observation that high-grade ore is characterised by a lower gold : sulphides ratio than low-grade ore is obtained from the Patchway miners' rule-of-thumb that extensive visible sulphide mineralisation in the reef is indicative of high-grade ore.

The same specimens were subjected to a second analysis in an endeavour to elucidate the relative proportions of different classes of gold particle size in the ore, and to determine whether there is any genetic affinity between gold and a particular sulphide. To this end the specimens were again examined under the ore microscope at a magnification of 96 x along traverse lines at intervals of 300 microns. Each particle of gold encountered along these traverses was noted and categorised, somewhat subjectively, into one of four classes of grain size. The results of this analysis are shown in Table 11, and in short, the following distribution pattern emerged for the 4022 particles of gold which were measured:

Grain Size	Percentage	Number-frequency
+ 250 microns	3.1	122
+ 75 microns	13.2	532
+ 50 microns	11.0	444
- 50 microns	72.7	2924
	100.0	4022

Expressing this differently, one may state that 72.7% of the gold particles counted were found to be - 325 B.S. mesh ($\doteqdot$ 50 microns) in size, indicating that the bulk of the gold in the Patchway vein is fine-grained.

During this examination the association of each gold particle or veinlet in relation to quartz or sulphides was noted, and it was found that out of a total count of 4022 gold particles only 459, or 11.3%, occur either touching or enclosed in sulphides. Of these, 5.3% occur either touching or enclosed in pyrite, 2.6% are associated with galena, 1.8% with sphalerite, 0.9% with pyrrhotite, and 0.7% occur either touching or enclosed in chalcopyrite. It will be noted that this order of association closely approximates the measured order of abundance of these sulphides in the vein quartz.

To summarise the salient features of this analysis:

(a) High-grade ore appears to be characterised by a lower gold : sulphides ratio than low-grade ore.

(b) The dominant sulphides in specimens of lower-grade ore are pyrrhotite, sphalerite, and chalcopyrite. Galena and pyrite predominate in specimens of high-grade ore.

(c) 88.7% of the gold particles counted occur as discrete grains or veinlets in quartz.

(d) More than 70% of the gold particles examined were found to be less than 325 B.S. mesh in size.

TABLE I

MICROMETRIC ANALYSIS OF GOLD AND SULPHIDES

The specimens measured are polished sections of the mine ore. They are indexed in order of the horizon in the mine and the profile of the stope whence they were collected. For example, the indices 320/5/1 are an abbreviation for the 320-foot level, 5 north stope profile, 1st specimen prepared from this horizon. The numerals listed under the various minerals are number-frequency data obtained by micrometric analysis.

Specimen	Pyt	Gal	Cpy	Spl	Pho	Gold	TOTAL
320/3/3	1	Tr	3	Tr	27	14	45
320/5/1	113	14	29	3	Tr	12	171
320/5/2	7	2	7	Tr	0	13	29
400/4/1	16	Tr	3	35	0	92	146
400/8/3	30	0	2	0	Tr	33	65
400/8/4	26	Tr	0	0	Tr	65	91
400/8/1s	67	0	Tr	0	Tr	39	106
500/4/2	14	33	16	126	1	44	234
500/6/1	55	1	19	15	Tr	69	159
500/6/4	1143	Tr	Tr	0	Tr	44	1187
500/7/3	1	0	0	0	0	36	37
500/4/1s	8	57	27	178	21	76	367
600/6/1	1	2	3	9	1	3	19
600/6/2	0	1	Tr	0	0	70	71
700/2/2	0	Tr	2	0	0	14	16
700/6/1	68	100	125	Tr	31	2	326
700/6/3	729	27	4	57	1	17	835
800/1/1	329	321	Tr	0	Tr	Tr	649
800/5/2	18	385	392	85	Tr	6	886
800/5/3	2	5	0	0	0	107	114
800/DN/4	5	2	0	0	0	9	16
900/1/1	422	222	0	11	0	Tr	656
1000/5/1	11	164	22	0	0	Tr	198
1000/5/2	4	0	0	0	0	67	71
1100/5/1	238	583	4	50	58	Tr	935
1100/DN/4	5	14	3	173	Tr	5	200
1100/5/5	2	1	Tr	0	0	11	14
TOTAL NO.	3315	1934	661	742	140	848	7640
PERCENT.	43.4	25.3	8.7	9.7	1.8	11.1	100.0

TABLE 11

MICROMETRIC ANALYSIS OF GOLD GRAIN-SIZE & DISTRIBUTION

Specimen	Grain-Size Class +250u	+75u	+50u	-50u	TOTAL	Grains Touching or Enclosed in Pyt	Gal	Cpy	Spl	Pho	
320/3/3	-	-	14	36	50	-	-	-	-	4	
320/5/1	-	-	1	61	62	3	5	1	-	-	
320/5/2	-	-	2	34	36	3	1	-	-	-	
400/4/1	19	34	53	491	597	8	-	-	18	-	
400/8/3	14	26	21	171	232	3	-	2	-	3	
400/8/4	13	31	41	333	418	14	-	-	-	-	
400/8/S/1	1	24	25	80	130	15	-	1	-	1	
500/4/2	12	42	43	169	266	9	22	-	21	3	
500/6/1	17	33	26	177	253	4	4	10	1	-	
500/6/4	-	3	7	86	96	79	-	-	-	-	
500/7/3	1	3	13	147	164	-	-	-	-	-	
500/4/S/1	12	80	35	93	220	4	35	11	23	14	
600/6/1	-	1	3	15	19	-	3	-	-	1	
600/6/2	10	54	35	491	590	-	2	-	-	-	
700/2/2	-	16	17	30	63	-	-	-	-	-	
700/6/1	-	3	-	2	5	-	2	3	-	-	
700/6/3	-	4	8	75	87	50	9	1	1	1	
800/1/1	-	1	-	3	4	1	1	-	-	-	
800/5/2	2	7	2	7	18	-	9	8	5	-	
800/5/3	2	91	54	209	356	4	6	-	-	-	
800/DN/4	1	5	7	28	41	3	1	-	-	-	
900/1/1	-	2	-	5	7	1	3	-	-	-	
1000/5/1	-	-	-	1	1	-	-	-	-	-	
1000/5/2	18	45	14	82	159	8	-	-	-	-	
1100/5/1	-	-	-	2	2	2	-	-	-	-	
1100/DN/4	-	3	9	59	71	2	1	-	4	-	
1100/5/5	-	24	14	37	75	3	2	1	-	-	
TOTAL NO.	122	532	444	2924	4022	215	106	38	73	27	TOTAL 459
%	3	13	11	73	100	5.3	2.6	0.7	1.8	0.9	11.3%

3.4 DESCRIPTION OF POLISHED ORE SPECIMENS

1. GANGUE

Hydrothermal quartz constitutes the bulk of the gangue filling the Patchway vein, and typically varies in colour between white, grey and blue-grey. In portions of the vein that contain economic concentrations of gold the quartz appears translucent and either white, grey or blue-grey in colour, whereas in unpayable sections of the vein the quartz is generally white and milky in appearance. On approaching the contact of a younger intrusive the quartz becomes white and saccharoidal in appearance, indicating a degree of recrystallisation.

Under the microscope, specimens of quartz from payable portions of the vein are seen to be full of myriads of minute inclusions and vacuoles, and to vary in size from microcrystalline granules up to allotriomorphic grains measuring 6 mm or more across. The larger crystals exhibit undulose or strained extinction when examined between crossed-nicols. Much of the finer-grained material appears to have been recrystallised, and granoblastic aggregates of microcrystalline quartz are commonly associated with younger chlorite-carbonate veinlets which transgress and partly replace the quartz host.

These transgressive chlorite-carbonate veinlets, which vary in width from less than 5 microns to more than 1 cm, are ubiquitous in mineralised quartz and can be seen to be genetically associated with the introduction of sulphides and gold.

11 OXIDES & OXYGEN SALTS

(a) Scheelite:

Irregular crystalline aggregates, blebs and stringers of scheelite are commonly found in the vein quartz. These patches are sometimes as large as 5 cm across and are generally to be found close to the upper or hangingwall margin of the vein.

In polished section (sp. 250/7/1) coarsely crystalline scheelite can be seen to be veined by younger chlorite-carbonate veinlets in which are included particles of chalcopyrite and galena. In thin section (sp. 400/8/TS/3 & 4) the transgressive relationship of these younger chlorite-carbonate veinlets to crystalline scheelite is clearly displayed.

Further evidence that these chlorite-carbonate veinlets, which effervesce vigourously on being treated with dilute hydrochloric acid, are genetically associated with a major phase of sulphide mineralisation will be presented. Suffice it to comment at this stage that the scheelite mineralisation is either contemporaneous with, or slightly post-dates, the introduction of the gangue quartz, and definitely ante-dates the main phase of sulphide mineralisation.

(b) Ilmeno-magnetite:

In one specimen (sp. 500/6/1) several highly corroded crystals measuring up to 1.5 mm across of what appear to have been ilmeno-magnetite were observed within a younger chlorite-carbonate veinlet. These crystals are now represented by oriented skeletal lamellae reminiscent of ilmenite that has been largely replaced by leucoxene, which in fact they may be. In part these skeletal relict crystals have been replaced by pyrite.

Similar pseudomorphs were observed in the epidiorite or quartz dolerite dykes described in the introductory section, so it is conceivable that those found in the chlorite-carbonate veinlet may have been scavenged from an epidiorite host. Alternatively they may represent a stage of oxide mineralisation earlier in paragenesis than the main phase of sulphide mineralisation, and associated in time with the introduction of scheelite into the vein quartz.

111 SULPHIDES

(c) Pyrite:

This sulphide occurs as idiomorphic crystals up to 4 mm square and as disseminated clusters and specks in both the vein quartz and the adjacent carbonated host rock. The development of pyrite is most conspicuous in the host rock within six inches of the vein, and in ribbon-like inclusions of the host within the vein quartz. As a generalisation, underground sampling reveals that pyritic host rock marginal to the vein commonly carries an economic concentration of gold which may or may not be intimately related to the pyrite mineralisation.

A micrometric analysis, designed to determine the relative proportions of gold and sulphides in polished specimens of the Patchway ore, showed that pyrite amounted to 43.4% of the sulphide particles counted. This information, coupled with underground observations, permit the generalisation that in the Patchway mine pyrite is the dominant sulphide.

Examination of the pyrite in a number of polished specimens of Patchway vein material under the ore microscope shows that there are at least two ages of pyrite mineralisation. The earlier phase is represented by euhedral to subhedral pyrite crystals, while the younger pyrite occurs as tiny veinlets or allotriomorphic granules. The early pyrite is partly replaced by tiny blebs, ranging in size from less than 5 to greater than 50 microns, of pyrrhotite, sphalerite, chalcopyrite, galena and gold (sp. 500/6/4). This age of pyrite has been shattered and later veined by the same minerals that form replacement blebs (sp. 500/6/4, 700/6/3), or can be seen to have been replaced marginally by these minerals (sp. 1100/5/1, 1200/DN/1).

In habit the early pyrite may vary from euhedral cubes to subhedral forms which display striated faces due to the partial development of pyritohedral faces (sp. 800/1/1). Pyrite displaying a rhombic cross-section was observed in two specimens (sp. 600/2/4, 800/1/1), and zoned subhedral pyrite was observed in one specimen (sp. 700/6/1) in which fragments of quartz and tiny spherical inclusions are arranged in layers parallel to faces of the form (100). Early pyrite replaces quartz and is veined by younger quartz (sp. 500/6/4). It may be seen fragmented and veined by comparatively soft chlorite-carbonate veinlets (sp. 320/5/1) which are intimately associated in space with galena (sp. 800/1/1) and with a younger period of pyrite mineralisation (sp. 800/5/2). Older pyrite may be seen veined by this younger pyrite (sp. 1100/5/1) and partly replaced by it (sp. 500/6/4). These younger pyrite veinlets also surround and replace pyrrhotite and sphalerite (sp. 600/2/4), and in one specimen a veinlet of younger pyrite transgresses crystalline sphalerite and is intimately associated in space with gold (sp. 1200/DN/1)

Summary:

Early euhedral to subhedral pyrite which replaces quartz is, in turn, replaced by younger quartz, pyrrhotite, sphalerite, chalcopyrite, galena, gold, pyrite and veinlets of chlorite-carbonate. The late-stage pyrite appears to be associated with chlorite-carbonate veinlets which accompany the introduction of galena and gold.

(d) Pyrrhotite:

In underground exposures massive and disseminated pyrrhotite may sometimes be observed in the vein quartz. Compared to the other sulphides, pyrrhotite is a relatively rare constituent although it has been observed in aggregates measuring 2cm x 1cm. Under the microscope pyrrhotite may be seen to be replaced by galena and gold (sp.500/4/1s). Replacement by galena may be extensive (sp.1100/5/1), while replacement by chalcopyrite is less evident (sp. 700/6/1). Sphalerite can be seen to contain angular fragments of pyrrhotite which it appears to have replaced. In another specimen (sp. 600/2/4) a vermiform intergrowth of pyrrhotite and sphalerite may be seen surrounding early pyrite. This complex intergrowth is, in turn, rimmed by younger pyrite. Prominent basal parting in pyrrhotite is evident in one specimen (sp. 700/6/1) and penetration or replacement of the quartz host appears, in part, to have been preferentially directed parallel to this crystallographic direction.

In two specimens (sp. 600/2/4, 1200/DN/1) tiny cubes, measuring 10 microns across, and blebs of a pale cream-coloured isotropic sulphide were seen entirely enclosed within individual hexagonal crystals of pyrrhotite or interstitial to contiguous crystals. These inclusions are softer than pyrrhotite, and some of them at any rate are probably pentlandite, thus accounting for the 0.01% nickel content of ore concentrates determined spectrographically.

Summary:

Pyrrhotite, sphalerite and chalcopyrite are essentially part of the same mineralisation phase, although pyrrhotite is replaced by both sphalerite and chalcopyrite. Pyrrhotite is also replaced by galena and, in turn, has replaced earlier pyrite. In paragenesis it appears to be intermediate between early pyrite and younger sphalerite.

(e) Sphalerite:

Small patches of dark-brown sphalerite may sometimes be seen in the vein quartz in both payable and unpayable areas of the mine, and this sulphide has also been observed as a veinlet, 3 mm wide, following a ribbon-like inclusion of chlorite-carbonate schist in the quartz. In transmitted light the sphalerite varies in colour between a deep reddish brown and a paler rosin tint, and may be observed both veining and replacing quartz gangue. Under the ore microscope blebs of chalcopyrite, varying in size from 20 microns to less than 5 microns across, are ubiquitous in sphalerite (sp. 1100/DN/4).

Sphalerite veins and replaces earlier euhedral or subhedral pyrite (sp. 700/6/1) and may be seen as replacement blebs less than 10 microns across within this pyrite (sp. 400/4/1, 500/6/4). Sphalerite veinlets in pyrite have been partially replaced by galena and gold (sp. 700/6/1), while sphalerite can generally be seen to have been replaced by chalcopyrite (sp. 500/4/1s) and by galena and gold (sp. 1100/DN/4). Early pyrite, apart from being veined and replaced by sphalerite can also be observed surrounded by this sulphide which is, in turn, rimmed by chalcopyrite (sp.1200/DN/1). Some sphalerite crystals have been veined by younger pyrite associated with tiny chlorite-carbonate stringers which appear to have re-mobilised part of the sphalerite (sp. 500/4/2, 400/4/1), however, in other specimens (sp.400/4/1s, 400/8/4) sphalerite can be seen streaming away from chlorite-carbonate veinlets which appear to have introduced this sulphide into the quartz.

Summary:

Sphalerite is younger than pyrrhotite and some pyrite, and is veined and replaced by later chalcopyrite, galena, gold and pyrite.

(f) Chalcopyrite:

Massive chalcopyrite in aggregates measuring 2 cm across may on occasions be seen in the Patchway vein quartz; it has also been observed to constitute the core of a patch of coarsely crystalline galena. Examination of polished specimens of ore under the microscope reveals that this sulphide occurs as veinlets and discrete replacement aggregates within the host quartz, and as exsolution blebs in sphalerite as well as intergrowths with other sulphides. Chalcopyrite may be seen moulded onto and partly replacing subhedral pyrite (sp. 800/5/2), and associated in space with sphalerite, may be observed as tiny veinlets filling fractures in euhedral pyrite (sp. 700/6/1). Chalcopyrite may also be seen as ovoid replacement blebs 100 microns in length within earlier pyrite (sp. 320/5/1).

This sulphide occurs in association with pyrrhotite in veinlets which corrode or partially replace sphalerite (sp. 500/4/1s) and, in turn, can be observed surrounding and transecting grains of pyrrhotite (sp. 700/6/1). Chalcopyrite is extensively replaced by galena and gold (sp. 500/6/4, 800/5/2) and, in one specimen, tiny rods measuring 20 microns by 4 microns of a pinkish brown isotropic sulphide are developed in chalcopyrite near replacing galena. This unidentified mineral may be bornite (sp. 700/6/1). Minor amounts of chalcopyrite also appear to be associated with galena in later chlorite-carbonate veinlets (sp. 600/6/1), which association may have resulted from the remobilisation of chalcopyrite replaced by galena.

Summary:

Chalcopyrite replaces pyrite, pyrrhotite and sphalerite, and is replaced by galena and gold.

(g) Galena:

Coarsely crystalline galena is commonly observed in vein quartz in high-grade stopes, but more often this sulphide occurs as disseminated blebs and stars filling minute fractures in the quartz. Under the ore microscope it is evident that galena crystallised later than the bulk of the pyrite in the specimens examined. Euhedral to subhedral pyrite crystals can be seen surrounded, replaced and veined by galena (sp. 700/6/1, 900/1/1, 1100/5/1). Some galena occurs as tiny ovoid replacement blebs within pyrite crystals (sp. 800/1/1). Pyrrhotite, sphalerite and chalcopyrite are all surrounded and replaced by galena, which corrodes the latter most extensively (sp. 500/4/1s, 700/6/1, 800/5/2).

Galena appears to be closely associated in both space and time with some of the gold mineralisation (sp. 700/6/1), and tiny transgressive veinlets of galena in pyrite commonly contain gold (sp. 800/1/1, 900/1/1). The phase of mineralisation, involving the introduction of galena and some gold, appears to be intimately associated with cholorite-carbonate veinlets which in part exhibit a contemporaneous relationship with galena and in part a transgressive relationship (sp. 800/5/2, 100/5/1). Tiny angular or subhedral particles of gold may be seen contained within these chlorite-carbonate veinlets which are also associated with a later phase of pyrite crystallisation. Younger pyrite may be seen replacing earlier chalcopyrite along cleavage planes (sp. 800/5/2) and is closely associated in space with some of the gold mineralisation. In distinction to the earlier phase of crystallisation of pyrite, which is extensively replaced and veined by galena, later pyrite is not replaced by any other sulphide.

The overall impression is that during the early stage of crystallisation of galena this sulphide corroded and replaced pyrite extensively, the displaced FeS_2 being subsequently precipitated as a younger phase of pyrite in the later stages of crystallisation. This may apply equally well to the replacement of other sulphides, notably chalcopyrite, by galena.

Summary:

Galena veins and replaces pyrite, pyrrhotite, sphalerite, chalcopyrite, and would seem to have crystallised later than these sulphides. In age of crystallisation it would appear to have been contemporaneous or very slightly earlier than some gold and the late-stage pyrite.

(h) Unidentified minor sulphides:

Unknown A

This is the pale cream-coloured isotropic mineral which occurs as tiny cubes and blebs within pyrrhotite. This may be pentlandite in part (sp. 600/2/4, 1200/DN/1).

Unknown B

Another pale cream-white isotropic to very weakly anisotropic sulphide occurs as tiny blebs in galena, and may be argentite (sp.900/1/1, 1100/5/1).

Unknown C

Slightly larger and more rounded particles of green-grey mineral also occur in galena. These are markedly anisotropic, with polarisation colours varying from orange to purple controlled by fine polysynthetic twinning. This sulphide may be bournonite (sp. 700/6/1).

Unknown D

Minute rods of a pink-brown isotropic sulphide are sometimes seen in chalcopyrite near replacing galena. This mineral may be bornite (sp. 700/6/1).

IV GOLD

The average gold content of ore in reserve at the end of June 1967 was just less than 0.5 troy ounces per ton of ore. A micrometric analysis of a number of polished specimens of ore from the Patchway mine has revealed that more than 80% of the microscopically visible gold grains and veinlets occur discrete in the quartz gangue. The bulk of the gold that appears to be intimately associated with sulphides occurs either replacing and exsolved from pyrite or intergrown with galena.

In pyrite, gold may occur as ovoid replacement blebs, some measuring less than 5 microns across, or as irregular lamellae that appear to be oriented along (100) crystallographic directions (sp. 500/6/4, 400/4/1). Gold also occurs filling microscopic fractures within idiomorphic pyrite, and in this manner may be associated with sphalerite (sp. 700/6/3) or with galena (sp. 700/6/1) in veinlets which are less than 20 microns in width. Occasionally gold may be seen in contact with pyrrhotite (sp. 400/8/3, 500/4/1s) but has not been observed enclosed by this sulphide. Some gold replaces both sphalerite and chalcopyrite (sp. 400/4/1, 1100/DN/4).

Other specimens demonstrate a close genetic relationship between the introduction of gold and veining of the quartz by a pyritic chlorite-carbonate phase of mineralisation (sp. 400/4/2s, 400/8/4). Here a mosaic of recrystallised hydrothermal quartz is intruded by a chlorite-carbonate stringer, which is Icm in width, in which euhedral to subhedral pyrite crystals are associated with 'flame' quartz suggesting crystallisation in situ. On one side of the veinlet a peripheral concentration of hypidiomorphic-granular pyrite is associated in space with crystalline sphalerite which continues as veinlets and tiny replacement bodies for some distance into the quartz host. Some gold is associated with this sphalerite, generally, however, the gold has crystallised further away from the chlorite-carbonate veinlet than sphalerite. In this fashion gold can be seen occupying tiny fractures in the quartz and appears to be associated with the development of chlorite in the same veinlets. Much of the gold replaces quartz and exhibits pronounced caries texture. In another polished section gold appears to be spatially associated with sphalerite, which it replaces (sp. 400/4/1), and in yet another gold appears to be associated with both sphalerite and chalcopyrite (sp. 500/6/1). In pyrite too, replacement blebs of sphalerite have been observed rimmed by gold (sp. 700/6/3).

In other specimens veinlets of chlorite-carbonate, with which are associated microscopic stringers of pyrite, appear to be related to the introduction of a galena and gold phase of mineralisation that is younger in age than the crystallisation of sphalerite (sp. 500/4/2, 600/6/2). These galena-bearing chlorite-carbonate veinlets can be seen transecting sphalerite which is also replaced by gold (sp. 700/6/3). Microscopic gold occurs intimately associated with galena in allotriomorphic-granular pyrite which replaces chalcopyrite (sp. 800/5/2). In the same polished specimen gold may be observed as minute angular or subhedral particles in chlorite-carbonate stringers that vein both chalcopyrite and galena. Veinlets of gold and galena commonly occur filling fractures in quartz which are less than 50 microns in width.

The bulk of the gold mineralisation in the Patchway ore appears to have crystallised as discrete veinlets, granules and replacement patches in hydrothermal quartz. In specimens containing abundant visible gold, artificial leaching of the silica by hydrofluoric acid shows that the gold structure is analogous to that of a sponge surrounding tiny fracture cells of quartz. Under the ore microscope these anastomosing veinlets of gold are frequently associated with chlorite-carbonate stringers, and in specimens where the gold is extremely abundant replacement bodies of gold have been observed as large as 1000 microns by 250 microns (sp. 800/5/3). Gold has been noted as discrete granules associated with a narrow chlorite-carbonate stringer in greenstone. In a specimen of pyritic greenstone, collected some three inches from the hangingwall margin of the quartz vein, (sp. 800/4/5) gold mineralisation can be seen to replace both greenstone and pyrite, and to be associated in space with minor amounts of sphalerite, chalcopyrite and galena.

Summary:

The majority of the gold in the Patchway ore evidences no obvious affinity with sulphide mineralisation except in so far as both the gold and sulphide mineralisation appears to have been introduced into the vein quartz by chlorite-carbonate veinlets. The minor proportion of gold that is in spatial association with sulphides appears in part to replace all the sulphides, and in part to exhibit a closer genetic association with pyrite, sphalerite and galena than with pyrrhotite and chalcopyrite.

Although there is known to be a wide variation in the fineness of gold in the Patchway ore (see section 4), careful scrutiny of both the colour and reflectivity of gold in different specimens and in association with different sulphides failed to provide any clue to the exact nature of this variation in the composition of the gold alloy.

3.5 PARAGENESIS

A critical examination of polished specimens of ore from the Patchway mine suggests that the material filling the mineralised fissure may have been introduced in two phases. During the earlier of the two phases the fissure was invaded by hydrothermal quartz together with scheelite and, possibly, ilmeno-magnetite. It is suggested that this phase was pulsatory in character, thus explaining the inclusion of ribbon-like portions of the greenstone host within the vein quartz, these representing former frozen contacts between different pulses of hydrothermal silica. During the later phase this consolidated hydrothermal quartz was fractured and invaded by a sulphide- and gold-bearing chlorite-carbonate stage of mineralisation. Pyrite was the first sulphide to crystallise during this phase, followed by pyrrhotite and sphalerite, and slightly later, chalcopyrite. All these sulphides are replaced by galena and late-stage pyrite which appear to have been the youngest sulphides in the crystallisation sequence.

The association of the crystallisation of gold with the sulphide paragenesis is not so clear. However, from the specimens examined it would appear that some of the gold crystallised contemporaneously with the early pyrite and with sphalerite, while most of the gold appears to have crystallised either contemporaneously with, or slightly later than, galena.

It is interesting to note that the gold mineralisation in the lower-grade stopes of the northern section of the Patchway mine is associated with a higher percentage of pyrrhotite, sphalerite and chalcopyrite than of galena, whereas in the higher-grade stopes the reverse is true. The inference may be drawn that there is some relationship between the structure of the vein fissure and the order of deposition of sulphides and gold, there being a concentration of galena, pyrite and gold of comparatively late deposition along the axial or low-pressure region of anticlinal flexures in the fissure. Lower-grade ore associated with sulphides which crystallised earlier in the paragenesis characterises the more regular or less distorted sections of the vein.

3.6 CONCLUDING DISCUSSION

Phaup (28, 1964) has generalised that in some Rhodesian gold mines the quartz veins are of composite nature and contain at least two or three generations of quartz, and a sequence of sulphide minerals. Observations made in the Patchway mine suggest that the vein quartz is composite in nature and appears to have been introduced in a series of penecontemporaneous pulses, followed by post-consolidation fracturing and the introduction of a generation of chlorite-carbonate veinlets and associated gold and sulphide mineralisation.

In describing the host minerals of native gold, Schwartz (31, 1944) made the observation that in the Battle-Branch mine, Georgia, the final mineralising phase was represented by the introduction of a chlorite-gold stage with contemporaneous deposition of galena. Commenting on mineralisation in the Homestake mine, Schwartz pointed out that visible gold is often found in chlorite near the vein quartz, and in the Red Lake area native gold occurs along fractures in quartz where chlorite has also crystallised. Citing Frohberg, Schwartz also pointed out that native gold in the Michipicoten district is almost invariably associated with a late generation of calcite which occurs as carbonate-feldspar veinlets.

Mines in the Hollinger district, where scheelite veins are related to porphyry intrusives, have been described by Allen and Folinsbee (1, 1944) who stated that the introduction of quartz, carbonate (ankerite), pyrite, and gold occured as a second wave of mineralisation following the consolidation and fracturing of an earlier scheelite and quartz phase. Coleman (5, 1957), in a description of the Giant Yellowknife mine, suggested that mineralisation of the ore body occurred in three phases. This comprised an early phase of pyrite and arsenopyrite deposition, followed by a phase of sphalerite, chalcopyrite and pyrrhotite crystallisation, and terminated by the deposition of minerals containing lead and antimony. Coleman concluded that some of the gold may have been introduced during each wave of mineralisation but that most of it was deposited before the third and last phase.

It is encouraging to find that the conclusion, based on textural evidence, that the Patchway vein material was emplaced in at least two phases obtains support from similar observations in other gold mining districts. The Patchway evidence suggests that an earlier pulsatory wave of quartz and scheelite mineralisation was followed by a later phase of gold and sulphide mineralisation which accompanied the introduction of chlorite-carbonate veinlets.

The apparent sequence of deposition of sulphides in the Patchway ore agrees with the paragenetic order suggested by Edwards (10, 1954). The same general sequence may be observed in zoning of metamorphic ore deposits of the 'skarn' type, for example the Ammerberg district of central Sweden, where pyrrhotite, sphalerite and galena were deposited in that order ahead of a migmatite front.

The empirical correlation of sulphides that crystallised early in the Patchway paragenesis with lower-grade stopes in the mine, and the correlation of sulphides of later crystallisation with higher-grade stopes suggests that the majority of the gold in the ore was deposited during the waning stage of mineralisation. However, an examination of the apparent fineness of gold in samples of ore from the mine indicates that there may be two gold populations in the ore, the one having a greater content of silver than the other. As discussed in the following section, gold in the Patchway ore concentrates which amalgamates with mercury is of a higher average fineness than gold which cannot be extracted by amalgamation. The inference follows that of the two gold populations, the one occurring in intimate association with sulphides contains a higher proportion of silver than the gold which crystallised in discrete veinlets, patches or grains in quartz.

However, Eales (8, 1968), following an examination of gold concentrates from the Blanket mine in the Gwanda district of Rhodesia, has noted that as the pyrrhotite content of the ore increases so does the proportion of silver. He suggested that this silver occurs in sub-microscopic form and probably not as an alloy with gold, with the result that assaying of pyrrhotite-rich ore may provide an unnaturally low fineness value when compared to the true fineness of gold in the ore. As the writer was unable to detect any difference in colour or reflectivity of gold in specimens of ore from low-grade or high-grade stopes which might account for the known difference in apparent fineness, it is possible that this is a function of the stage in the paragenesis at which the gold was precipitated. Gold from the lower-grade stopes may have been deposited in association with argentiferous pyrrhotite, sphalerite and chalcopyrite comparatively early in the paragenesis.

Regardless of this, it is evident from the present investigation that in specimens of low-grade ore from the Patchway mine the dominant sulphides, excluding pyrite, are pyrrhotite, sphalerite and chalcopyrite of comparatively early crystallisation, while in specimens of high-grade ore the dominant sulphide, excluding pyrite, is galena of later crystallisation. It is also significant that high-grade ore is associated with the axial region of anticlinal flexures in the vein, whereas lower-grade ore is confined to the less contorted, more regular portions of the vein. The suggestion follows that during the gold and sulphide mineralisation phase the narrower, less deformed sections of the vein were soon choked by the deposition of pyrrhotite, sphalerite and chalcopyrite, together with some gold, while galena and the bulk of the gold of later crystallisation were channelled into the comparatively low pressure regions of the anticlinal flexures, resulting in payshoots aligned along these structural features.

PLATE 1

A photograph showing veining of hydrothermal quartz (pale grey) by a chlorite-carbonate stringer (medium grey) mineralised with gold (black). x 60

4. THE FINENESS OF GOLD FROM THE PATCHWAY MINE

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4.1 INTRODUCTION

Following the examination of the fineness of gold in a number of hydrothermal deposits in Rhodesia, Eales (9, 1961) concluded that there is a definite relationship between the fineness of gold and the grade of the ore. He generalised that silver-rich gold is typical of low-grade ore, while silver-poor gold is usually associated with the richer sections of a payshoot. Eales presented evidence to show that the composition of gold being precipitated during mineralisation may change from an earlier phase of deposition of silver-rich gold to a later phase of mineralisation involving the deposition of silver-poor gold.

The converse was suggested by Fisher (11, 1945) following his investigation into the fineness of gold in the Morobe goldfield in New Guinea, where he found that gold associated with the Morobe granodiorite batholith was of a higher fineness than gold associated with younger porphyries. From this he concluded that silver-poor gold, in the Morobe district, was associated with an early phase of mineralisation in contrast with the later deposition of silver-rich gold.

Macgregor (21, 1928), in a description of the Lonely mine in the Bubi district of Rhodesia, noted that there was a progressive increase in the silver content of bullion produced from increasing depth in the mine. According to the data presented in Macgregor's report, between the years 1908 and 1924 over 700,000 fine ounces of gold were won from the mine of which 65% was recovered by cyanidation. Despite the high percentage of gold recovered by the cyanidation process, Macgregor was able to detect a decrease in the bullion fineness from 958 above 10-level to 891 below 23-level, this decrease being accompanied by a progressive diminution in the gold content of the ore. In contrast to Patchway, where galena is ubiquitous in the ore, the only sulphide present in the upper levels of the Lonely mine appears to have been pyrite, while the decrease in grade of ore and the decrease in bullion fineness in the lower levels was accompanied by the appearance of sphalerite, galena and chalcopyrite below 25-level.

These relationships are by no means peculiar to Rhodesia, and Eales noted that mines in the Porcupine and Kirkland Lake areas of Ontario, Canada, showed a similar variation between bullion fineness and the tenor of the ore. However, the reverse relationship has been noted, that is, an increase in both bullion fineness and grade of ore with depth. For example, in the O'Brien gold mine, Quebec, Mills (24, 1954) noted that from 500 to 1200 feet below the surface the bullion fineness increased from 860 to 920, while below the 1200-level the composition remained constant. Quoting Pryor, Park (27, 1957) wrote that the fineness of gold in the Kolar goldfield of India systematically increases from 800 in the upper levels to 930 in depth. In a comprehensive review of the literature on this subject, Gay (13, 1963) concluded that the evidence indicates that an increase in the grade of ore is almost always accompanied by an increase in fineness, but that fineness may either increase or decrease with depth of deposition.

For the purpose of this examination fineness is expressed as 1000 Au / (Au+Ag), following Fisher's recommendation in which the base metal content of the bullion is discounted. Further, following Eales, the bullion fineness is termed "true" fineness in distinction to the value 1000 Au / (Au+Ag) given by the assaying of ore samples which is termed "apparent" fineness.

4.2 BULLION FINENESS

In a consideration of the fineness of bullion won from the Patchway mine account must be taken of the fact that reduction at the mine is accomplished by cyanidation. Following grinding in cyanide solution, agitation in pachucas, and filtration, the pregnant solution is passed through a standard Crowe-Merrill plant where the gold in solution, as sodium aurocyanide, is precipitated by the action of zinc and later recovered by smelting.

Fisher (11, 1945) has pointed out that cyanidation dissolves many silver minerals with the result that cyanide bullion commonly has a lower fineness than the true value of the gold-silver alloy being treated, except where the only silver in the ore is that alloyed in this fashion. As the Patchway ore contains relatively abundant galena, which is argentiferous to a degree, it is possible that the bullion fineness figures are not a true gauge of the composition of gold in the mine.

Goldschmidt (15, 1958) has generalised that galena commonly contains between 100ppm (0.01%) and 1000ppm (0.1%) of silver, and exceptionally may contain silver in amounts up to 10,000ppm (1.0%). Examination of the number-frequency proportion of gold and galena in specimens of ore from the Patchway mine subjected to micrometric analysis, suggests that galena is slightly more than twice as abundant as gold. Considering run-of-mine ore having an average gold content of 10 dwts/ton, then from the above reasoning, the galena content of this ore may be twice that of the gold, or the equivalent of 20.0 dwts/ton. If this galena contains 0.1% silver, and Goldschmidt has suggested that argentiferous galena commonly contains this amount, then the silver content of galena in the Patchway ore may amount to 0.02 dwts/ton. During an average month, when some 5000 tons of ore are milled, the argentiferous galena may result in an increment of some 5 troy ounces of silver to the bullion. Again, in an average month the silver content of the bullion totals some 600 ounces, so the addition of 5 ounces of silver to this amounts to an error of approximately 1.0%, assuming that the galena is moderately argentiferous and that the majority of this silver is dissolved by cyanidation. Discounting the possibility of other silver-bearing minerals in the ore, one may conclude that argentiferous galena alone may be responsible for an error of 10 parts per 1000 in the Patchway bullion fineness data.

Examination of mine records for the years 1964 to 1967 reveals that the 170 bullion bars smelted during this period ranged in fineness from 737.5 to 787.5, with an arithmetic mean fineness of 762 and a standard deviation of 19.7. An histogram of these values appears on the right-hand side of Figure 14, while on the other side of the same figure appears a plot of the bullion fineness data against grade of ore milled during the 41 months between July, 1964, and November, 1967. It will be noted that this presentation only tenuously duplicates the relationship noted by Eales (9, 1961), whereby bullion of high-grade commonly is associated with silver-poor gold.

4.3 APPARENT FINENESS OF GOLD IN SAMPLES

In an endeavour to obtain a more clear picture of the variation in silver content of the gold in the Patchway mine, a number of grab samples of ore were taken from various stopes on different levels in the northern section of the mine. These samples were then assayed at the laboratories of the Cam and Motor mine. Following cupellation, the assay buttons were parted, using nitric acid, and the silver content of the gold-silver alloy beads was obtained by determining the difference in weight after parting.

The apparent fineness values obtained from the assay and parting of 118 special grab samples range from 317 to 999 fine. The arithmetic mean of these values is 722, with a standard deviation of 142.8. However, the fineness value obtained by totalling the gold and silver content of these 118 samples, and expressing the result as 1000 Au / (Au+Ag), is 753.7. This is remarkably close to the bullion or true fineness arithmetic mean value of 762.

Eales found that the apparent fineness of gold in samples from the Turk mine in the Bulawayo area of Rhodesia ranged from 400 to 882 fine, while Fisher found that the total range in the Morobe goldfield was from 460 to 935. In the same paper Fisher went on to state that:

> "No authenticated case has been found of gold, or more strictly electrum, occurring naturally with a fineness less than about 450 parts per thousand. In cases where bullion of a lower fineness has been reported

the low value has been due to the
presence of native silver or other
assimilable silver minerals"

Be this as it may, only four of the 118 samples parted in the Patchway investigation had a fineness of less than 450, and it may be that these samples are not truly representative. However, no allowance has been made for this possible source of error.

The cumulative frequency distributions of gold and silver values obtained from samples taken from various stopes in the northern section of the Patchway mine are tabulated below:

(a) Gold content of 4455 stope grab samples:

Class limits (dwts/ton)	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40 +
Number	1243	1314	717	392	236	156	98	71	228
Percent	28	57	74	82	88	91	93	95	100

(b) Gold content of 118 special grab samples:

Class limits (dwts/ton)	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50 +
Number	28	38	17	10	4	4	5	2	0	2	8
Percent	23	55	69	78	81	85	89	91	91	92	99

(c) Silver content of 118 special grab samples:

Class limits (dwts/ton)	0–5	5–10	10–15	15–20	20–25	25–30	30–35	35–40	40–45	45–50	50 +
Number	79	27	5	4	2	0	0	0	0	1	0
Percent	67	90	94	97	99						

These data are shown plotted on logarithmic probability paper in Figure 15. Reference to this figure may prompt the following comments and observations:

1. Except for the lowest class, with a mid-mark of 2.5 dwts/ton, the distribution of the 4455 stope grab samples closely approximates a straight line. The lowest class may diverge from this pattern as a result of dilution of the samples by waste rock, resulting in an artificial increase in the percentage of samples in this class by some 5 to 6%. On this score it is pertinent to note that an analysis of material other than quartz vein in run-of-mine ore showed that 24.7% of the +2" fraction of the mill feed assayed a gold content of only 1.13 dwts/ton. This waste rock must influence any evaluation of the distribution of the gold population in the quartz vein and will result in an unnatural increase in the percentage of samples showing a low tenor.

11. The distribution of gold values determined in the 118 special grab samples approximates a straight line up to the 91 percentile, after which there is a marked change in the slope of the curve which then approximates a straight line of different slope.

111. There is a remarkable similarity between the distribution of the 4455stope grab sample gold values and the 118 special grab sample gold values, both in position on the graph and in slope. This suggests that the 118 special grab samples are more or less representative of the gold population in the mine.

1V. The distribution of the silver values determined for the 118 special grab samples approximates a straight line up to the 90 percentile. This by itself cannot be considered significant for only two points are plotted in this range, however, it may well be significant that when these two points are joined the line between them trends parallel to the straight line joining the eight points on the curve for gold values. This suggests that the silver values bear a close sympathetic relationship to the gold content of the samples. Above the 90 percentile the silver values resume a straight line distribution having a markedly different slope; again, reference to the curve for gold values shows a very similar phenomenon.

V. The point of inflection in the curves for both the gold and silver values occurs at about the 91 percentile, at which the value for gold is 37.5 dwts/ton and the value for silver is 8.2 dwts/ton, equivalent to an apparent gold fineness of 820.

In studying the distribution of some geochemical data, Tennant and White (34, 1959) pointed out that a single lognormal distribution plots as a straight line on logarithmic probability paper. Breaks in the slope of this straight line suggest that more than one lognormal distribution occurs in the data. So that, according to them, in some sets of data more than one distribution can occur, resulting in a double-peaked or bimodal histogram when plotted in this manner, or in two intersecting straight lines having different slopes when logarithmic probability paper is used. Tennant and White concluded that the latter method is more sensitive for detecting double distributions.

In a more recent investigation into the use of statistics in the interpretation of geochemical data, Williams (39, 1967) examined data concerning the threshold concentration of copper, nickel and zinc values determined by geochemical exploration in New Zealand. Williams concluded that when such results are plotted as cumulative frequencies on logarithmic probability paper, the point of inflection, if any, establishes a value for the boundary between two different metal populations in the same sample.

These comments, relating to the distribution of gold and silver values determined for the 118 special grab samples from the Patchway mine, prompt the conclusion that there may be two gold populations in the mine, the one having a higher silver content than the other.

Taking this further, attention is invited to Figure 16 which is a plot of the cumulative frequency of the apparent fineness of gold determined in the 118 samples. Again logarithmic probability paper has been used, and, as might be expected from the previous figure, the points plotted approximate a straight line which has a break in slope or point of inflection at about 820 fine. Conversely, the bullion data plotted on the same figure show no change in slope although the points do appear to lie along a straight line. It is not altogether surprising that the true fineness data do not show evidence of what appears to be two gold populations, such a comparatively minor variation having been averaged out, as is suggested by the more horizontal character of this curve.

In Figure 17 B the same fineness data are plotted in the form of an histogram which shows a markedly bimodal character, the two peaks at 725 and 875 fine

fine being separated by a trough at 825 fine. This trough coincides, naturally, with the value for the point of inflection in the cumulative frequency curve when plotted on logarithmic probability paper.

On the left-hand side of Figure 17 the apparent fineness values are plotted against the gold content of the samples expressed as dwts/ton. It will be noted, by comparison with the similar plot of the true fineness data in Figure 14, that the apparent fineness data agree broadly with Eales' generalisation that high-grade ore contains gold of high fineness and vice versa, but that silver-poor gold may also be found in low-grade ore.

In summary, it may be stated that an examination of the distribution of gold values, silver values, and the fineness of gold in samples from the Patchway mine suggests, without reference to source areas or mineral paragenesis, that there may be two populations of gold in the mine. The one population is relatively silver-poor, with an histogram peak at a class mid-mark of 875 fine, while the other is comparatively silver-rich, with an histogram peak at a class mid-mark of 725 fine. The apparent fineness of gold in the mine exhibits what Eales considers to be the normal distribution for hydrothermal gold ores.

4.4 LATERAL VARIATION IN FINENESS

After considering the data presented in Figure 17 A, the conclusion was reached that in the Patchway mine the determined apparent fineness of gold lends further confirmation to Eales' generalisation that high-grade ore contains gold of higher fineness than low-grade ore in the same ore-shoot. In determining whether or not there is any systematic lateral variation of the apparent fineness of gold in samples taken across the north ore body payshoot, attention was paid to the distribution and grade of the 116,000 tons of ore in reserve in this section of the mine as at 30 June, 1967.

The following table was compiled to illustrate any lateral variation in tenor and proportion of ore in reserve in this section of the mine, it being emphasised that these grade figures are obtained from routine ore-reserve evaluation data. At a rough estimate more than 500 samples are assayed to determine the grade of a single stope in this mine, each stope averaging some 150 feet of vein strike and 180 feet of back. As these data relate to 35 different stopes, the assay values involved amount to around 20,000 determinations of the gold content of channel samples from the reef:

Stope profile	Grade (dwt/ton)	Percentage of total ore
1 North	9.39	25.74
2 "	6.75	1.64
3 "	6.30	5.79
4 "	7.71	13.39
5 "	10.61	20.90
6 "	9.84	17.14
7 "	8.88	9.95
8 "	6.72	5.44

The same approach was adopted in examining the variation in the apparent fineness determined for the 118 special grab samples taken from different stopes in the same section of the mine, and the relevant data are tabulated below:

Stope profile	Arithmetic mean of apparent fineness	Number of samples
1 North	753	23
2 "	630	4
3 "	0	0
4 "	632	13
5 "	726	31
6 "	752	25
7 "	684	6
8 "	659	7
9 "	728	7

It might be argued that the latter data are scant, but reference to Figure 18, which is a plot of both the average grade of ore in reserve and the apparent fineness of samples of this ore against the relevant stope profiles, shows a strikingly sympathetic relationship between high-grade ore and gold that is silver-poor, and vice versa. The conclusion that high-grade ore commonly contains gold of a higher fineness than low-grade ore appears to be entirely valid for the northern section of the Patchway mine. In addition, the striking trend displayed in Figure 18 lends support to the contention that the determination of the apparent fineness of gold in these 118 random samples is generally representative of the apparent fineness of the gold in this section of the mine as a whole.

Finally, it should be noted that the 5 and 6 north profile stopes, which contain the ore of highest average grade and fineness, straddle the structural axis of this section of the mine, as determined by means of a structural contour diagram and described in a previous section. This suggests that there may be a close link between the deposition and fineness of hydrothermal gold and the form or attitude of the vein fissure. These same two stopes contained roughly one-third of the ore in reserve at the time these data were collected, further suggesting that the fissure contains more vein filling along the structural axis than along the flanks of this upwarp. The other high-grade, high-fineness stopes occur on the 1 north profile line which indexes stopes containing roughly one quarter of the ore in reserve; the mineralisation along this profile is apparently associated with a separate and more localised upwarp or drag fold. In short, then, high-grade ore is characterised by comparatively silver-poor gold and is aligned along anticlinal fold axes affecting the vein fissure in the northern section of the Patchway mine.

4.5 VERTICAL VARIATION IN FINENESS

As has been mentioned in the introduction to this section, a general conclusion reached by several workers in this field is that gold fineness may either decrease or increase with increasing depth of deposition. The apparent fineness values of the 118 samples taken from all horizons, in the northern section of the Patchway mine, between the 250- and the 1000-level are reproduced in the following table, where they are arranged in order of increasing depth in the mine:

Depth in feet	Number of samples	Arithmetic mean of apparent fineness	Paired mean
250	10	676	
320	12	765	753
400	6	730	
500	17	665	713
600	12	795	
700	13	639	699
800	26	730	
900	6	782	740
1000	17	726	

It will be noted that whether one considers the fineness data level by level or in pairs of levels there is no definite pattern of variation in the apparent fineness with increasing depth in the mine, whereas the same data provided evidence of an extremely marked lateral variation in fineness.

In case the variation, if any, is too subtle to be detected on a level to level basis, these data were treated in a more composite fashion by considering those samples taken between the 250- and 600-level and those taken between 700- to 1000-level. For comparative purposes these data were plotted on separate histograms which are reproduced in Figure 19 B. This method of examination shows that there is a slight decrease in the arithmetic mean of the apparent fineness values from 728 fine, with a standard deviation of 143, for the values from the 600-level and above, to a value of 716 fine, with a standard deviation of 126, for the values from below the 600-level. This can hardly be considered to be a significant variation in the apparent fineness with increasing depth.

Examination of the mine records for the years 1964 to 1967 reveals that the 170 bullion bars won from the mine during this period ranged in fineness from 737.5 to 787.5, with an arithmetic mean fineness of 762. During 1964 most of the gold produced from Patchway was mined from the southern section of the mine, so the 1964 bullion fineness values have not been included in the histograms reproduced in Figure 19 A. These histograms have been arranged according to the year of production because during 1965 the upper levels of the northern section of the mine were being stoped, while during the following year most of the ore was pulled from stopes above the 500-level, and during 1967 the bulk of the ore was mined from below the 500-level. So by arranging the true fineness data according to the year of production these histograms express the distribution of true fineness with increasing depth in the northern section of the mine, and should expose any distinct variation in the value of this fineness. It will be noted that the arithmetic mean of these true fineness values increases very slightly from 757 for the 1965 bullion production to 763 the following year and 764 in 1967. This is an ill-defined trend indeed, and is opposite in sense to the variation shown by the apparent fineness values with increasing depth.

In brief, neither the true fineness values nor the apparent fineness values show any significant variation between 250 and 1000 feet below the surface. The very slight trends displayed are contradictory and negligible when compared with the marked lateral variation in apparent fineness across the ore body.

What may well be significant is the bimodal distribution of the apparent fineness values displayed by the histograms reproduced in Figure 19 B. It will be recalled that a similar distribution pattern was noted in section 4.3, when it was concluded that there appear to be two gold populations in the mine, the one relatively silver-poor with a histogram peak at 875 fine and the other comparatively silver-rich with a histogram peak at 725 fine. Reference to the histograms reproduced in Figure 19 B will show that this bimodal distribution of apparent fineness values is more pronounced between the 700- and 1000-level than in the shallower horizons. In fact, with increasing depth there has been a noticeable increase in the number of values having an apparent fineness with a class mid-mark of 875.

In summary, it may be stated that while the results of an examination of the vertical trend of true and apparent fineness in the northern section of the Patchway mine has been somewhat inconclusive, there is some evidence to suggest that there has been an increase in the proportion of silver-poor gold with increasing depth in the mine. From the economic point of view this may be interpreted as a favourable trend, bearing in mind that in many Rhodesian mines, for example the Lonely mine in the Bubi district, the Lone Hand at Gwanda, and the Makanga near Bulawayo, it was a pronounced decrease in silver-poor gold that heralded the bottoming of the payshoot.

4.6 VARIATION OF APPARENT FINENESS WITH GRAIN-SIZE

It has been noted from several hydrothermal gold deposits that there is often a systematic relationship between the silver content and the grain-size of gold particles, and a general conclusion is that the fineness may either increase or decrease with a diminution in gold particle size. In conducting an examination into this aspect of the gold mineralisation in the Patchway mine, it was decided to investigate the mill concentrates rather than pulverised assay concentrates, the former having undergone less comminution. Run-of-mine ore at Patchway is crushed to - ½" in size and is then fed into either the main 8' x 5' Allis Chalmers ball mill or the auxilliary 5' x 6' ball mill. In the former the ore is milled in a solution of sodium cyanide, whereas in the latter the ore is ground in water and concentrated on a Gallagher strakes table, whence the concentrates are pumped to the main ball mill circuit for cyanidation.

During October and November, 1967, the concentrates from the Gallagher strakes table were sampled on several occasions. These samples were bulked to form a composite sample of the mine ore concentrates which was coned and quartered to reduce it to a convenient size. This was then wet screened through 60, 200 and 325 B.S. mesh sieves resulting in four graded fractions of the mill concentrates that contained particles in the following size categories: plus 251 microns, plus 76 microns, plus 47 microns and minus 47 microns.

These graded fractions were split two ways, the one portion being retained for an amalgamation analysis while the other portion was submitted for assaying and parting to determine the gold and silver content.
The results of the latter determinations are

tabulated below:

Grain-size grading (B.S.mesh)	Value ½ assay ton Au + Ag	Au	Value dwts/ton Au	Ag	Value $\frac{1000\ Au}{(Au+Ag)}$
+ 60	231.2 242.0	192.0 192.0	384.0	89.2	811.5
+ 200	110.8 106.2	99.0 76.0	175.0	42.0	806.5
+ 325	313.0 305.6	264.0 264.0	528.0	90.6	853.5
- 325	250.4 259.4	203.0 210.0	413.0	96.8	810.1
	Total		1500.0	318.6	824.8

It will be noted that these determinations were undertaken in duplicate and the results presented are, therefore, a summation of these values. Also one may note, as a generalisation, that of the total gold tenor in the concentrate, of 1500.0 dwts/ton, more than 60%, or 941.0 dwts/ton, was contained in the - 200 B.S. mesh fraction. This might be related to the degree of milling, as the Patchway ore is ground to 75% less than 200 mesh, except that of the 774.2 grams constituting the total weight of the samples assayed only 39.5% was less than 200 mesh in grain size.

The retained portions of the sample were then examined in the following manner. Each size fraction was treated in an 8" Wedgewood mortar with 1 cc of mercury and ground by hand with a porcelain pestle for twenty minutes. The amalgam so obtained was concentrated by careful panning and separated from the residue. This residue, containing unamalgamated and non-amalgamable gold, was submitted for determination of the gold and silver content. The results of this assaying are tabulated below:

Grain-size grading (B.S.mesh)	Value Gold (dwt/ton)	Value Silver (dwt/ton)	Value	$\frac{1000\ Au}{(Au+Ag)}$
+ 60	148.2	30.6		828.9
+ 200	25.2	11.2		692.3
+ 325	53.3	22.1		706.9
- 325	127.9	54.6		700.8
Total	354.6	118.5		749.5

Examination of these data indicates that the gold which did not amalgamate displays a markedly different trend to that shown by the untreated fractions of the concentrate, where a tenuous increase in the apparent fineness of gold appears to accompany a diminution in grain size. In the case of the gold which did not amalgamate there is a very marked decrease in apparent fineness with decreasing grain size of the ore particles, from an apparent fineness of 829 for the 42% of the total gold which did not amalgamate and was contained in the + 60 mesh fraction, to an apparent fineness of approximately 700 for the three gradings in the - 60 mesh fraction.

By difference, the apparent fineness of the gold which formed an amalgam with the mercury is expressed as follows:

Grain-size grading (B.S.mesh)	Gold (parts)	Silver (parts)	Value	$\frac{1000\ Au}{(Au+Ag)}$
+ 60	235.8	58.6		801.0
+ 200	149.8	30.8		829.5
+ 325	474.7	68.5		873.9
- 325	285.1	28.3		909.7
Total	1145.4	186.2		860.2

Thus the gold which amalgamated displays a clearly defined trend with decreasing grain-size, the percentage of gold and the apparent fineness both increasing with diminishing particle size.

The trends displayed, by the gold which amalgamated and the gold which did not form an amalgam in this examination of a sample of the Patchway mill concentrates, are shown diagrammatically in Figure 20. While these trends are in themselves striking, even greater significance is attached to the average apparent fineness of the two categories of gold, it having been demonstrated that the gold which did not amalgamate averages 750 fine and the gold which did amalgamate averages 860 fine. This immediately recalls to mind the earlier conclusion that there may be two gold populations in the Patchway mine ore, the one displaying an histogram peak at a class mid-mark of 725 fine and the other a peak at a class mid-mark of 875 fine. The fact that the average fineness of the concentrates, at 825 fine, is so much higher than that of run-of-mine ore, which averages an apparent sampled fineness of 754, is due to the upgrading in free gold relative to gold associated with sulphides, as a result of the process of concentration. In other words, the fineness of the Gallagher concentrate is not truly representative of the bullion which will later be extracted by cyanidation.

4.7 DISCUSSION

For convenience, the salient points arising from this investigation into the fineness of gold in ore from the Patchway mine are summarised below:

(a) A strikingly sympathetic relationship between high-grade ore and silver-poor gold has been found to exist when considering the ore-shoot in the northern section of the mine in a lateral sense. No significant trend in gold fineness variation was found with increasing depth in the mine.

(b) A consideration of the cumulative frequency distributions of gold, silver and fineness values determined for samples of ore from the mine has suggested that there may be two gold populations in the ore; the one consisting of silver-poor gold and the other of comparatively silver-rich gold.

(c) When these fineness data are plotted as an histogram, two frequency maxima are apparent, the one at a class mid-mark of 725 fine and the other at 875 fine.

(d) Examination of ore concentrates has shown that gold in the concentrates which forms an amalgam with mercury has an average fineness of 860, whereas gold which did not amalgamate has an average fineness of 750. The former increases in fineness with decreasing grain-size, while the latter decreases in fineness with diminishing particle size.

From this one may infer that the gold in ore from the Patchway mine may be referred to one of two populations which may be distinguished by the silver content of the natural gold alloy. On the one hand we have gold of comparatively high fineness which readily amalgamates with mercury, and on the other we have gold of lower fineness which does not form an amalgam. It is obvious that the gold in the Patchway ore which does not amalgamate must have been protected in some manner from the action of the mercury. The logical deduction is that this gold is intimately associated with sulphide minerals which acted as a physical barrier between the gold and the mercury. In considering this aspect of the fineness of gold from the Olympus mine in Rhodesia, Eales (9, 1961) made the following statement:

> "... gold which is easily amalgamated is purer than that which cannot easily be recovered by amalgamation. This in turn implies that the gold which is relatively easily liberated from enclosing minerals during stamp milling is purer than that which remains entrapped within or coated by sulphides, and it is reasonable to argue that this again points to the greater purity of late gold in contrast with the silver-rich quality of early-separated gold forming inclusions in sulphides."

This statement applies equally as well to the gold in the Patchway mine ore.

Mills (24, 1954) reported that at the O'Brien gold mine in Canada gold recovered by amalgamation is generally coarser than gold recovered by cyanidation, and that the percentage of gold and silver recovered by cyanidation increased with depth in the mine. In other words there was a decrease in the proportion of free gold in the ore and in the fineness of the gold with increasing depth. In the case of the Olympus, Lonely and Horn mines in Rhodesia, Eales found there to be a well-defined tendency for the purer gold in the ore to occur in more finely divided form than the gold of lower fineness. It will be recalled that gold in the Patchway concentrates which forms an amalgam with mercury increases in fineness with decreasing particle size. In considering the Lonely mine, Eales concluded that in the deeper portions of the ore channel the gold occurs in fairly large grains associated with chalcopyrite, whereas in the upper levels of the mine, where both the tenor of the ore and the fineness of the gold were higher, most of the gold grains occur discrete in quartz, the balance being associated with or wholly enclosed by pyrite. Conversely, Eales quoted the work undertaken by the staff of the Lake Shore mine in Canada who determined that a small proportion of the gold, which is silver-rich, occurs as minute particles in pyrite. By implication, gold which occurs in intimate association with pyrite may be either silver-rich or silver-poor. Eales considered the former case to be typical of gold that was deposited early in paragenesis, whereas Fisher (11, 1945) considered silver-rich gold to be more characteristic of later phases of mineralisation.

It will be recalled that in a previous section, in which the mineragraphy of the Patchway mine ore was described, it was pointed out that 88.7% of the gold particles counted during a micrometric analysis of polished specimens of ore occur as discrete grains or veinlets in quartz. The rest of the gold occurs intimately associated with one or other of the following sulphides, namely, galena, pyrite, chalcopyrite, sphalerite, or pyrrhotite. Of greater significance is the finding that the dominant sulphides in specimens of lower-grade ore are pyrrhotite, sphalerite and chalcopyrite. In other words, these three sulphides are associated with ore which contains gold that is silver-rich when compared to the gold in higher-grade ore. It should be noted again that the ore specimens examined were selected for their apparently high gold content, and the fact that only 11.3% of the gold particles counted were intimately associated with sulphides may not be of great significance. It would require more than this percentage of gold, having an average fineness of 750, to reduce the free gold fineness value of 860 to the average bullion fineness value of 762. Some of the gold associated with sulphides may be extremely small in particle size, or even sub-microscopic. In a discussion on the solid solution of gold in sulphides, Schweigart (30, 1965) pointed out that extensive mineralogical investigations and chemical processing tests on refractory gold ores from the Barberton mountain land in South Africa showed that the main reason for the refractory nature of some of these ores is the extremely small particle size of the gold locked in the sulphides. In an interesting experiment involving samples of auriferous pyrite from the Getchell mine, Nevada, Joralemon (16, 1951) reported that treatment of these sulphide concentrates, by heating to 600°C in the presence of sulphur vapour in a sealed tube, caused sub-microscopic gold to migrate to the margins of the pyrite grains or to coalesce into visible blebs of gold within the pyrite. Joralemon suggested that economically worthless sections of the mine contained rather uniform minor amounts of gold, assaying less than 1.0 dwt/ton, might be related to pyrite mineralisation, whereas gold in the ore shoots occurred as discrete particles of the metal.

Eales (8, 1968) has suggested that, in pyrrhotite-rich ore, silver may occur in a sub-microscopic form and probably not as an alloy with gold, with the result the assaying of ore of this nature may provide an unnaturally low fineness value when compared with the true fineness of the gold in the ore. He also noted that in the deeper portions of the Lonely mine the gold, which is of lower fineness than the gold recovered from higher levels in the mine, is associated with chalcopyrite. In this investigation it has been demonstrated that Patchway ore which is characterised by silver-rich gold has a higher gold : sulphide ratio than richer ore which is characterised by silver-poor gold. It has also been found that the dominant sulphides in the ore containing silver-rich gold are pyrrhotite, sphalerite, and chalcopyrite. It is possible that some of this silver-rich gold, or some of the silver alone, occurs in a sub-microscopic association with these sulphides.

4.8 CONCLUSIONS

Statistical and empirical evidence indicates that there are two gold populations in the Patchway mine ore, the one population having a greater average content of silver than the other. Further evidence indicates that the silver-rich gold is associated in space with pyrrhotite, sphalerite and chalcopyrite; that is, minerals that crystallised comparatively early in the ore paragenesis. However, these conclusions should be treated with some reserve, for it seems probable that some of the apparent variation in fineness of gold in the ore is a function of the argentiferous nature of the sulphides which crystallised at the same time as the gold was deposited. In which case it would be more correct to state that gold which was deposited contemporaneously with sulphides of early paragenesis crystallised in an argentiferous chemical environment, by comparison with gold of later deposition which crystallised in a relatively silver-poor environment.

FIGURE FOURTEEN

A. Being a plot of the fineness of bullion from the Patchway mine versus the tenor of the ore.

B. Being a histogram showing the frequency distribution of the bullion fineness.

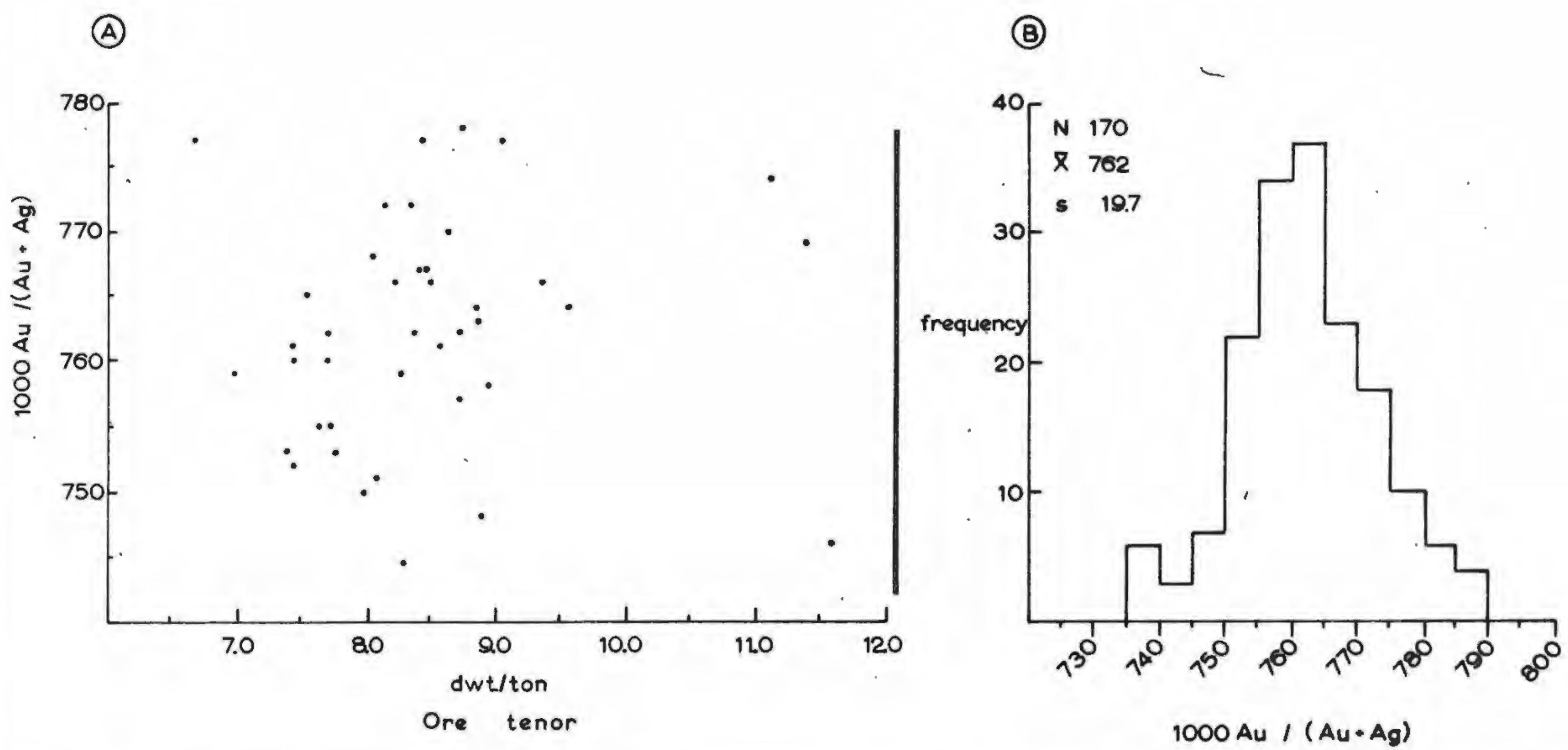
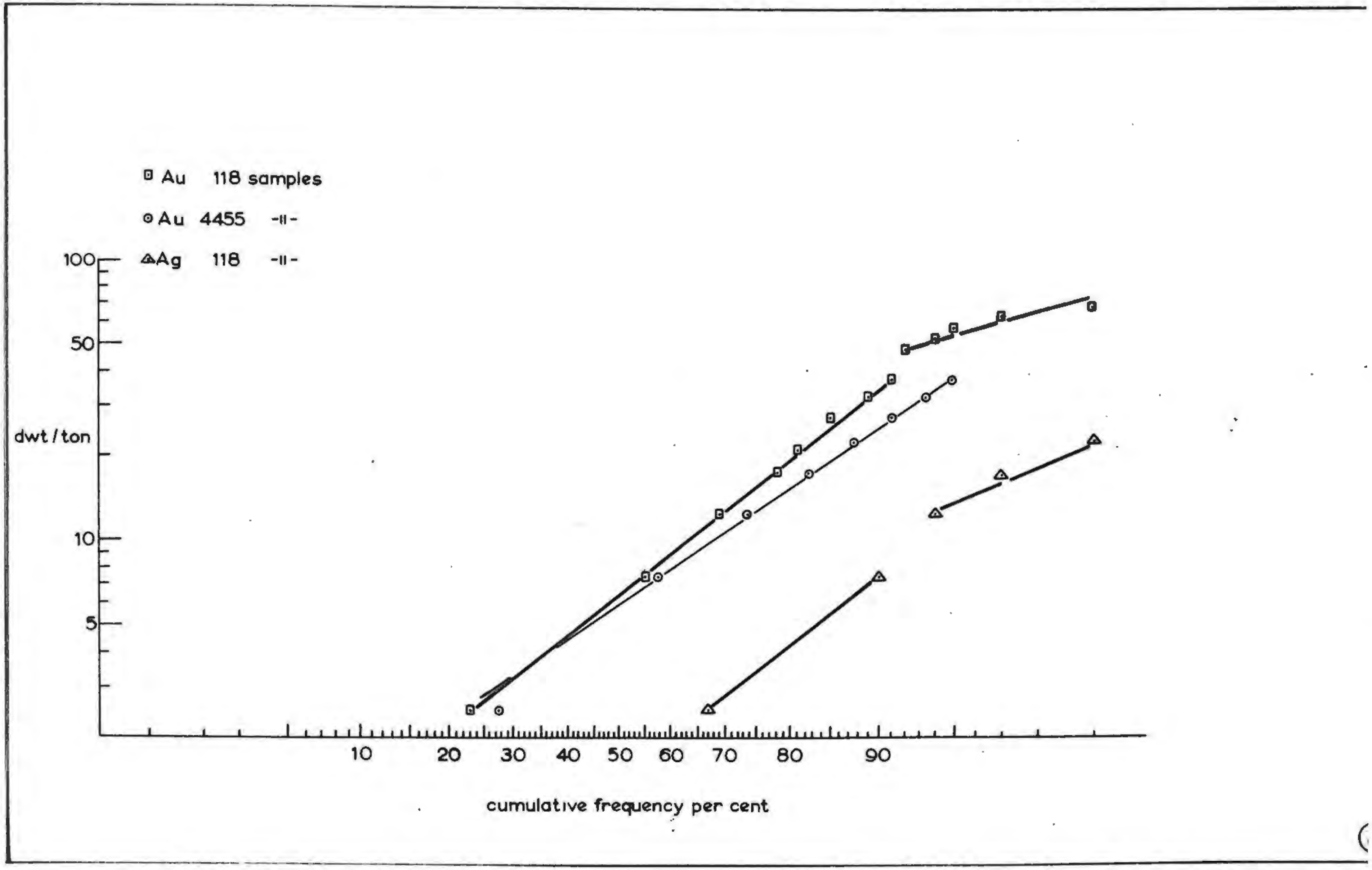

A
780
770
760
750
1000 Au /(Au + Ag)
7.0
8.0
9.0
10.0
11.0
12.0
dwt/ton
Ore tenor
B
40
30
20
10
frequency
N 170
X̄ 762
s 19.7
730
740
750
760
770
780
790
800
1000 Au / (Au + Ag)

FIGURE FIFTEEN

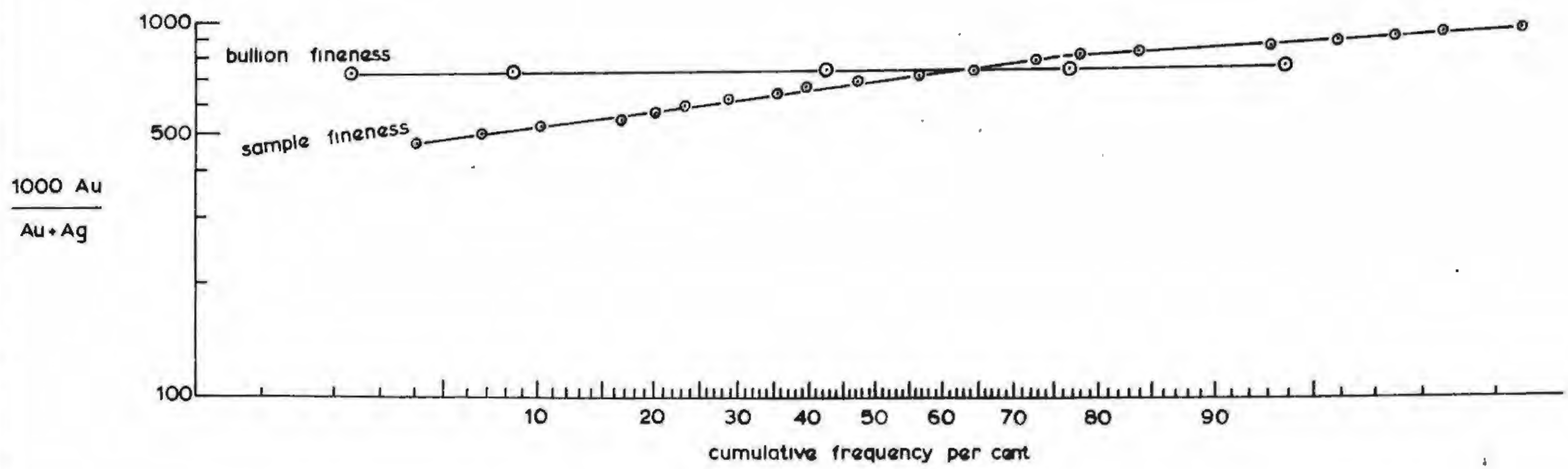
Being the cumulative frequency distributions, plotted on logarithmic probability paper, of the gold and silver values determined for 118 samples of ore from the Patchway mine, compared with the gold content of 4455 stope grab samples.



Au 118 samples
Au 4455 -ıı-
Ag 118 -ıı-
100
50
10
5
dwt / ton
10
20
30
40
50
60
70
80
90
cumulative frequency per cent

FIGURE SIXTEEN

Being the cumulative frequency distributions of the apparent or sampled fineness of Patchway ore compared with the true or bullion fineness.

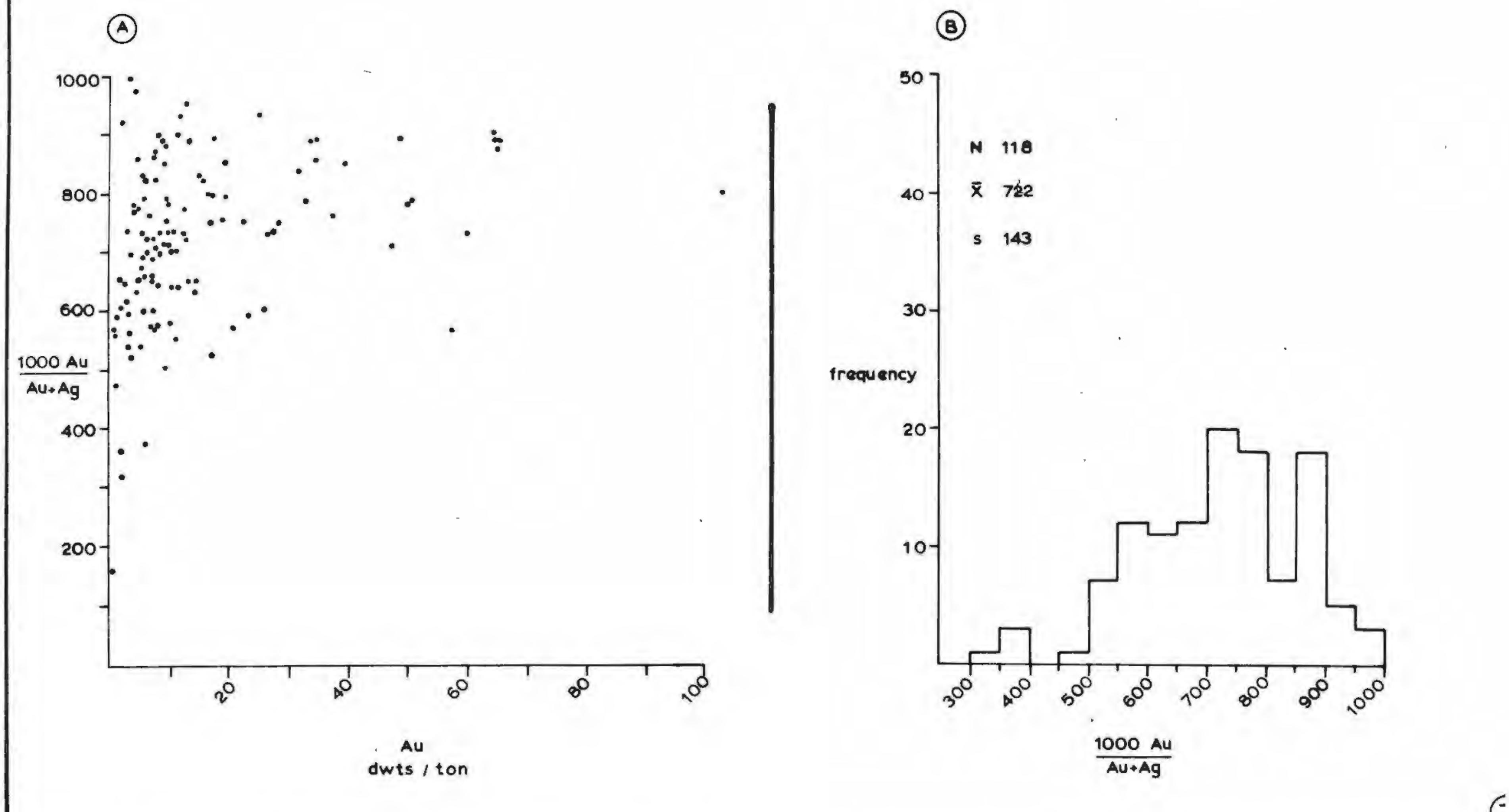


1000 Au
Au + Ag
1000
500
100
bullion fineness
sample fineness
10
20
30
40
50
60
70
80
90
cumulative frequency per cent

FIGURE SEVENTEEN

A. Being a plot of the apparent fineness of 118 samples versus the gold content of the samples

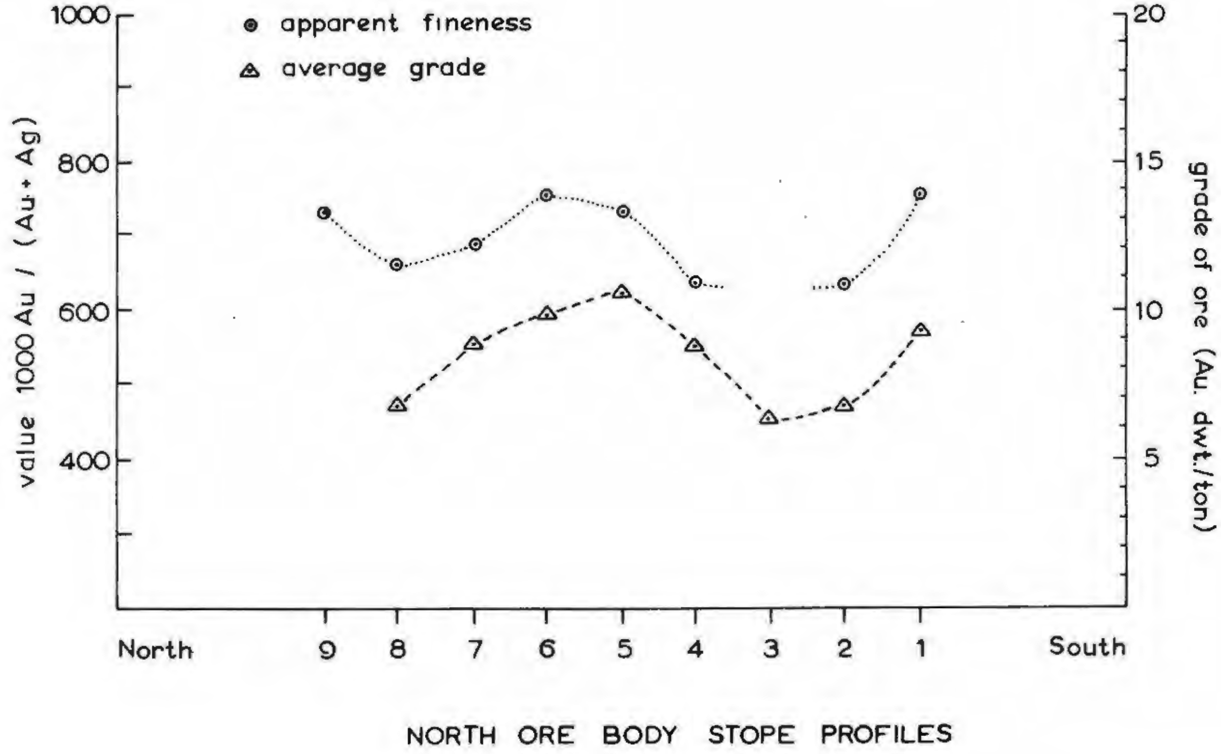
B. Being a histogram showing the frequency distribution of the apparent fineness of 118 samples of the Patchway ore.



A
1000
800
600
400
200
1000 Au / Au+Ag
20
40
60
80
100
Au
dwts / ton
B
50
40
30
20
10
frequency
N 118
X̄ 722
s 143
300
400
500
600
700
800
900
1000
1000 Au / Au+Ag

FIGURE EIGHTEEN

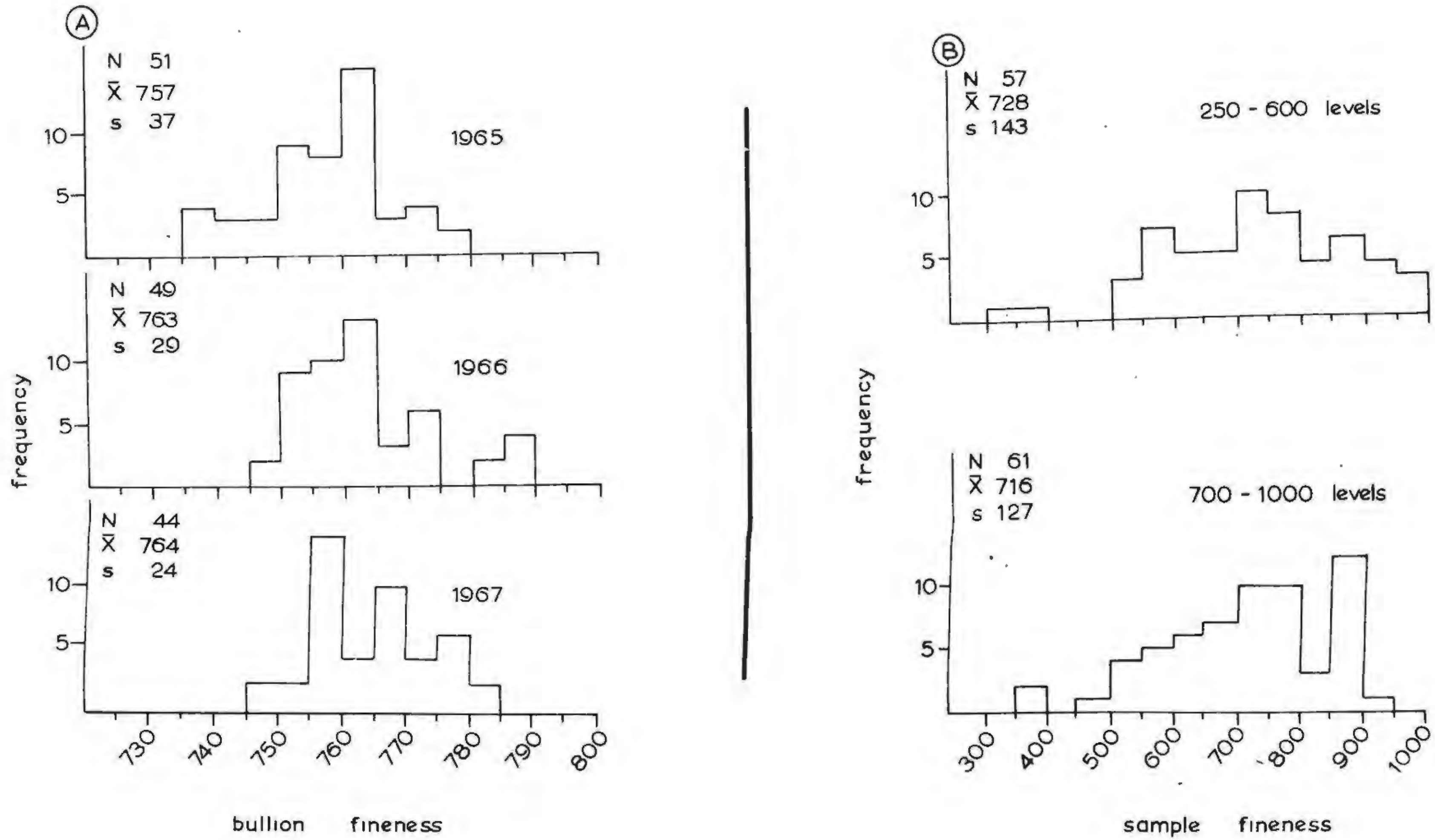
Being a graphical representation of the sympathetic relationship between ore-reserve grade and the apparent fineness of 118 samples of the ore. Note that high-grade ore is comparatively silver-poor.



apparent fineness
average grade
value 1000 Au / (Au + Ag)
1000
800
600
400
grade of ore (Au. dwt./ton)
20
15
10
5
North
9
8
7
6
5
4
3
2
1
South
NORTH ORE BODY STOPE PROFILES

FIGURE NINETEEN

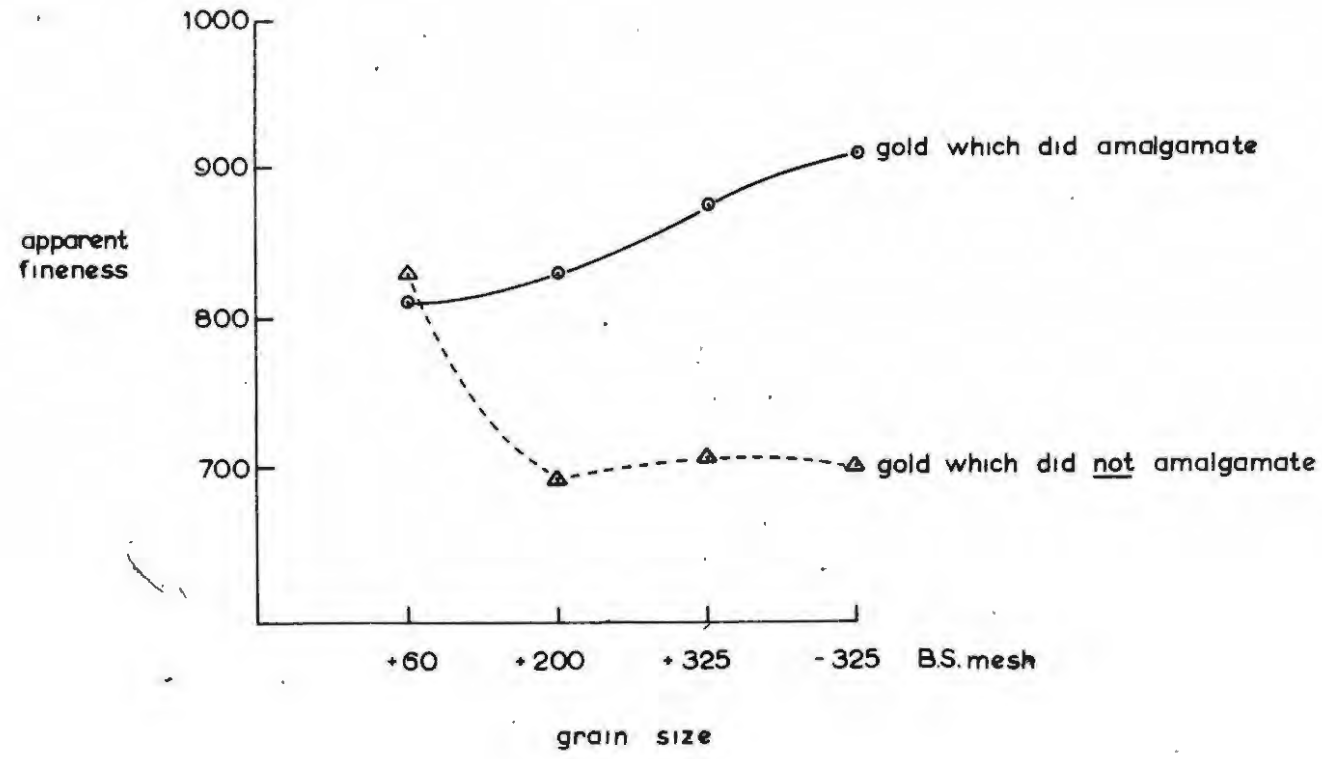
Being a plot of the Patchway bullion fineness and sampled fineness arranged in order of increasing depth in the mine. There appears to be no marked zoning of fineness with depth of deposition.



A
N 51
X̄ 757
s 37
1965
N 49
X̄ 763
s 29
1966
N 44
X̄ 764
s 24
1967
frequency
10
5
730
740
750
760
770
780
790
800
bullion fineness
B
N 57
X̄ 728
s 143
250 - 600 levels
N 61
X̄ 716
s 127
700 - 1000 levels
frequency
300
400
500
600
700
800
900
1000
sample fineness

FIGURE TWENTY

Being a graph illustrating the variation in apparent fineness with decreasing particle size of Patchway mill concentrates.


1000
900
800
700
apparent
fineness
+60
+200
+325
-325
B.S. mesh
grain size
gold which did amalgamate
gold which did not amalgamate

(20)

5. EPILOGUE

5.0 EPILOGUE

This examination has disclosed that there is a remarkable correlation between structure and gold mineralisation in the Patchway mine. On the structural side, it has been found that the pattern of fracturing in the Patchway area appears to be the result of fundamental wrench faulting of sinistral sense. Auriferous vein quartz has been emplaced along tension fissures which are believed to have opened in response to movement along associated shear zones. Economic concentrations of gold are associated in space with the axial region of anticlinal warps affecting the attitude of the vein, except where the fissure transgresses certain epidiorites which are poor host rocks to gold mineralisation in this mine.

Concerning the mineragraphy of the ore, it has been found that in specimens of low-grade ore the dominant sulphides, excluding ubiquitous pyrite, are pyrrhotite, sphalerite, and chalcopyrite, whereas in specimens of high-grade ore the dominant sulphide is galena. The former were deposited earlier in paragenesis than the latter, and low-grade ore is associated in space with the less contorted portions of the vein, whereas high-grade ore is concentrated along the axial region of the anticlinal warps affecting the attitude of the fissure.

The determination of the apparent fineness of gold in samples of ore from the mine has shown that there is a marked lateral variation in the silver content of the gold across the ore-shoot. High-grade ore is associated with gold that is silver-poor, and vice versa.

It is likely, however, that some of this silver may occur in a sub-microscopic form and not solely as an alloy with gold.

The impression created is that the mineralisation of the Patchway vein was structurally guided in the formation of ore-shoots. Minerals deposited early in paragenesis are relatively argentiferous, whereas those deposited later appear to be silver-poor. The latter period of deposition is closely associated in space with the crestal zone of comparatively gentle anticlinal flexures in the vein, which may have constituted low pressure areas favouring a more protracted period of metallization than the less contorted portions of the fissure. These crestal zones constitute the axes of payshoots in the mine.

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