THE GEOLOGY OF PIONEER GOLD MINE

LILLOOET MINING DIVISION, BRITISH COLUMBIA

by

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We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April, 1960

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ABSTRACT

Pioneer gold mine is 100 miles north of Vancouver in the Bridge River area of the Lillooet Mining Division, British Columbia. The mine has been worked extensively for more than 30 years and has produced over a million ounces of gold. The gold occurs in ribboned quartz veins which average less than three feet in width and are classified as mesothermal. The gold content of the veins is variable and it occurs with a small amount of sulphides. Gold values greater than 0.5 oz. Au/Ton are considered economic.

The Pioneer mine occurs in a northwesterly trending zone, called the Cadwallader Gold Belt, formed by the Hurley-Noel formation of sedimentary rocks and the Pioneer formation of volcanic rocks. The gold-quartz veins are genetically related to the Bralorne intrusions which occur within the rocks of this zone.

There is a repetition of these formations in the Pioneer property, which can be explained by normal movement on a fault. A wide zone of serpentine marks the position of this fault, which is called the Cadwallader Break. This Break is a first order fault and can be related to second order faults formed during the same period of deformation. These second order faults are now occupied by quartz and form the veins which are mined.

Planes of liquid inclusions in the quartz of the quartz veins have attitudes similar to those of the megascopic planes

of rupture. These planes of inclusions were formed by the annealing of microscopic fractures in the quartz veins. The attitude of these fractures was determined by the same deformation which produced the megascopic fractures, including the 'Cadwallader Break'.

The Bralorne intrusion in the mine area is composed of the Bralorne diorite and soda granite which contain albite as their only feldspar. No evidence has been formed to indicate that the intrusion is formed by the process of granitization. Sodic solutions, possibly parts of the final differentiate of the magma which formed the Bralorne intrusion have caused albitization of the intrusion and the Pioneer formation.

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CHAPTER I

INTRODUCTION

This thesis is based on the field work undertaken from July 1956 to September 1958, and during the summer of 1959, while the author was employed as geologist at Pioneer gold mines. Laboratory work was carried out during the winter of 1959-1960 at the Geology Department of the University of British Columbia. The object of this thesis is to present an account of the geology of Pioneer mine, with particular emphasis on the problems of the distribution, and origin of the gold-quartz veins, which have been extensively exploited for over thirty years.

LOCATION AND ACCESS

Pioneer mine, consisting of 28 crown granted claims and fractions, is situated on the left bank of Cadwallader creek, a tributary of the Bridge River, and is 3 miles upcreek from Bralorne mine. The area containing the two mines has been succinctly termed the "Cadwallader Gold Belt" by Joubin (1947) and lies within the Lillooet Mining Division of British Columbia. The geographic location is latitude 50° 10' north and longitude 123° west.

There are many methods of access, ranging from air transportation to a nearby lake, to a circuitous route of 300

miles by road from Vancouver via the Fraser Canyon. A shorter route is 50 miles by road to Lillooet and then by P.G.E. railroad to Vancouver. Alternative routes are now considered by the community, which has commenced to build a pilot road to connect with the village of Pemberton, at a point nearer Vancouver. The old trail up Cadwallader creek and then over McGillivray Pass is used only by the B.C. Telephone company and the occasional hunter.

TOPOGRAPHY AND GLACIATION

The area is on the eastern flank of the Coast Mountains, and all ranges have the same trend as the Coast Mountains proper. Elevations range from 2,100 feet in the Bridge River valley up to 9,600 feet as the peak of White Cap mountain. In the vicinity of Pioneer the relief is 4,000 feet or more. The mountain peaks are usually matterhorn in type, and most of the ridge crests are narrow, rocky and precipitous; and the valleys steep-walled.

Glaciation has formed numerous U shaped valleys which seem to be controlled by zones of structural weakness - the valleys follow fault zones and are separated by steep rocky ridges which are cut by rivers, in some sections, flowing at right angles to the trend of the physiographic features.

The effects of the glaciation seen as the ridges and matterhorn peaks, together with the development of cirques, and hanging valleys, suggest that the ice was only restricted to the lower elevations and did not form a continuous ice sheet.

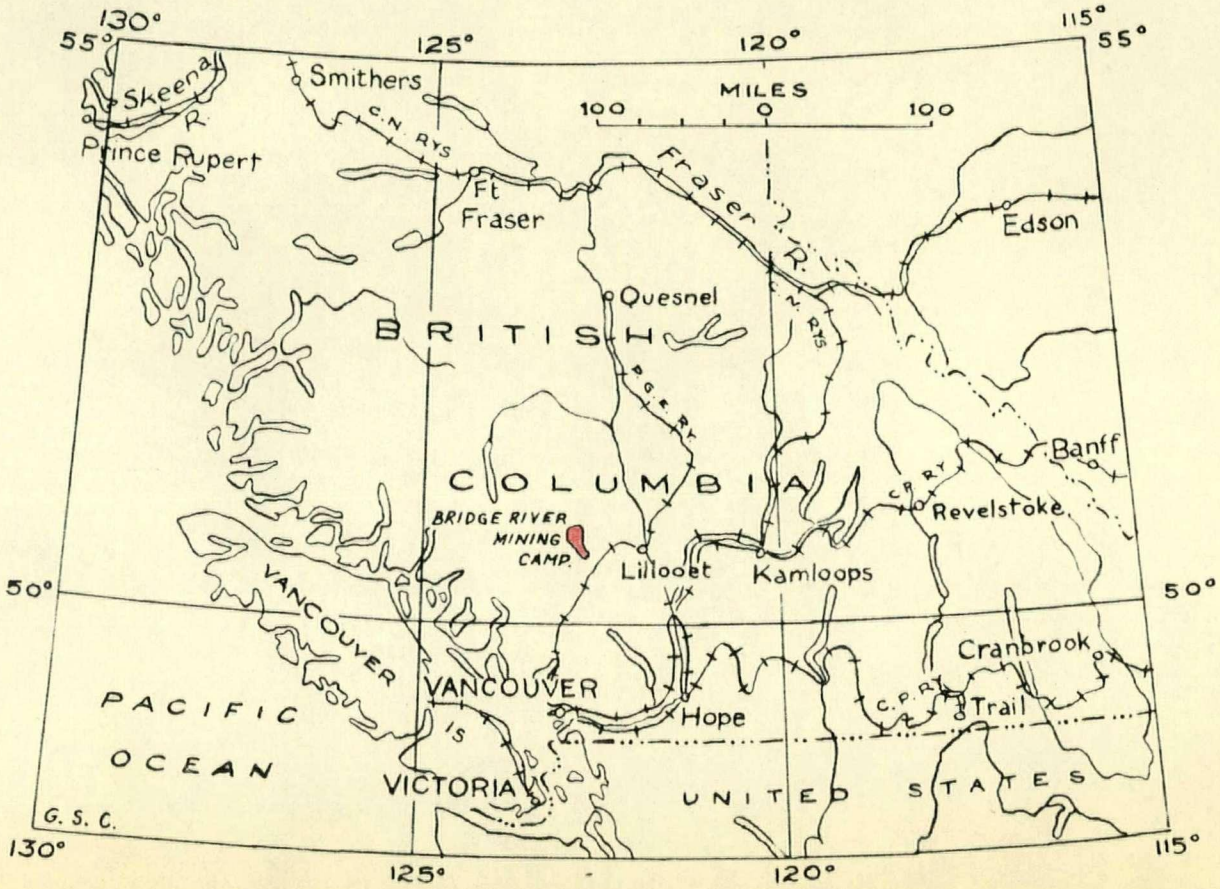


Figure 1 Index map showing position of Bridge River mining camp.

The highest elevation of glacial evidence is given as well over 8,200 feet on the Glacial map of Canada.

The tributary valley glaciers to the main glacier which occupied the Cadwallader creek have formed U shaped valleys, which are now occupied by streams. These streams cascade over the lip of a hanging valley into the main creek of Cadwallader. In the upper reaches of these streams cirques are found which are now filled with large scree fragments, and patches of residual snow.

DRAINAGE

The drainage in the district is still in a youthful unorganised state. All streams join the Cadwallader or Hurley River, which flows north westerly into the Bridge River, to join the Fraser River 3 miles north of Lillooet.

FLORA

The area is fairly heavily timbered but most trees are small and there is evidence that there has been an extensive fire in the valley, a long time ago. Timber line is generally about 6,500 feet above sea level. Below timber line the southern slopes are fairly open but the northern slopes sustain a dense growth of rather inferior and bushy forests.

Douglas fir, black spruce, balsam, larch, and jackpine are present at higher elevations, while cotton woods and poplar grow in the valley bottoms. Luxuriant growths of alder, devils club, and huckleberry form the undergrowth.

FAUNA

The surrounding area is well known for big game hunting, and the Taylor Basin to the north has produced many record animal trophies.

Nearly all creeks and lakes are well stocked with fish. Blue grouse, willow grouse, and ptarmigan are common. Hares, groundhogs and marmots are to be found at higher altitudes, and in the area of Piebiter creek, Bighorn sheep, mountain-goat, and mule deer are present. Grizzly bears are also in this area, and wolverines have been seen.

CHAPTER II

PREVIOUS GEOLOGICAL WORK

Information regarding the location, ownership, and history of individual claims of the Bridge River mining camp has been given adequately in the Annual Reports and Bulletins of the Minister of Mines British Columbia. References to other reports on this area are given in the bibliography.

The most comprehensive reports on the area are by McCann (1922), Cairnes (1937), and the unpublished report of Stevenson. More detailed reports on the geology of the two main producing mines have been written by Cleveland (1938), (1940); Gibson and Poole (1945); Joubin (1948); and Poole (1955). The work of Joubin is a comprehensive discussion of the structural geology of the Pioneer mine. In the report Joubin relates the vein systems to the conventional strain ellipsoid.

HISTORY OF PIONEER MINE

Although alluvial gold had been found in the Bridge river in the 1850's and expeditions had reported the presence of quartz veins as early as 1865, there was little prospecting in this area until the turn of the century. During 1897 and the preceding year several properties were staked throughout the valley, amongst them the Why Not, Lorne, and Ida May mineral claims.

The original Pioneer claim was staked on September 6th, 1897 by a prospector named Harry Attwood. He named the claim

after the popular hotel at Lillooet, whose owner Billy Allen had supplied his grubstake. Attwood soon sold out, and Allen acquired a new partner F. H. Kinder who profitably worked the claim, single handed, from 1900 until 1911. Amongst the tales that are told of this mining camp is the story that concerns the small hand crusher, that now stands on the lawn by the Pioneer mine office.

Sloan (1935:p.339) records that F. H. Kinder, a prospector with a keen nose for ore, obtained his partnership by offering to supply a mill. This was agreed upon, but the mill Kinder supplied was little more than a hand crusher. Another story is given in special edition of the Bridge River - Lillooet News for Thursday October 29.1936. "Kinder was a painter by trade and Allen a hotel keeper." Neither one knew anything about machinery when they ordered the mill from San Francisco using a catalogue for reference, and were more than surprised when it was delivered by freight car from Lytton!

The operation of the mine began in the spring when a mud slide from a prospecting trench exposed a small vein carrying free gold. Kinder drove a small adit about 40 feet below the exposure and cross cut 70 feet to a vein and a further 30 feet to a second vein. Two shorter adits driven above the original level, are now inaccessible.

Kinder soon constructed an arrastra and water wheel, processing 500 pounds of ore a day, which he operated until 1911 when he sold out to A. F. Noel.

The property was then sold to a syndicate, whose

principal members were, Peter and Andrew Fergusson, and Adolphus Williams, which soon increased the holdings to seven claims and three fractions. Work on Kinder's cross-cut continued. A 100 feet adit was driven from a point 700 feet west of the original cross-cut. In 1914 a company called the Pioneer Gold Mines Limited was formed and a small Chilean-type mill was later constructed. By 1917 $135,000 worth of gold had been produced, which amply repaid the syndicate. Although an inclined shaft had been sunk to about 187 feet below the original cross-cut, operation was difficult and the company decided to sell.

From late 1919 to 1924 little work was done on the property, but extensive examinations were made by interested companies. In 1920 the Mining Corporation of Canada took an option for $100,000 but later dropped this option when the second payment fell due. Early in 1921 the property was acquired by A. E. Bull, Wallbridge and Associates of Vancouver and the workings reopened. By the next year no more money could be raised, and David Sloan, a young engineer from the east, was hired by Wallbridge, to make an examination of the holdings. Sloan was sufficiently impressed to advise raising $30,000. This sum could not be obtained.

Again companies were approached, and an eastern enterprise from Binghampton, N.Y., showed interest. Officials who came to visit the mine were disillusioned and demanded a refund of the $1,000 they had advanced for the dewatering of the shaft. Sloan was severely criticised but he continued to

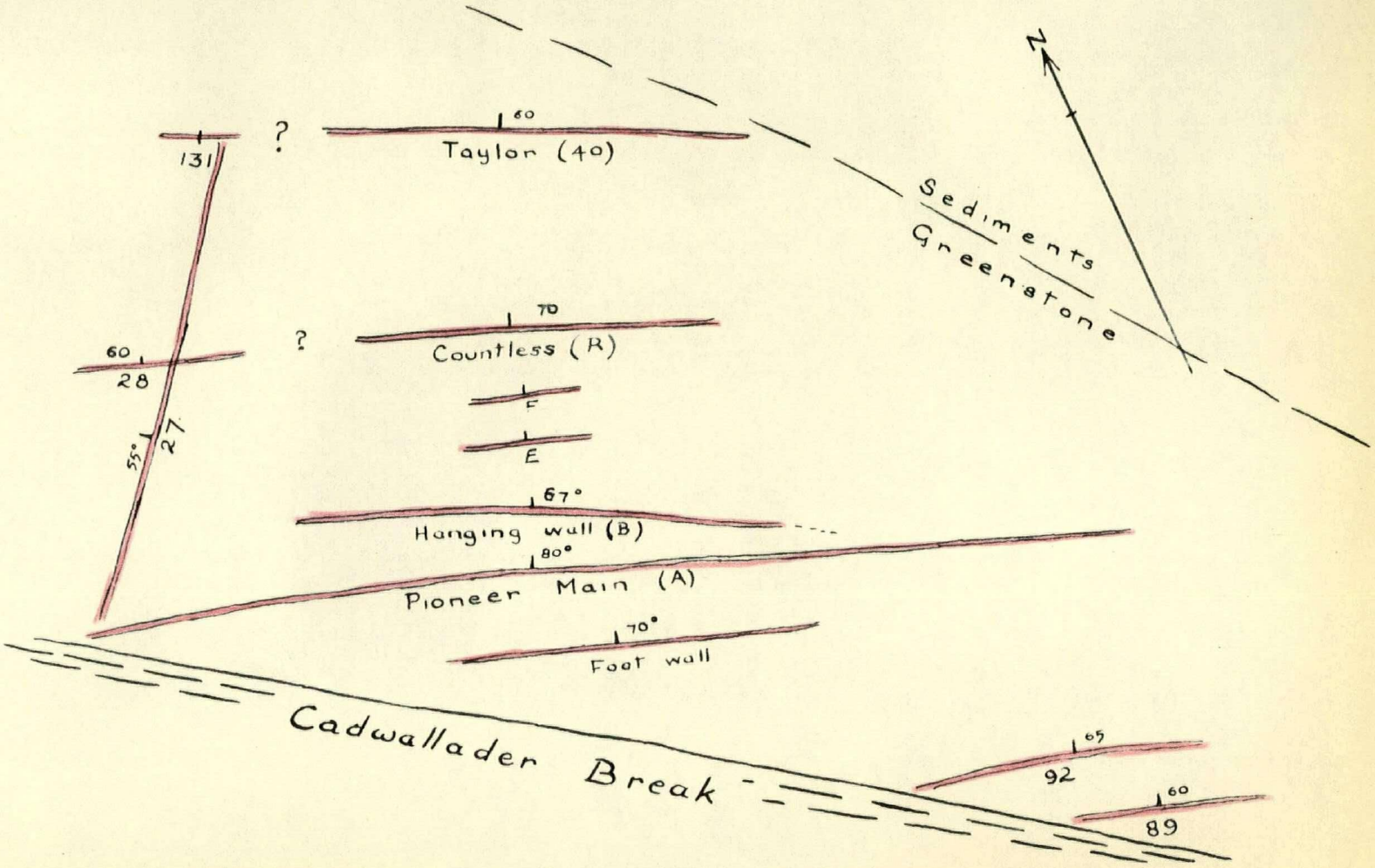


Figure. 2. Diagram to show approximate distribution of the Pioneer Veins.

develop the property.

Sloan then took a lease on the property, and with J. I. Babe as a partner, and operating capital of $3,000 commenced working in July 1924. Milling of gold ore left in the stopes, and the development of a length of ore beyond a small pinched section of the vein was successful. By September 10th a three thousand dollar gold brick was poured, and each month succeeding bricks were more than double this size, until winter curtailed operations.

The syndicate was reorganised in 1928 when the Pioneer Gold Mines of B. C., Limited, was incorporated. This Company continued to operate the mine until it amalgamated with Bralorne Gold Mines, Limited, in early 1959.

Development in 1924 involved the continued sinking the inclined shaft, the bottom of which was still only 187 feet below the level of the Kinder cross-cut, and by 1926 5 level was established at a depth of 350 feet below the surface level. In 1927 a vertical shaft was raised to replace the old inclined shaft. A new 100-ton per day all-cyanide plant replaced the old mill, and the efficient extraction enabled the company to rework, at a profit, the old mill tailings, while essential development was completed.

By 1932 No 3 shaft was raised from 9 level to the surface and had been sunk to 14 level, and in September 1932 a new unit was added to the mill increasing the capacity to 300 tons per day. In the following year, 1933, not only the greatest development was made, but the largest gold production of any

mine in the province was obtained.

By 1938 the ore on the main vein had been fully blocked out and the No 4 shaft, an internal shaft, commenced the previous year from 24 level, was sunk to 29 level, over 3,500 feet below the surface.

Strikes curtailed some of the work in 1939, but it is significant that some ore was produced from the 27 vein on 18 level. This 27 vein was later to become the main producing vein on the property.

By 1941 some development had been made on the 27 vein, and only small amounts of drifting on the 29 and 28 veins. Wartime conditions, with labour restrictions, prevented extensive development during the early period of the decade.

Development of the 27 vein on levels 20, 21, and 25 was carried out in 1946 and more than 800 feet of good grade ore was found on the lowest level. In December 1952 after extensive diamond drilling, work started on sinking No 5 shaft, an inclined shaft to follow in the foot wall of the 27 vein. The shaft sinking was stopped below 29 level, the bottom level for many years.

In 1956 an extensive diamond drilling and development program was conducted under the guidance of Dr. A. C. Skerl, P.Eng., of Vancouver, to locate any remaining veins and potential ore sections. A long cross-cut was driven into the foot wall of the main vein on 20 level, and a 2,000-feet cross-cut was driven easterly towards the Pacific Eastern workings. Extensive drilling into both walls of this cross-cut failed to

show any major vein structures on the 20 level other than the 89 and 92 veins.

In 1959 the mine became the property of the amalgamated Pioneer and Bralorne companies. The No 5 shaft was sunk to expose the 27 vein at the 30 level, and the diamond drilling program was integrated with the drilling program of Bralorne to investigate the ground between the two properties, that had previously been ignored by mutual agreement.

CHAPTER III

GENERAL GEOLOGY

The rock units in the Bridge River area are listed in the table of formations on page 15.

Drysdale (1915) has stated that the regional structure of the Bridge River area is "a broad anticlinal dome elongated in a northwest-south east and pitching at a low angle to the northwest."

Since 1915 most of the geologist working in the area have accepted Drysdales structural interpretation. However, detailed mapping of smaller areas has shown that the structure is not a simple anticline. Stevenson considers the area to be an anticlinorium, and cross sections by Cairnes (1937) show complicated folds on the southwest limb of the anticline in the vicinity of Pioneer mine.

The core of this anticline is composed of various types of rocks belonging to the Fergusson series. Cairnes (1937;p.14) considers that the Fergusson series is overlain by the Noel formation which consists of sedimentary rocks. He also considers that the Noel formation is succeeded by the Pioneer formation, which is in turn overlain by the Hurley series of sedimentary rocks.

Intrusions related to the Coast Range batholithic complex present in the Fergusson series comprise the Bendor batholith. Isolated bodies of rocks of dioritic composition,

known collectively as the Bralorne intrusives, are considered somewhat older than the Bendor rocks, and are found in a broad discontinuous belt that includes Pioneer mine. Small ultrabasic intrusions of the alpine type occur on both flanks of the anticline, and are called the Shulaps and President intrusions.

The complex and confusing contacts between individual rock units and the scarcity of outcrops except along the ridges, make detailed structural interpretations difficult. It is significant that MacKenzie (1920) who investigated the area to the north, was unable to find any supporting evidence for the presence of an anticline.

The ages of the rock units mentioned above are not accurately known. It is upon lithologic similarities that the Fergusson series is correlated with the Cache Creek group which is found near Lillooet.

The presence of carbonate in the Hurley series distinguishes this rock unit from the Noel formation, which is otherwise lithologically similar. This distinction may not be valid. Such a mineral may be readily introduced during metamorphism. These two rock units are not recognised by Joubin (1948:p.41), who considers them to be one unit which he names the Hurley-Noel formation.

In the immediate area of Pioneer mine there is a repetition of the Hurley-Noel formation and Pioneer formation which Joubin explains by folding. Additional information obtained in a recent exploration program is interpreted by the writer as indicating that such repetition can be more readily explained by faulting.

Era	Period	Formation	Lithology
CENOZOIC	Recent		Stream deposits, volcanic ash, slide debris; soil.
	Pleistocene		Fluvioglacial, glacial and stream deposits. (Total thickness ± 300 ft.)
Erosion unconformity - faulting?			
MESOZOIC	Upper Mesozoic	Bralorne Intrusions	Lamprophyre
			Gold Quartz veins
			Aplite Albitite. Quartz and feldspar porphyries. Soda Granite. Bralorne Diorite.
		President Intrusions	Peridotite (mainly) diorite, pyroxenite. (Mainly Serpentinized).
		Pioneer Formation	Green, massive, amygdaloidal, to finely crystalline andesites, and meta-andesites, andesitic tuffs, and breccias; associated, intrusive, dioritic phases. Albitised at Pioneer. (Thickness ± 2,000 ft.)
	Local unconformity but generally transitional		
		Hurley (Noel) Formation	Banded, argillaceous and tuffaceous sediments, minor cherty sediments, conglomerate and agglomerate, locally limy and fossilliferous; minor intrusive phases. Minor local rhyolitic flows and breccias. (Thickness ± 1,200 ft.)
Structurally unconformable			
PALEOZOIC		Fergusson Group	Mainly thinly bedded chert and dark grey to black or reddish; graphitic argillite, massive chert. Minor andesitic to basaltic lavas and associated limestone.
Unexposed			

CHAPTER IV

DETAILED GEOLOGY OF PIONEER MINE

The relative positions of the rock units exposed in the vicinity of Pioneer mine are indicated in figure 3 in the text. The distribution of rock units underground is shown in the 300 scale plans of 20 level and 29 level which accompany this thesis.

The plans show parallel belts of sedimentary and volcanic rocks on both sides of a fault zone. This fault zone is the "Cadwallader Break" and is composed of serpentine which forms the southern limit of the mine workings.

The repetition of these rock units is explained by Joubin (1948) to be due to folding of the volcanic rocks into two sharp anticlines with the overlying sedimentary rocks now occupying the position of the synclines. The author considers that the repetition of these rock units may be produced by the faulting of a homocline.

The individual rock units and intruded igneous rocks are discussed in the following paragraphs.

FERGUSSON GROUP

The name Fergusson series was first applied by Cairnes (1943:p.9) to the sedimentary and volcanic rocks previous assigned to the Bridge River Series which formed the core of

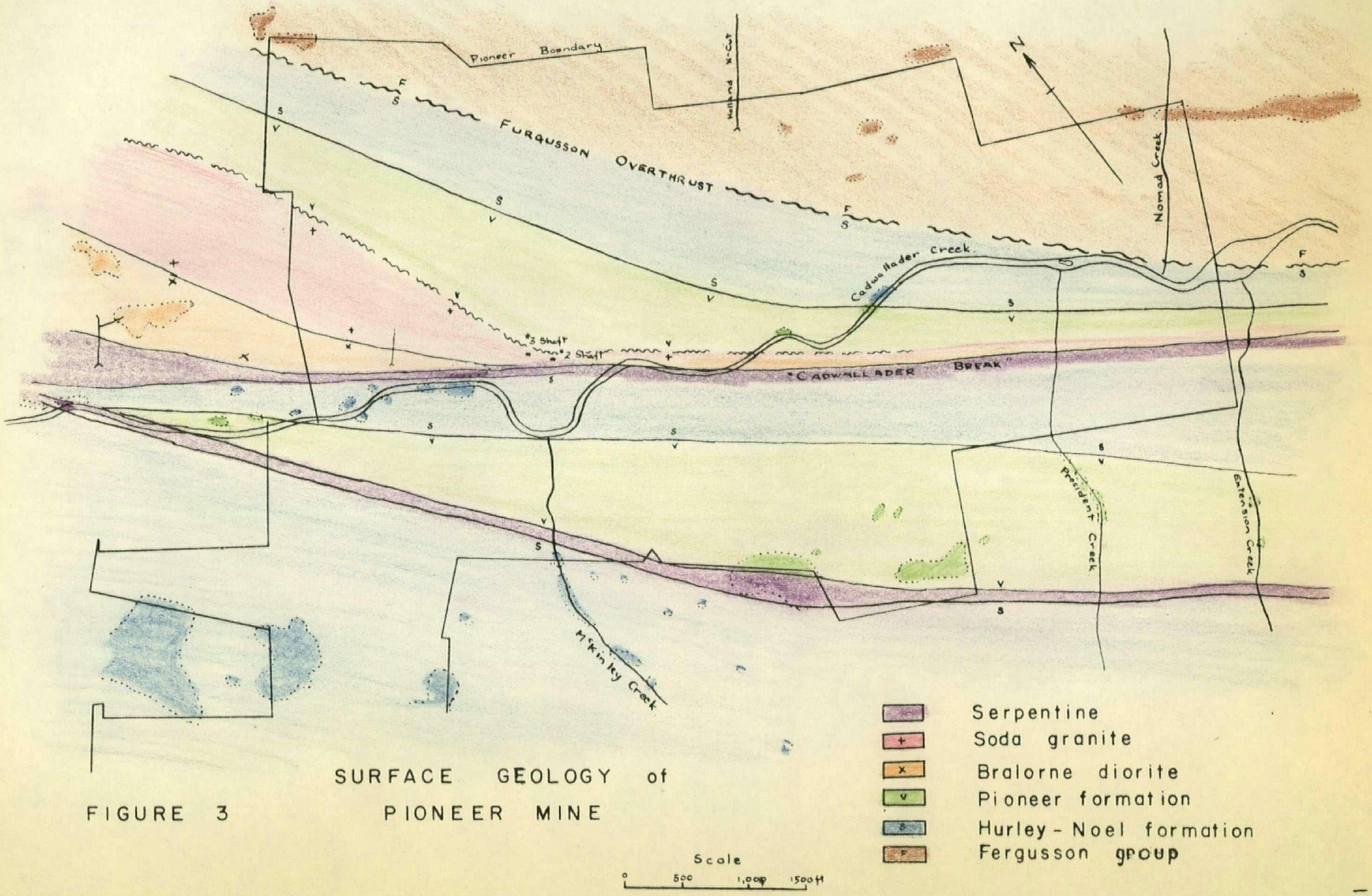


FIGURE 3 SURFACE GEOLOGY of PIONEER MINE

the anticline proposed by Drysdale (1915). Cairnes (1942:p.2) later discarded the term series in favour of the term group.

The Fergusson group occur on the northern part of Pioneer mine but do not form any part of the mine workings. This surface exposure is found to exist to the top of Mount Fergusson directly north of Pioneer mine. The exposed formation here may be regarded as the type section although much variation is to be found both here and elsewhere in the group.

The contact with the sediments to the south is nowhere seen on the surface, but is exposed underground in the Pacific Eastern workings where it is seen to be a broad fault zone dipping 45 degrees in a north westerly direction. Joubin (1948:p.45) refers to this fault zone as the Fergusson overthrust.

The Fergusson group although highly variable in composition is dominantly composed of ribbon cherts which are much contorted. At lower elevations on the side of Mount Fergusson the group is composed of narrow layers of grey-white chert from fractions of an inch to several inches thick separated by partings of black shaley argillaceous material usually only a fraction of an inch thick, which have been squeezed into the areas between the contorted chert bands. At higher elevations the chert bands become less numerous but much thicker and the thick intervening members of argillite become massive. At the top of the mountain chert bands are not present and most of the group is composed of massive argillite.

It is this variable nature of the rock type that causes great difficulty in the separation of the Fergusson group and other rock units in the area, for each unit may contain similar lithologic sections.

Cairnes (1937:p.14) says:

> "At a few places within the outcrop areas of this formation (the Noel) narrow belts or lenses of cherty sediments much resembling those of the Fergusson series were noted."

Volcanic rocks are found in the Fergusson group in several outcrops as fine to medium grained flows up to several tens of feet thick showing pillow structures. One of these flow horizons has been investigated by the Holland cross cut (see Figure 3). Stevenson records such lavas to be "..... coarse grained, diabasic with prominent hornblende phenocrysts set in a groundmass of plagioclase laths." Cairnes reports that many of the lavas contain fibrous actinolite and small flakes of biotite, commonly with abundant secondary minerals such as carbonate, sericite, and zoisite. This metamorphism is attributed to the thermal effects accompanying the intrusion of the Bendor batholith.

Limestone pods are not unknown in the Fergusson group. These pods may range from a few inches to several tens of feet and occur in the lavas, or may form lenticular bodies up to 100 feet thick and several hundred feet long. The larger bodies are composed of grey to white coarsely crystalline carbonates, and may contain along the contacts garnet, epidote, and minor amounts of sulphides. These minerals are the result

of thermal metamorphism by the Bendor batholith.

As stated previously the lack of fossil evidence has resulted in the Fergusson group being correlated on lithologic similarities to the CacheCreek series about Lillooet. Trettin (1960:p.33) considers the Cache Creek series near Lillooet to be Upper and perhaps partly Middle Permian in age.

HURLEY-NOEL FORMATION

The Hurley-Noel formation is the name given by Joubin (1948:p.42) to the dominantly sedimentary rocks that occur to the north of the volcanic rocks in the Pioneer mine, and repeated immediately south of the "Cadwallader Break", and again south of the second serpentine zone as shown in figure 5. The exposures farthest south were considered previously as part of the Noel formation and distinguished from the Hurley group by the lack of carbonates.

The Hurley-Noel sedimentary rocks included mainly argillite, and minor amounts of finer grained sandstone, tuffaceous argillite, and local lenses of conglomerate. Almost undeformed ribbon cherts and small bands of volcanic rocks can be found, which are similar in appearance to some of the exposures of the Fergusson series. Such similarities in rock types have resulted in the misidentification of the rock units which resulted in erroneous correlations.

The argillites is dark grey to black in colour, and the beds may be massive or finely laminated. All beds are veined

with thin seams of carbonate. The thickness of individual beds may range from a fraction of an inch up to several feet, and although there may be variation in the grain size of the component minerals few top determinations can be made. Conglomerate beds in the Hurley-Noel formation appear to be local lenses a few feet thick and a few tens of feet long. The pebbles are rounded to angular fragments of limestone, granite, with rounded fragments of chert and felsitic rocks. The matrix is fine sandy material.

Joubin (1948:p.42) considered these lens to form a local basal conglomerate but because of their presence, throughout the sequence and their local distribution they are regarded by Cairnes as intraformational breccias.

PIONEER FORMATION

The Pioneer formation, locally called greenstone, occurs as bands both sides of the Cadwallader Break, overlapping in the vicinity of Pioneer mine. Each band of greenstone lies to the south of the Hurley-Noel sedimentary rocks, and in each case appears to be conformable and gradational to this formation. The 2,000 feet wide northern band forms part of the area in which the economic gold-quartz veins are found, and also to the Pacific Eastern workings to the east. The greenstone belt south of the Cadwallader Break forms a zone 2,000 feet wide which pinches out against the Cadwallader Break to the west, but continues eastwards for several miles.

The dominant colour of the Pioneer formation ranges from dark to light green. Colour variations may be accompanied by changes in the relative competence of the greenstone.

Surface exposures do not show any structures other than vague ellipsoidal forms. Drill cores and fresh surfaces underground show primary structures which indicate a volcanic origin for the greenstone. On the basis of such structures Joubin recognised 4 main lithologic types. These types although distinctive were not sufficiently continuous to be used as marker horizons.

The main varieties of greenstone include amygdaloidal flows, tuffs, pillow lavas, flow top breccias, pyroclastics, and massive fine grained rocks that may be in part intrusive.

Undisturbed contacts of these varieties of the greenstone are rarely preserved, because of subsequente deformation. For example the volcanic breccia shown in Figure 4 is traversed by irregular dark green bands that upon microscopic investigation prove to be mylonite. Such fine grained mylonite contains large cubes of pyrite that appear to have been partly rotated, and secondary comb quartz occupys the pressure shadows. In other instances deformation of the greenstone has taken the form of intricate faulting so that the rock is now broken into discrete blocks a few 10's of feet in size. The net result is that the beds cannot be correlated over distances of more than one hundred feet, and the overall structure of the greenstone remains imperfectly known.

Amygdaloidal flows occur in several parts of the mine and are described by Joubin (1948:p.40) as "The amygdaloidal type occurs most commonly as a repeated succession of thin flows, followed by successions of thin tuff beds", and further ....."amygdaloidal flows rarely exceed one foot in thickness and amygdule size variation commonly indicates the flow top".

Thin sections show the flows are composed of albite laths with a trachytic texture, in an unresolved groundmass of chlorite and opaque minerals. The amygdules are filled with chlorite, quartz and epidote minerals.

Tuff is recognised by its relatively coarse grained texture compared to the other varieties of greenstone. Although grain size variation occurs grading is not sufficiently well developed to be used for top determinations. Dark particles, up to a few m.ms in size, occur in a fine grained matrix.

A thin section of a specimen of tuff from the diamond drill station at the end of the 20-135 cross-cut contains shards and fragmental portions of highly vesicular aphanitic rock. The vesicles are now filled with fine-grained intergrowths of quartz, chlorite, and epidote. The remainder of the section is composed of fragments of hornblende and albite with some chlorite in a fine grained groundmass (see figure 5).

Numerous ellipsoidal shapes, identified as pillow lavas, are recognized in areas of apparently homogeneous rock by the contrasting colour. These shapes may be outlined by concen-

Figure 4. Photograph of Breccia (Amygdaloidal pyroclastic) at start of 20-135 x cut. Note the irregular bands of mylonite, and the light coloured amygdaloidal rims of the fragments.

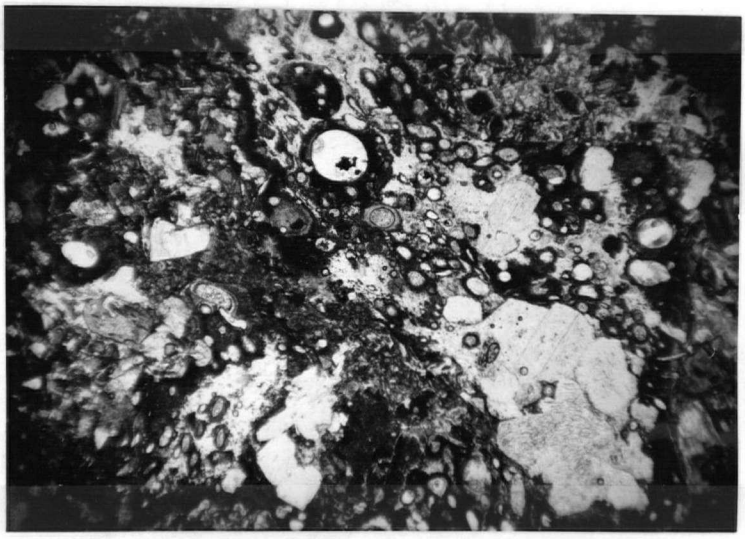


Figure 5. Photomicrograph of tuff at face of 20-135 x cut. Plain light x 16. Thin section 20-135. No 1A.

trations of sulphide minerals, or the development of amygdules at the borders. Cairnes (1938:p.16) records that such structures are rare, and Cleveland (1937) states that ".....at one place in the King mine pillow structures are present." Because these structures have smooth outlines and occur singly they cannot be used for top determinations.

Joubin states that the flow-top breccias grade into what he calls "amygdaloidal pyroclastics". These pyroclastics can be found near the portal of the Taylor Tunnel, in a short stub drift from the R drift on 5 level, and again at the start of the 20-135 cross-cut. Figure 4 shows the appearance of the amygdaloidal pyroclastic with its peculiar light-coloured, sub-angular to rounded, fragments up to a few inches in size, with light coloured amygdaloidal selvedges, set in a dark fine-grained cementing material. In thin section the fine-grained groundmass is seen to be composed of small albite laths with a trachytic texture in a mass of fine-grained chlorite and impalpable dust. A fracture crossing the thin section is infilled with epidote, comb quartz, and fresh albite. A small amount of carbonate occurs throughout the slide mainly replacing the groundmass.

The massive greenstone generally has a dark green colour and is medium- to fine-grained, the individual crystals being too small to identify with a hand lens. In thin section the rock is composed of small laths of albite with a trachytic texture in a dark, unidentified, fine-grained, groundmass. In other

thin sections, areas of fine-grained micas and carbonate may represent original feldspar grains and patches of chloritic material may represent the mafic minerals. Circular patches of chlorite and epidote indicate vescicles in the original flow.

BRALORNE INTRUSIONS

All the granitic rock types that occur in Bralorne and Pioneer mines including all the varieties of augite diorite, quartz diorite, greenstone diorite, and soda granite, will be discussed under this heading. The name Bralorne intrusions was given by Cairnes (1937:p.21) to a group of coarse-grained rocks that had been variously described in previous reports.

The rock types classified as the Bralorne intrustions are confined to a broad, discontinuous zone extending northwestwards from the Pacific Eastern property to the Wayside mine in the Bridge River Valley. This zone has an overall length of 9½ miles and a width up to 2,500 feet. The most prevalent rock type is the Bralorne diorite, which is well-exposed in the Bralorne mine workings; on the Pioneer holdings in the outer few feet of the Countless adit; and also in the diamond drill holes (C-537, C-543) drilled southward toward the serpentine from a position inside the Countless adit. Throughout the valley the contacts between granitic rock types are gradational. Cairnes (1937:p.24) states:

> "The diorite may, in places, as in the California working on the B.R.X. property, be traced through

> every gradation into a fine-grained rock indistinguishable from greenstone such as forms part of the Pioneer formation and known to be of volcanic origin".

Poole (1955:p.2) in considering the Bralorne diorite in and about the Bralorne property states:

> ".....variations in composition and texture occur in the greenstone diorite complex of the contact zone.
>
> The contact between the greenstone and diorite is a transitional zone several hundred feet wide in which the diorite appears to have replaced or absorbed much of the greenstone. As the contact is approached the diorite becomes finer grained and the greenstone so altered that it is difficult to demark one rock from the other."

Stevenson (unpublished report of B.C. Dept. of Mines) considering the same contact records:

> "The contact between hornblendite and diorite is not sharp and a gradation may be traced from hornblendite, through hornblende rich diorite to the average diorite. This feature suggests that the hornblendite is an intermediate stage in the alteration of greenstone to diorite".

Granitic rock known as the soda granite occurs on the north side of the main body of Bralorne diorite as a large elongated body extending from Bralorne mine eastwards through Pioneer, and narrowing considerably to a small dyke-like body as it continues into the Pacific Eastern workings.

Poole (1955:p.2) records that the soda granite also occurs in the Bralorne property as small isolated masses and dykes irregularly distributed throughout the northern section of the diorite.

Most exposures of contacts between the Bralorne diorite

and soda granite are gradational.

Joubin (1948:p.43) records:

> "The contacts of the soda granite and diorite are commonly gradational across a patchwork-like zone of hybrid type; the contacts between the soda granite and greenstone are sharply defined with local shearing of the greenstone."

Poole (1955:p.2) reports that the contacts of soda granite and greenstone are sharply defined.

Cairnes (1937:p.27) is puzzled by such relationships, and concludes that, ".....beyond reasonable doubt the soda granite and the augite diorite are related in origin, though the granite may be younger." He states further that the Pioneer greenstone and the Bralorne diorite originated from the same deeply-buried magma, presumably at widely-spaced times. Such an explanation creates problems regarding the timing of the various intrusions. However, the common presence of albite, and absence of K feldspar in all rock types suggests that they may have some common origin.

An alternative explanation for these conflicting contact relations of the Bralorne diorite and the soda granite was first made by Dr. A. C. Skerl (1956 private report to Pioneer company) who writes:

> "During a visit to these mines in 1946 I was quite impressed by the variation and transitions in the intrusive rocks in this area and suggested that they formed an excellent example of dioritization and granitization."

On field evidence Skerl suggests the original greenstone was soaked in hot alkaline solutions resulting in its trans-

formation to a diorite and ultimately soda granite.

Stevenson records there is evidence that the diorite has replaced the greenstone and the series has been intruded by a later granite which contains fragments of the diorite.

In the following sections the petrology of the main types found in Pioneer mine will be described.

1) SODA GRANITE

In Pioneer mine the soda granite occupys an area immediately south of the northerly belt of Pioneer greenstone, and forms a zone about 600 feet wide at the western boundary of Pioneer, which narrows to a width of less than 50 feet towards the eastern border of Pioneer mine as it crosses into the Pacific Eastern holdings.

The soda granite is a light grey, medium-grained rock with a hypidiomorphic texture. Essentially, it is composed of irregular grains of clear quartz and whitish feldspar, ranging in size from less than 0.5mm to 5mm with minor amounts of chlorite in thin dark green streaks and clots. Some samples contain small light green spots of epidote.

The composition of the soda granite as estimated from thin section is as follows:

Quartz		45%
Plagioclase	An_2-An_{10}	30%
Chlorite		8%
Epidote		5%
Opaque minerals		2%
Apatite		1%
"Sericite"		2%
Biotite		1%
Carbonate		6%

The petrographic relations of the individual minerals are described in the following paragraphs. Most sections show evidence of cataclasis which is wide spread throughout the soda granite.

Mineralogy and Mineral Habit

QUARTZ The quartz content of the soda granite is highly variable and may compose up to 50% of some thin sections. The quartz occurs either interstitially to the plagioclase, or as anhedral grains up to 4mm in diameter, commonly in clusters, with individual grains having sutured contacts. Most of the grains show stain extinction, fracturing, and planes of fluid inclusions. Contacts between the quartz and the feldspar are smooth with embayments into the feldspar. These contacts indicate that some replacement of the feldspar has occured.

PLAGIOCLASE The plagioclase varies between 20% and 40% of the mineral composition, and occurs in crystals having rough rectangular shapes with a random orientation but in some sections showing a trachytoid texture. Both thin section studies and stained hand specimens show that K-feldspar is absent. The potash content of analysed rocks may be explained by its occurence either in the micas or in solid solution in the plagioclase. The composition of the plagioclase ranges from An 0 to An 10, and some crystals show normal zoning the margins being relatively more sodic than the core. Some

plagioclase crystals have clear margins in contrast with the cores which are partly altered to "sericite" with or without clusters or disseminations of epidote and other secondary minerals.

CHLORITE The chlorite is present in irregular shaped areas between the quartz and plagioclase and rarely amounts to more than 10% of the total composition of the rock. It is pale green, slightly pleochroic and almost isotropic, or with anomalous brown birefringence. It forms pseudomorphs after an amphibole that may preserve the amphibole cleavage. (see figures 6, 7). Some of the chlorite has small birefringent areas, showing brown pleochroism, which are identified as biotite.

Small irregular veins of isotropic chlorite are considered to be pseudomorphs often pyroxene (?), and such areas may occur in the large chlorite pseudomorphs after horneblende. Figure 10.

CARBONATES Carbonate occurs in highly variable amounts as small irregular grains generally confined to cracks, and zones of brecciation, although it can be found replacing the plagioclase. Near the quartz veins the carbonate content of the altered rock reaches 70% or more.

OTHER MINERALS In numerous sections small amounts of fine grained biotite can be seen replacing chlorite. Ilmenite and pyrite occur as primary accessory minerals, and leucoxene, sericite (?), and epidote are other alteration products.

The light coloured quartz-albite rocks occuring in Pioneer mine may by readily classified as soda granite. (Brown 1952).

2) BRALORNE DIORITE

The most abundant rock type among the Bralorne intrusions is known as the Bralorne diorite. It occupies most of the ground of the Bralorne mine but only a narrow wedge protrudes into the Pioneer property. This wedge, only a few 10's of feet wide is bounded on the immediate north by the soda granite and on the south by the serpentine.

The typical Bralorne diorite is a greyish-green, medium-grained, rock characteristically suffused by a network of irregular seams of albite and/or carbonate. The main minerals are dark blackish-green hornblende, and large whitish subhedral crystals of albite. These minerals occur in irregular knots and clusters giving the rock a patchy appearance which is also a characteristic of the Bralorne diorite.

The mineral content of typical Bralorne diorite estimated from thin sections is as follows:

Albite (An_0-An_7)	45%	
Hornblende	32%	
Pyroxene	--	found in some sections from Bralorne mine
Chlorite	7%	
Epidote	5%	
Quartz	4%	
Calcite	4%	
Actinolite		(only in certain sections)
Opaque minerals	1%	
2ndary micas	1%	

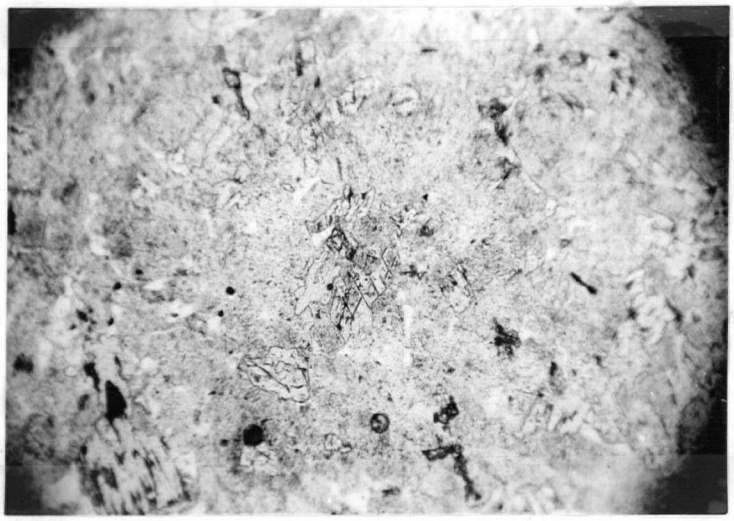


Figure 6. Photomicrograph of soda granite showing pseudomorphs of chlorite after hornblende. Plain light x 16. Note relict cleavage of hornblende. Thin section 20-90 No 10.

Figure 7. Photomicrograph of soda granite showing chlorite. Polarized light x 16. This is same section as Fig. 6. Note birefringent areas of biotite within the chlorite.

Thin sections show the Bralorne diorite to be composed of hornblende, albite, partly altered pyroxene, and minor amounts of quartz, opaque iron oxides, carbonates, chlorite and actinolite. The pyroxene in specimens from Bralorne mine occurs as small crystals some of which are rimmed and partly replaced by hornblende. Fibrous amphibole was found in certain slides replacing the mafic minerals.

Mineralogy and Mineral Habit

PLAGIOCLASE The amount of plagioclase is variable and may amount to 60% of the rock. Plagioclase occurs as large crystals 3mm to 5mm in length, commonly clustered together. In addition, some plagioclase occurs as small subhedral crystals often with a trachytoid texture and poikilitically enclosed in hornblende.

The composition of the feldspars was found to range from An_0 to An_{10}. The individual crystals are very similar in size and occurence to those of the soda granite but are less alterated. No orthoclase was found in any thin sections nor stained hand specimens.

HORNBLENDE Hornblende is present in all thin sections and may make up to 40% of the total mineral composition. The hornblende occurs as small irregular areas occupying the interstitial areas between euhedral plagioclase crystals or as large patches poikilitic enclosing smaller crystals of plagioclase.

In plain light the hornblende has a green colour and is distinctly pleochroic, but has a mottled appearance.

x = dark green
y = olive green
z = yellowish green

Birefringence colours are low second order, and the 2v is large, and negative. The extinction angle of $z_{\wedge}c$ is usually less than 23 degrees.

The hornblende may show extensive alteration to an acicular amphibole which has less pheochroism and a smaller extinction angle. $Z_{\wedge}c$ is usually less than 20 degrees. This acicular amphibole is in grains too small for refractive index determinations, but it is considered to be actinolite.

PYROXENE Cairnes (1938:p.22) records augite as a characteristic mineral of the Bralorne diorite although it is rarely abundant. Pyroxene was identified in a thin section of a specimen of diorite obtained from Bralorne mine 31 level, and another from Pacific Eastern. The pyroxene was rimmed by and partly replaced by hornblende. The extinction angle of $Z_{\wedge}c$ was determined always less than 45 degrees and there is very low dispersion. The pyroxene is intimately mixed with hornblende and as it was impossible to separate these minerals, using a binocular microscope, no refractive index determinations were made.

On the basis of the extinction angle and low dispersion the pyroxene was determined as diopside.

In several thin sections from Pioneer, both in the soda

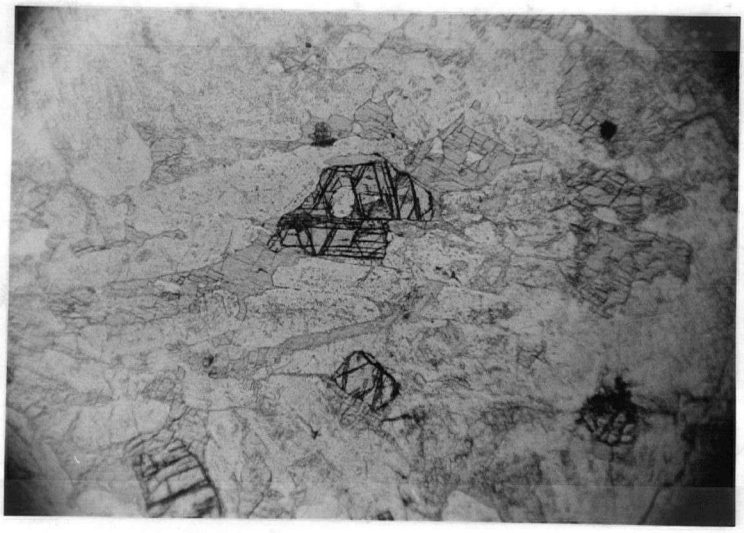


Figure 8. Photomicrograph of Bralorne diorite showing pseudomorph of chlorite after pyroxene (?) Plain light x 16. Thin section 20-458 at 417 ft.

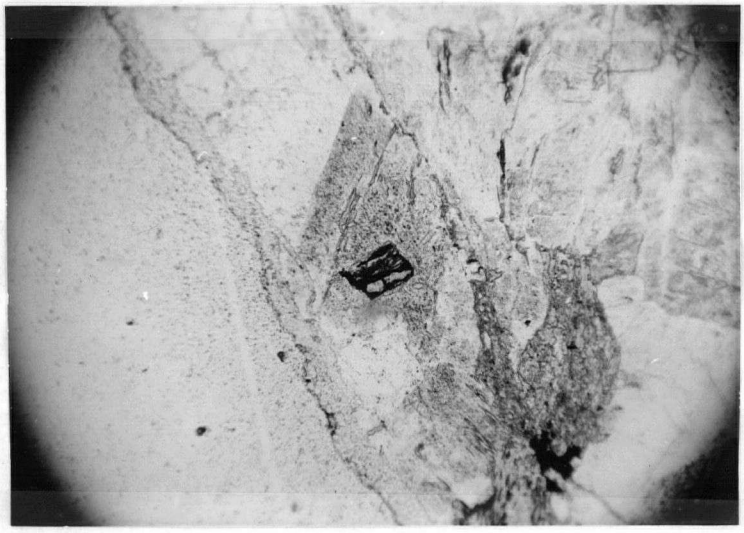


Figure 9. Photomicrograph of soda granite showing pseudomorphs of chlorite after pyroxene (?) Plain light x 46. Thin section 20-90 No 7.

granite and more particularly in the diorite, there are crystals of pyroxene (?) up to 1mm in size which are now altered to chlorite with some epidote. The crystals outlines are irregular, marked by opaque iron ores which also form along the cleavage. (Figures 9 and 10) Carbonate generally forms broad zones, emphasizing the cleavage, and chlorite composes the main body of the pseudomorph. This chlorite is pale green, not pleochroic, and its refractive index is less than that of epidote. Under crossed nicols it is almost isotropic, and is similar to some of the chlorite which replaces the hornblende.

CARBONATE Carbonate occurs in veinlets, and fractures, and partly replaces zones of brecciation. Carbonate may also occur together with quartz replacing the groundmass in these zones.

OTHER MINERALS Other minerals include pyrite, sphere, ilmenite, and magnetite, with secondary epidote and alteration minerals of feldspars. A minor amount of quartz is interstitial to the plagioclase and hornblende.

The numerous textural and compositional varieties of this rock are most easily referred to by the use of the non committal term Bralorne diorite.

GREENSTONE DIORITE

The peculiar and complex relationships of the Bralorne diorite and the Pioneer greenstone have been stressed by many

authors. Cairnes in particular is puzzled by the gradational contacts between the diorite and the greenstone, and in his plate V (facing page 18 in Cairnes 1937) shows examples of the peculiar textured greenstone diorite which he believed represents a near surface phase of the Bralorne intrusives.

In the Pioneer mine the greenstone diorite occurs as a narrow belt of variable width usually only a few tens of feet between the diorite to the north, and the serpentine of the Cadwallader Break in the south.

Specimens taken from drill holes on 20 level, in particular D.D.H. 20-458 show that the fine grained material about the dioritic patches is identical to the diorite in composition, but the crystals of hornblende and albite are severely brecciated and comminuted. Figure 10 shows a large plagioclase crystal which has been broken, and now occurs in a matrix of finely-ground material.

In the hand specimen, the greenstone diorite grades into the serpentine, by the increase in the number of dark green slip planes and a darkening in the body colour. These changes occur as serpentine minerals replace the general matrix and crystal fragments.

The greenstone-diorite is regarded as sheared diorite with peculiar remnants of original medium grained diorite. Although the comminuted diorite has a similar megascopic appearance to that of the Pioneer formation, there are no primary structures of volcanic origin, and the greenstone and the green-

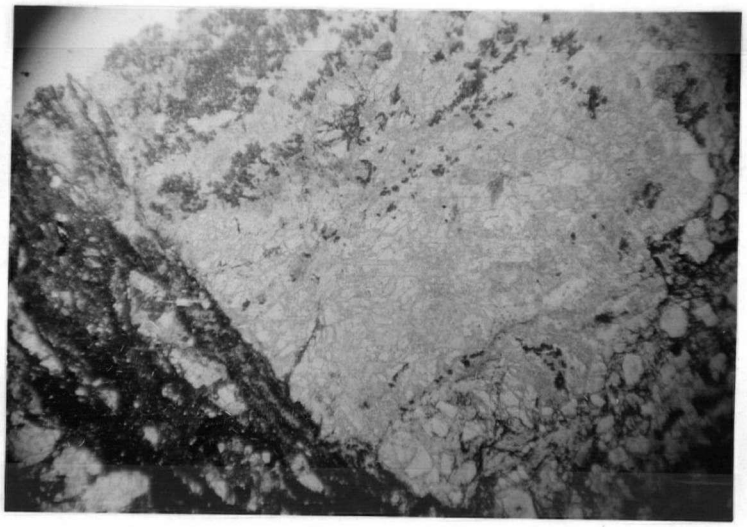


Figure 10. Photomicrograph of greenstone diorite. Polarized light x 46. The large shattered crystal of albite is now surrounded by a matrix of comminuted material. Specimen 20-458 at 376 feet.

stone diorite are not considered to be related in the manner suggested by Cairnes.

PRESIDENT INTRUSIONS

The President intrusions (Cairnes 1937:p.28) is the name given to the dykes and small stocks of alpine-type ultrabasic rocks that occur in several places in Bridge River area. The cores of these bodies are massive dunite and/or peridotite, but their margins commonly are altered to serpentine, particularly along faults. A larger body in the Shulaps Mountains to the north, previously regarded as an extrusive rock by Drysdale and McCann, is now known to be a layered ultrabasic body, similar in many respects to the President intrusions. The Shulaps ultrabasic body has been extensively discussed by Leech (1953).

The serpentine that occurs in the Cadwallader Creek area, and in particular that on Pioneer property is evidently derived from, and part of, the President intrusions.

There are two main serpentine zones on Pioneer property both of which are sub parallel to the dominant northwesterly structural trend. The more southerly zone does not occur in the mine workings and forms the southern limit of the Pioneer formation on the south side of Cadwallader creek. The northern zone, forms the present southern limit of the Pioneer gold-quartz veins, and occurs as a major fault zone known as the "Cadwallader Break". Serpentine of this zone is exposed on the surface along Cadwallader creek, and in the more southerly mine

workings, and in drill holes drilled towards the south.

Thin sections of specimens from this fault zone contain bladed antigorite with chrysotile and minor amounts of magnetite. Large broken crystals of hornblende, similar in appearance and optical properties to those found in the Bralorne diorite, may be altered partly to serpentine. This suggests at least some of the serpentine may be formed from the Bralorne diorite. Adjacent to the soda granite in 20-89 drift west the serpentine contains small grains of quartz of a size similar to those quartz grains in the soda granite and this would suggest that there has been movement of the Cadwallader fault zone after the emplacement of the soda granite.

A chemical analysis of material from the outcrop near the Pioneer mill compared with the analyses of other local serpentines shows a remarkable similarity, and suggests a common origin for all serpentines. All analyses are given by Cairnes (1937).

The age of the President intrusions is essentially unknown, but elsewhere in the Cadwallader creek area, the occurence of soda rich dykes cutting the President intrusions led Cairnes to suggest emplacement of the ultrabasic rocks prior to the formation of the siliceous phases of the Bralorne intrusions.

MINOR INTRUSIONS

The numerous dykes and other small intrusive bodies in

the Bridge River area are divided into 6 general groups by Cairnes (1937:p.31), as listed below:

1) Post-Bendor (Tertiary) lamprophyres and basaltic dykes.

2) Intrusions related to the Bendor batholith.

3) Intrusions probably somewhat older than, but related to, the Bendor batholith.

4) Altered dykes of intermediate composition, probably related to the Bralorne intrusions.

5) Dykes related to the President intrusions.

6) Intrusions in part or entirely related to the Bralorne intrusions.

Of these, only examples of groups 1 and 6 are found in the Pioneer mine area.

GROUP I

LAMPROPHYRE

Lamprophyre dykes that range in width from an inch to several feet cut all rock types including the quartz veins. These are not faulted and represent the latest visible tectonic event in the area. The dyke contacts are fine-grained but the lamprophyre has caused little or no alteration of the country rock.

Sampson (1953) has described in detail the lamprophyre dykes found on 15 level. Other dykes have been exposed on 21, 20 and 25 levels; and on the southern end of the 27 vein from the 27 level downwards. In this last place the dykes occur within and along the walls of the vein, creating mining dif-

ficulties and causing poor core recovery in the drilling from the 29-41 x cut. Diamond drilling shows that these dykes persist to depths of 1,000 feet below 29 level.

In hand specimen the lamprophyre is porphyritic with dark brown glistening euhedral biotite flakes up to 4mm in size in a dark brown aphanitic groundmass. The groundmass is soft and on exposure weathers rapidly to a lighter brown crumbly material, which is very dry.

In thin section the biotite is dark brown and highly pleochroic, occuring as small unoriented flakes up to 4mm in length within a brownish matrix composed of magnetite dust and unresolved isotropic material with a spherulitic texture. Finer-grained material occurs towards the contact and the biotite has parallel orientation suggesting flow layering.

GROUP 6

THE PORPHYRITIC INTRUSIONS

In the Pioneer property dyke-like bodies of variable width usually occur as steeply-inclined sheets with sheared contacts. Fine-grained contacts are rare and if originally present have been obscured by later movement. The only members of this group present in the Pioneer workings are aplite albitite and quartz and/or feldspar porphyries.

QUARTZ AND/OR FELDSPAR PORPHYRIES

These occur in greenstone and also soda granite as dyke-

like bodies with irregular sheared contacts but some have fine-grained margins. Generally the dykes within the greenstone are more brittle than the volcanic material and in places exhibit a ladder of narrow quartz-filled fractures. (Figure 11)

The porphyries within soda-granite are generally finer-grained with a dark green colour, whereas those in greenstone are typically massive, porphyritic, with a light green to grey colour. In thin section phenocrysts of quartz or albite may be either euhedral, or anhedral with corroded margins. The fine-grained matrix is composed of interlocking grains quartz and albite in varying proportions. Secondary chlorite, "sericite" and carbonate occur in many slides. Biotite has been noted replacing large patches of chlorite.

APLITE ALBITITE

The name albitite porphyry was first applied by McCann (1922:p.32) to a great number of fine grained dyke rocks closely associated with the gold-quartz veins. The name has now become aplite albitite by common usage.

The dyke rocks are fine-grained, rarely with conspicuous phenocrysts, and have a light grey to buff colour, generally with enough pyrite to cause discolouration upon weathering.

In thin sections the rock is seen to be composed of clear albite laths forming a matrix of small crystals with intergrown, interlocking quartz. Occasional phenocrysts of feldspar are partly altered to a mass of carbonate. Recorded accessory minerals include ilmenite, arsenopyrite, and pyrite.

The age of these intrusions is given by Cairnes to be later than the main period of the Bralorne intrusion. The veins are post Bralorne intrusion in age but are pre vein, for they can be found offset by the veins.

PETROGENESIS OF THE BRALORNE INTRUSIONS

The rocks of Pioneer mine are unusual, for they contain no orthoclase and only plagioclase. The close association of the gold quartz veins and the Bralorne intrusions implies a common origin. Any theory of genesis of the Bralorne intrusions should explain the many variations in the mineral content of the Bralorne diorite, the origin of the soda granite, and the widespread albitization of the area.

The Bralorne diorite contains varying amounts of hornblende and albite. Cairnes and McCann consider this diorite is an earlier product of consolidation of the magma which formed the Coast Range intrusions. Basic masses similar to the Bralorne diorite have been described from other areas, and a hybrid origin has been proposed. Compton (1955) considers that several basic bodies associated with the batholith near Bidwell Bar California are basic intrusions emplaced prior to the main granitic body of the area. About the batholith replacement migmatites are found. A syenite body northeast of the "Colville batholith" is described by Waters and Krauskopf (1941: p.1404) and they concluded that a hybrid origin for this body is possible. Roots (1954:p.165-175) described several basic

Figure 11. Photo of quartz feldspar porphyry dyke at start of 20-135 x cut. Note veinlets of quartz which are confined to the brittle dyke rock and do not pass into the 'greenstone' wall rock.

masses of variable composition and textures occuring at the margins of the Omineca intrusion, B.C. He states that such bodies are typically found in orogenic regions. He gives the following theories of genesis for such basic bodies:

1) They may be formed from ultrabasic and basic magma which possessed a high content of volatiles and were intruded at high temperatures. It is stated by Roots that Buddington calculated the analysis of a specimen of hornblendite from southeastern Alaska in terms of anhydrous minerals and found it to be the equivalent of an olivine gabbro.

2) They may be the results of contamination of a granitic magma by fragments of the intruded rocks.

No evidence has been found to suggest that the Bralorne diorite was formed by contamination. The Bralorne diorite is in contact with soda granite to the north and with serpentine to the south. The rock called greenstone diorite which was considered as a transitional phase from greenstone to Bralorne diorite, actually is sheared Bralorne diorite. Therefore at the Pioneer mine it is impossible to demonstrate that contamination of the soda granite has occured despite the hybrid appearance of the diorite. The writer considers the evidence at Pioneer mine indicates that the Bralorne diorite has a magmatic origin.

The origin of the soda granite is not readily explained. It has a very limited horizontal distribution in comparison with the Bralorne diorite, possibly because of faulting on the northern flank.

The soda granite is composed mainly of albite and quartz with some chlorite and epidote. No potassium feldspar was observed by the writer, and the small potash content determined in rock analyses is probably in the plagioclase. A mineral assemblage of albite and quartz is not unique but it is sufficiently rare to invite comment.

The possibility of the existence of a magma whose composition would give such a mineral assemblage has been debated by Bowen and Tuttle (1958:p.127):

> "Rocks consisting essentially of quartz and albite, or of quartz and orthoclase are not only rare but it is questionable whether they are ever found among the unaltered glassy extrusive rocks."

It is possible that the magma which formed the quartz-albite assemblage may have been produced by the removal of potassium from a 'normal' granite magma, the mechanism being obscure.

The exposed contacts of the Bralorne diorite with the soda granite are mainly gradational with only minor local intrusive features. The gradational contacts can be explained by progressive magmatic crystallization, by hybridization, or by replacement.

There is no conclusive evidence for an origin by a magmatic process or by contamination so that the possibility of a replacement origin for the soda granite must be considered. Granitic rocks similar to those exposed in Pioneer mine, occur near Sparta Oregon, and have been discussed extensively by Gilluly (1933). The soda granites near Sparta are considered

by Gilluly to have formed by the alteration of diorite rocks by pegmatitic solutions which had a high soda content. The data presented by Gilluly does indicate that there may have been some replacement of the diorite, although some of the evidence may be explained by magmatic processes.

Gilluly considers that albite-quartz rocks are unusual, and he shows a gradation from diorite to granite in his specimens. He suggests that the gradation is due to replacement. At Pioneer mine the transition from Bralorne diorite to soda granite is sharp but a zone of mixed rock occurs over several feet. The rocks exposed have been effected by the later quartz veins and it was not possible to obtain a suite of rocks showing a progressive change from Bralorne diorite to soda granite.

Thin sections of specimens from Pioneer showed that the quartz content in the diorite and granite is too variable to indicate a progressive increase in quartz. However it is noted that the quartz in the Bralorne diorite is fine grained and interstitial and only partly replaces the other minerals, whereas in the soda granite it forms much larger grains. These grains may have intricately sutured contacts and they may partly replace the feldspar. The replacement of albite by quartz is suggested by the presence of lobate and penetrative forms of the quartz embaying feldspar.

Although no partly chloritized hornblende was observed in the soda granite it is evident that the chlorite of the soda granite occurs as pseudomorpho after hornblende. Within the diorite the hornblende has a patchy colour and may be partly

chloritized and this suggests that hydrothermal activity has caused hornblende to be partly altered.

If the hydrothermal solutions which caused this alteration were sodic in nature, it would albitize all previously existing plagioclase. A process such as this might account for the absence of K feldspar in all the rock types. In such a process the calcium would be freed from the original minerals to form epidote, and in this respect it is significant to note that epidote is common in the soda granite, particularly as small grains in the feldspar and as clusters of grains associated with chlorite.

The solutions which Gilluly considered were responsible for the alteration of the diorites near Sparta were thought by him to be more effective in areas which had suffered brecciation. At Pioneer the rock which shows most evidence of brecciation is the soda granite. It is possible that much of the brecciation is associated with the formation of the quartz veins. Albitization is associated, at least in part, with the solutions which formed the quartz veins for in samples of rocks adjacent to the veins strained crystals of feldspar may be seen to have clear unstrained albite-rich margins.

In the granites near Sparta, complex intergrowths of quartz and feldspar are considered by Gilluly to be the result of replacement of the feldspar by quartz. Graphic intergrowths similar to those described by Gilluly are present in the soda granite at Pioneer mine. The quartz and feldspar also may

form worm-like intergrowths which may occur in rosettes. Figure 14 shows such an intergrowth. Many intergrowths have a rectangular nucleus of quartz. Intergrowths similar to those shown in Figure 14 have been described by Spencer (1929). He discussed the various theories put forward to account for the intergrowths of quartz and feldspar. Workers previous to Spencer regarded intergrowth of quartz and feldspar to be the results of crystallization in eutectic proportions, or as replacement of feldspars by quartz. Spencer has considered the arguments and concludes that such intergrowths are the results of crystallization in eutectic proportions.

However it may be argued that in the soda granite of Pioneer Mine there has been some replacement of the albite by quartz. The quartz present in the soda granite has lobate contacts with the feldspar. Certain intergrowths of quartz, all portions of which are in optical continuity, 'replace' several associated albite grains which have no common orientation. Such intergrowths as shown in Figure 12 are regarded as indicating replacement and are distinctly different from the intergrowths formed by crystallization. (Figure 14) The intergrowths formed by crystallization are composed of quartz and feldspar in small units and each unit is formed by quartz and feldspar which is in optical continuity only within the unit. In the replacement intergrowths the quartz is in optical continuity in one or more grains of feldspar.

Gilluly stated that a comparison of the chemical analyses of the Sparta diorites with the granites showed a distinct trend

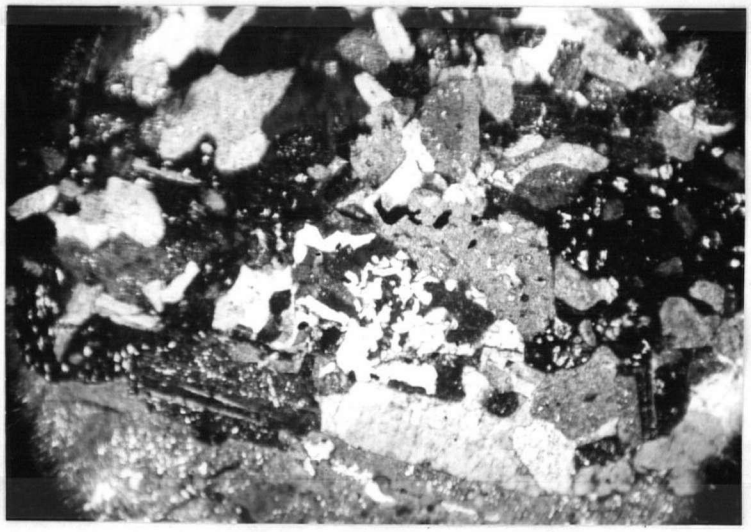


Figure 12. Photomicrograph of soda granite showing quartz-albite intergrowths considered to be indicative of replacement. Polarized light x 16. Thin section 20-90. No 10

Figure 13. Photomicrograph of soda granite showing quartz-albite intergrowths considered to indicate replacement. Polarized light x 16. Thin section 20-90. No 7.

Figure 14. Photomicrograph of soda granite showing intergrowth of quartz and albite. Polarized light x 16. This intergrowth is assumed to be simultaneous crystallization.

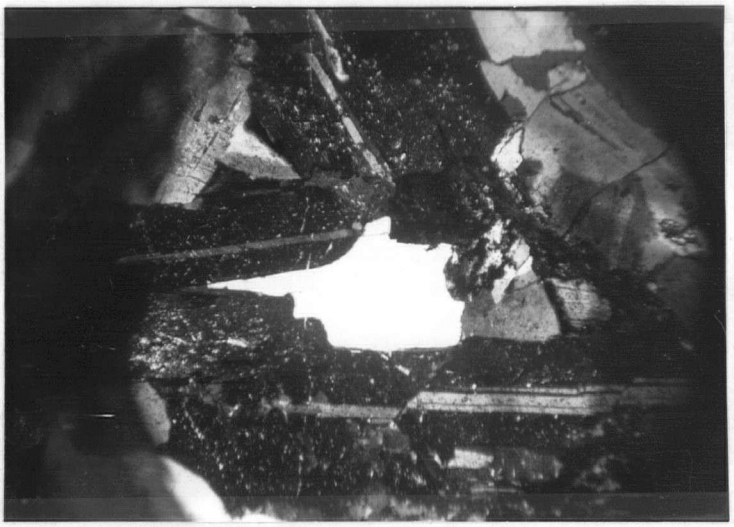


Figure 15. Photomicrograph of soda granite Polarized light x 47. Quartz interstitial to and partly replacing albite. Thin section 20-90. No 7.

of replacement. He plotted these analyses on a variation diagram and used the diagram to extrapolate the composition of a hypothetical 'pegmatitic' solution. Gilluly's diagram which is reproduced here as figure 16 could be interpreted as a distinct trend of magmatic differentiation. However Gilluly argues that if the variation between the diorite and granite were a normal differentiating trend the variations of the individual oxides would form a gentle curve as shown by Bowen in his work relating to the area of Katmai. By comparison with the gentle curve shown by a differentiating magma, the trend in the Sparta rocks is seen as a straight line - this straight line relationship of the oxides is considered by Gilluly to indicate a replacement origin for the Sparta granite.

For the purpose of comparison the values of certain analyses of the Bralorne intrusion given by Cairnes are plotted on the figure 16. These analyses show that for the granite rocks of Pioneer mine and Bralorne mine a replacement origin for the soda granite cannot be proved because the composition of the Bralorne diorite is too variable to show any progressive change in oxide content when a series of rock analyses is plotted on a variation diagram.

The writer concludes that the Bralorne diorite and the soda granite may be related in origin and that later sodic solutions of a hydrothermal nature have modified the original composition of these rocks by widespread albitic replacement, and some alteration of the mafic minerals to chlorite. The secondary nature of the albite is indicated by the numerous

veins of albite in the Bralorne diorite, and the presence of clear albite rims of altered plagioclase crystals.

This same sodic solution could have permeated the whole area about Pioneer mine, causing extensive albitization of the Pioneer formation.

The Pioneer formation is composed of rocks of a volcanic origin whose composition is now mainly albite, chlorite, and epidote. This mineral assemblage cannot be regarded as the original assemblage and the alteration to the present composition has been brought about by the introduction of soda. The formation of soda rich volcanic rocks has been extensively discussed by Gilluly (1935:p.347) with reference to the spilites of eastern Oregon. He concluded that the sodic materials were in large part of deep-seated derivation. Waters (1955:p.707) considers that the alteration of Eocene basalts of the Pacific northwest to spilites is due to fluids expelled from depths by a metamorphosing root zone. The sedimentary rocks underlying the spilites contain albite and quartz. Turner and Verhoogen (1951:p.211) consider that quartz and albite are readily mobilized and state

> "Prevalence of albite-quartz veins and laminae in low grade schists of grey wacke testifies to the ease with which the components of albite diffuse and segregate in the presence of water at temperatures far below those that prevail in reservoirs of molten basalt."

A pervading hydrothermal solution rich in soda could easily produce the albite in the Pioneer formation. The carbonate which characterises the argillaceous rocks, the

ANALYSIS OF BRALORNE DIORITE AND SODA GRANITE

	(1)	(2)	(3)	(4)
SiO_2	74.38	52.15	50.69	48.07
Al_2O_3	12.87	15.05	18.61	21.61
Fe_2O_3	0.61	2.30	1.51	0.87
FeO	1.96	6.35	7.45	5.16
MgO	1.27	8.31	6.05	8.56
CaO	1.12	10.14	8.30	11.85
Na_2O	5.27	2.48	3.80	1.40
K_2O	0.36	0.07	0.80	0.36
H_2O^+	1.21	0.77	2.89	1.09
H_2O^-	0.10	0.10	0.16	0.09
TiO	0.14	0.88	0.34	0.16
CO	1.32	Nil	--	Nil
P_2O_5	0.07	0.22	0.07	Nil
MnO	trace	0.10	0.11	trace
BaO	--	--	--	--
SrO	--	--	--	--
S	0.61	0.61	0.02	0.37
NiO	--	Nil	--	Nil
Cr_2O_3	--	0.12	--	0.06
	101.17	99.65	100.70	99.65

1. Soda granite from Pioneer mine.

2. Greenstone diorite from a specimen taken a few feet from specimen 4.

3. Bralorne augite diorite: Analysis made for McCann from King (Lorne) mine.

4. Bralorne diorite from a drill core at a depth of several hundred feet on the Ural claim. B.R.X. Cons. Mines Ltd.

Analyses by Fabry, reproduced from Cairnes (1937:p.23,26).

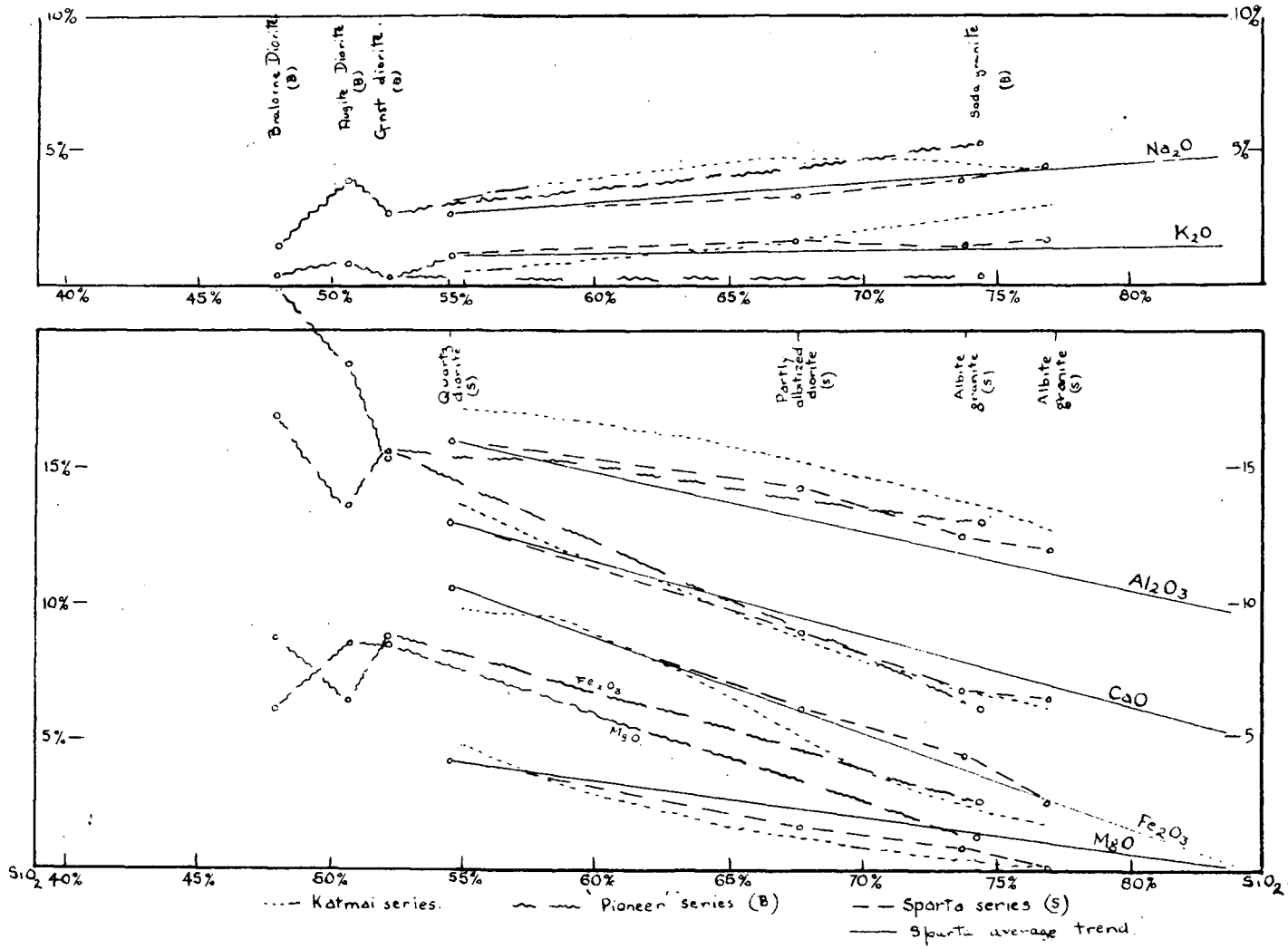


Figure 16

Variation diagram showing chemical composition of diorite and granite of Pioneer compared to those of Sparta

Hurley-Noel formation, may also be dependent upon the solution and obtain the calcium, and carbonates from the alteration of the original minerals of the Bralorne intrusions.

STRUCTURAL GEOLOGY OF PIONEER MINE

The earliest interpretation of the detailed structure in the vicinity of Pioneer mine was made by Cairnes (1937:p.42). He considered the structure to ba a northwesterly-trending syncline within the regional anticlinal arch proposed by Drysdale (1915). The core of this syncline was thought to be occupied by considerable thicknesses of material younger than the Fergusson series which formed the core of the regional anticline.

Cairnes, states that ".....the Bralorne, and in part the President intrusives were emplaced along the major synclinal axis of the area". The diagram of Joubin (1948) shows the Bralorne intrusion emplaced almost within the core of an anticline formed by the Pioneer formation. This proposed anticline of greenstone is repeated to the south, and has an intervening syncline formed by the overlying Hurley-Noel formation. A fault is present on the southern limb of the northern anticline formed by the greenstone, and this fault is the "Cadwallader Break".

The rapid narrowing of the "north greenstone belt" as seen in the underground plans of 29 level, 20 level, and on the surface plan, would suggest that if the greenstone has been folded into an anticline it would have a steep plunge to the east. The corresponding anticline which forms the south green-

stone belt also should be expected to have similar plunge. Although such an explanation concerning anticlines can account for the repetition of greenstone, and overlying sedimentary rocks and would explain the rapid narrowing towards the west of the sedimentary rocks south of Cadwallader Break, it does not account for rapid westward narrowing of the south greenstone belt. The anticlinal theory would require the south greenstone belt to widen to the west.

Diamond drilling in the period 1956-1959 shows that the south greenstone belt does not increase in width between the surface and 5 level, nor does the Hurley-Noel argillite south of the Cadwallader Break rapidly decrease in width with depth. A horizontal diamond drill hole, 5-555 drilled from 5 level intersected a great width of argillites of the Hurley-Noel formation, whose apparent dip of bedding in the core was seldom less than 50 degrees. Now, if these sedimentary rocks had been symmetrically folded, as suggested in the anticlinal theory, the axial plane would be represented by the bedding which should have been horizontal at some point along the drill core (see figure 17).

Present interpretations of the structure is that the Pioneer formation is conformable with the Hurley-Noel series, along the gradational contact which can be seen in the holes S-165 and S-166 (these holes are shown on the surface map, in the back of this report) and hole 20-519 at the end of 20-152 x cut.

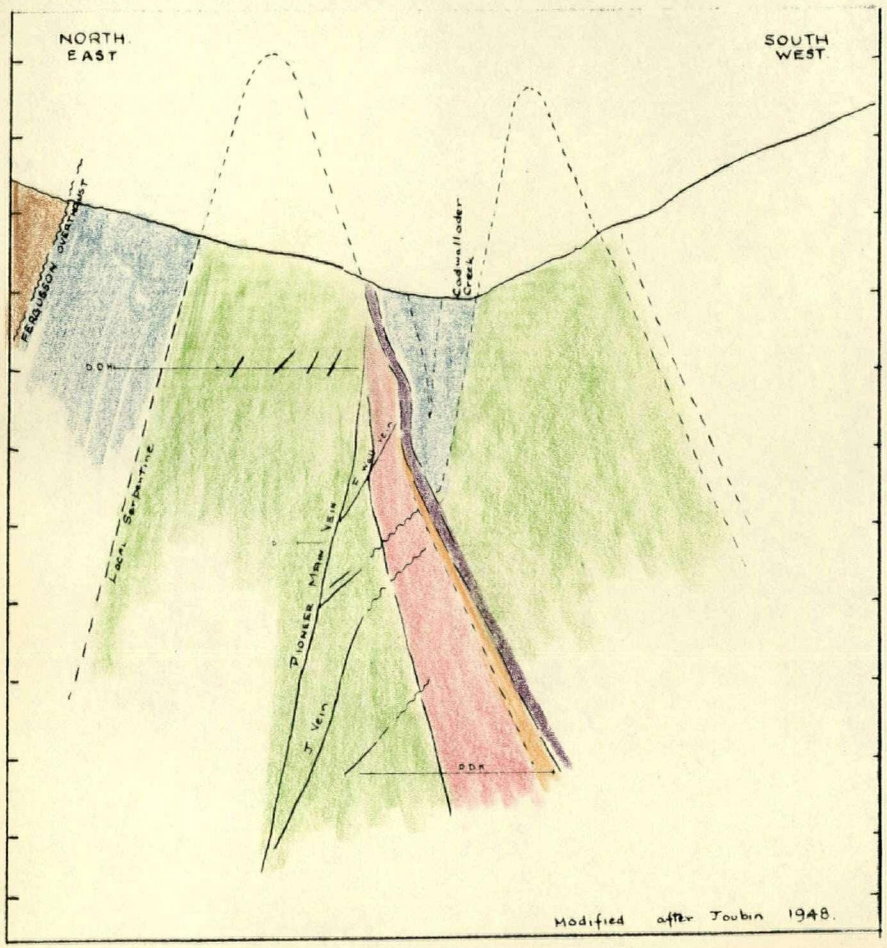
The whole sequence of the Pioneer and Hurley-Noel form-

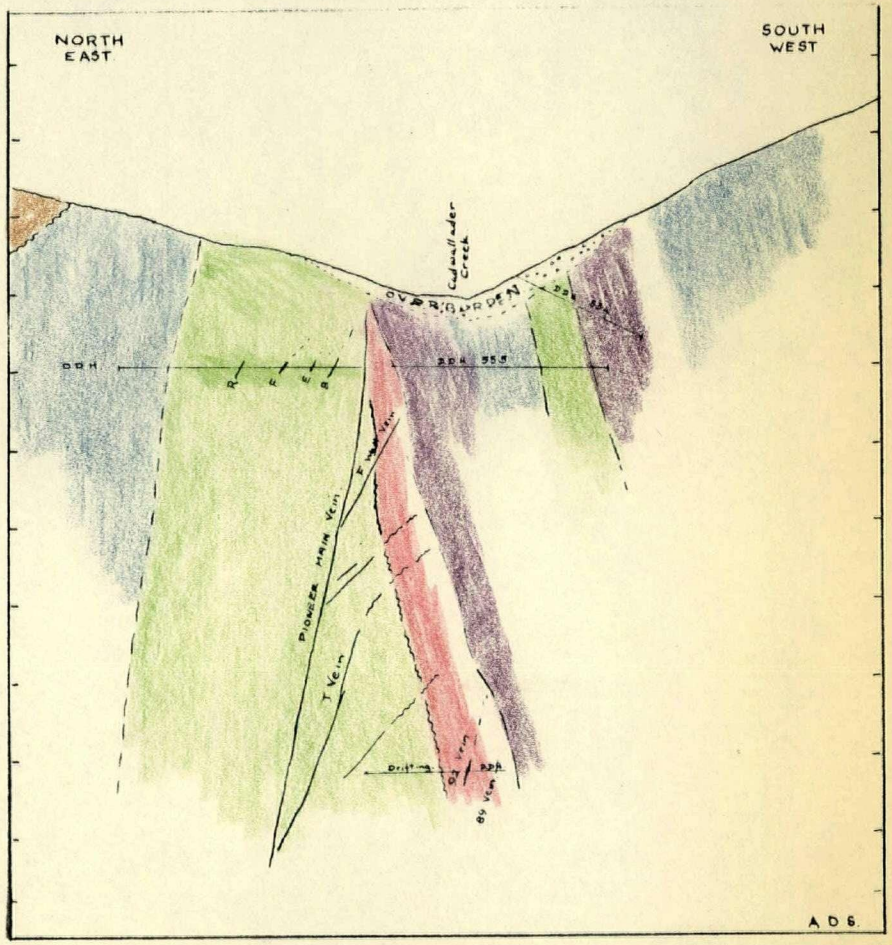
ations has been tilted to an almost vertical attitude and then faulted, the overlapping sections of the Pioneer volcanics and the Hurley-Noel sediments occuring within the Pioneer holdings.

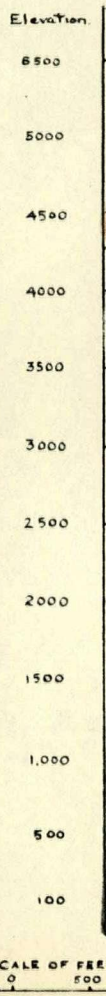
The fault which causes this duplication is known as the "Cadwallader Break" or the serpentine belt, as mentioned previously. The dip of the fault as determined underground is steep and to the south with local reverse dips.

The movement upon this fault zone is considered to be normal, the actual movement possibly having a steep plunge towards the west. Figure 18 indicates the relative movements which would result in the relative distribution of the rock units as seen in the surface plan (figure 3).

This interpretation that the repetition of the Pioneer and Hurley-Noel formations is caused by faulting rather than folding is based mainly on the overall distribution of the rock units. The plan of 20 level shows that the relative width of the greenstone is similar to that exposed on the surface and suggests that there is no anticline. If such a structure existed the greenstone should have increased in width between the surface and 20 level which it has not done.







SCALE OF FEET.
500 0 500 1000

Figure 17 A

Cross section of Pioneer mine
- anticlinal interpretation -

LEGEND

- Serpentine
- Soda granite
- Bralorne diorite
- Pioneer Formation
- Hurley-Noel Formation
- Fergusson GROUP

Figure 17 B

Cross section of Pioneer mine
- fault interpretation

- Drifts and veins
- DDH Drill holes
- Contacts
- faults

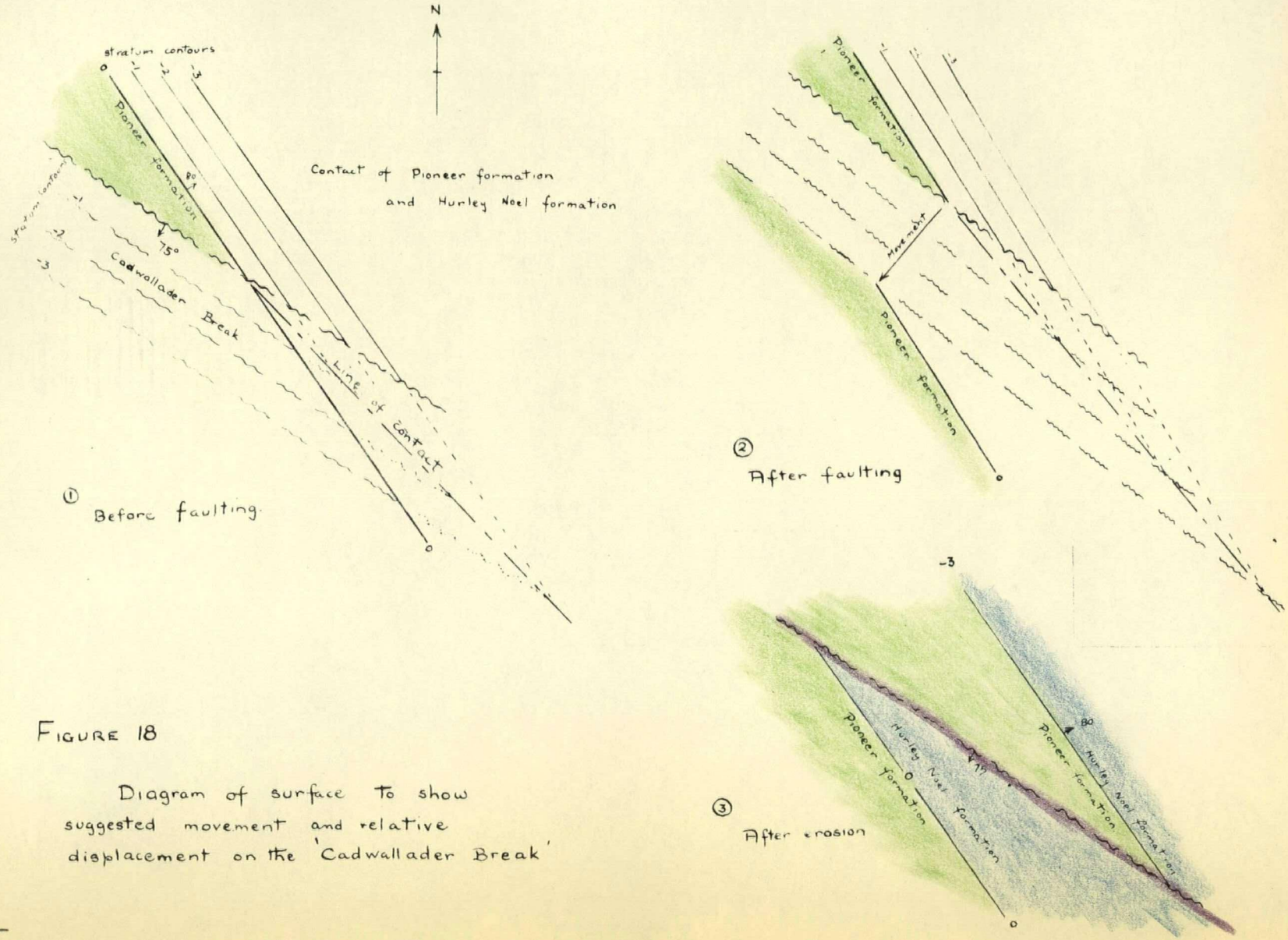


FIGURE 18

Diagram of surface to show suggested movement and relative displacement on the 'Cadwallader Break'

CHAPTER V

ECONOMIC GEOLOGY

INTRODUCTION

Gold is present in many veins in the Bridge River area but it is only in the vicinity of the Cadwallader creek that there has been extensive commercial development of gold-quartz veins. These economic veins are confined to a broad zone called the "Cadwallader Gold Belt" which is formed by the Pioneer formation and Bralorne intrusion. The Pioneer and Bralorne mines within this belt have produced nearly all of the gold from this area. By March 1958 Pioneer mine had a recorded production of 1,215,048 oz. of gold from 2,222,633 tons of ore, the grade of which averaged 0.55 oz. Au/Ton. The gold-quartz veins of Bralorne mine and Pioneer mine are remarkably similar in physical appearance and over-all mineralogy. The veins occur mainly as fissure fillings which range from a few inches to several feet in width but generally about 2 feet wide. Those veins which have been developed have proven continuous for several thousand feet in strike and dip directions. The quartz veins are fillings of fissures that occur in both the Pioneer formation and the Bralorne intrusions, but do not continue into the Hurley-Noel formation, or into the serpentine. It may be significant that veins elsewhere in the

Hurley-Noel formation have not proven commercial. Possibly sedimentary rocks of the Hurley-Noel type could not sustain open fissures sufficiently long to become mineralized. Wall rock alteration is not extensive in any rock type but it is most readily observed in the Pioneer formation.

The close association of the economic gold quartz veins with the Bralorne intrusions is considered to be due to their common origin.

Throughout the Cadwallader creek valley most veins have a fairly persistent westerly strike and a steep dip to the north. Most veins have similar attitudes and the average attitude of the veins is related by Joubin to one shear direction of a strain ellipsoid.

The mineralogy of the veins is simple. Quartz and minor amounts of carbonate form the bulk of the gangue material, and contain an average of 2 to 4% sulphides, and variable amounts of gold. Most of the higher gold values occur in well defined ore shoots, and the extent of most of the ore shoots is defined by assay limits rather than physical discontinuities in the veins.

DISTRIBUTION AND DESCRIPTION OF PIONEER VEINS

The gold quartz veins of Pioneer mine are confined to the Pioneer formation and Bralorne diorite, and represent fillings by quartz and minor sulphides of a series of fissures that may be related to the fault zone of the Cadwallader Break. This fault forms the most western limit to most of the veins. The relative distribution, and analysis, of the fracture system

is discussed at greater length in a subsequent section, but it will suffice to know that veins occupy a series of parallel reverse faults which possess a general southeasterly strike and dip from 90 degrees to 60 degrees to the north.

All vein structures have narrow widths of between 2 or 3 feet and dip steeply. Striations and lineations on the wall rocks and internal banding all plunge steeply towards the east. The attitude of these main fissures has been related to a strain ellipsoid and represents one direction of shear. The tension direction is represented at Pioneer mine by the 27 vein which dips at 52 degrees to the northeast.

Main vein fissures are represented by several veins on the Pioneer property and Figure 19 shows the relative positions of these veins.

TAYLOR VEIN

The Taylor vein or 40-vein has been investigated mainly on the adit level and a sublevel about 100 feet higher in elevation. Although it contains sections of good grade, ore values are spotty and the vein generally is considered non commercial. During initial development of this vein in 1945 a small pocket of gold containing more than 700 oz. was discovered, and subsequent raising and sub-drifting in the immediate area disclosed a split with good values on the foot wall branch. A further section containing good values was found beneath a serpentine overhang at the eastern extremity of the vein. Diamond drilling from 5 level indicates that the vein structure is present on the 5 level as a series of narrow vein-

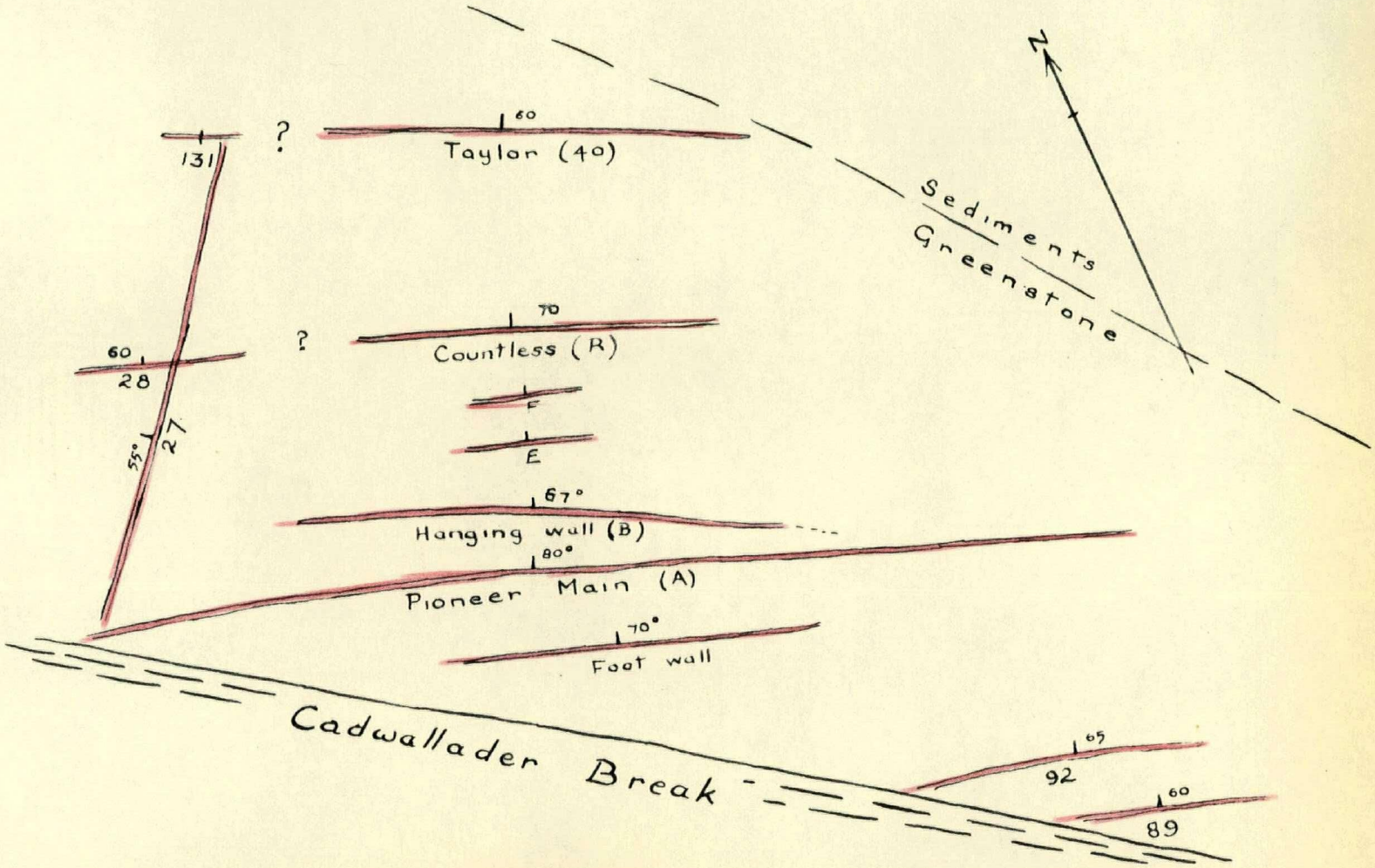


Figure. 19 Diagram to show approximate distribution of the Pioneer Veins.

lets containing only small amounts of gold.

131 VEIN The 131 vein exposed at the northern end of the 27 vein has been developed for only a few 10's of feet on various levels without favourable indications of ore. Although there are no intermediate intersections to prove the continuity of the structures, it is felt that this vein corresponds to the Taylor vein exposed some 3,000 feet higher in elevation.

COUNTLESS VEIN The Countless vein has been exposed on the surface by a series of open pits and trenches, and has been shown to pass into the Bralorne property where it is correlated with the Coronation vein.

Sub-surface development has been made on the adit level and from 5 level for several hundred feet in the 'R' drift, and although the vein is fairly persistent, only two short sections 100 feet long were found in the adit workings that might be considered marginal (0.3 oz. Au/Ton over an expanded width of 3 feet).

28 VEIN The small vein known as the 28 vein was found on 21 level near the 27 vein and is tentatively correlated with the Countless vein although evidence to support such a statement is the similarity in strike, dip and relative positions. However, they are separated by 2,000 feet vertically and the intervening levels have not been investigated.

E. F. Veins Work in 5 level exposed several narrow veins that are developed for a few hundred feet. These veins have a low gold content despite the prominent banding. The veins are called the E. and F. when going northerly along the 5 level cross-cut. These veins are only exposed on the 5 level and in a few diamond drill holes at lower elevations.

MAIN VEIN The Hanging wall (B), the Main (A), the J vein and the numerous foot wall splits in the area of the No 2 and No 3 shafts may be classified as one unit. The Main vein of Pioneer mine developed in the early days of the mine was responsible for much of the company's success and the spectacular museum specimens of gold for which Pioneer is famous.

The numerous splits from the Main vein have resulted in a complexity of drift names of certain levels. (i.e. 15 level has three foot wall drifts, each named the Main vein drift). The whole series of veins is regarded by the author to represent a 'composite' vein system which originated at one and the same time. This system is formed by the Main vein and numerous loops. Such loops have been defined as cymoidal loops by McKinstry (1955:p.314), however, the Hanging wall vein (B vein) on the upper levels, and the J vein on levels 20 to 29 are sufficiently well-developed to be considered as distinct splits.

HANGING WALL VEIN (B VEIN) The Hanging wall vein has been developed on several levels between the surface and had only a few short ore shoots. The vein strikes almost parallel to the Main vein and dips at a smaller angle, 50 to 65 degrees.

J VEIN The J vein developed by several drifts from 20 level to 29 level parallels the main vein in strike but it has a flatter dip. No ore shoots have been found. Diamond drilling on 15 and 13 levels has proved the existence of the J vein, but not of ore, at these levels.

MAIN VEIN The Main vein and associated cymoidal loops is the most extensively developed fracture system in the mine. It is exposed by drifts and stopes from the surface down to the 29 level a vertical distance of 3,510 feet, (a dip distance of 3,580 feet). Along the strike direction it has been developed from the western end near the serpentine on 15 level, to the eastern termination on the 20 level where the vein virtually disappears before reaching the Hurley-Noel/greenstone contact. This entire horizontal distance is some 3,800 feet.

The strike of the vein is westerly and the dip varies from 75 to 80 degrees northwards, with only local reversals. Reverse movement of the main vein fault has given a left handed displacement of the greenstone-granite contact 50 to 200 feet. The fault components as given by James (1934:p.346) are 400 vertically, and 200 feet horizontally. Indication of the movement direction is given by the striations and lineation on the vein walls and on the ribbon structure in the vein. These striations pitch to the east at angles of 45 to 65 degrees.

Gold can be found throughout the Main vein but it is concentrated into four main shoots.

1) The west end ore shoot is immediately beneath the

overhang of serpentine formed by the "Cadwallader Break". The ore shoot extends from the contact of the vein with the serpentine for several hundred feet. The ore shoot follows down the rake of this contact from the surface to below 9 level, a vertical distance of over 1,000 feet. This ore shoot was the original ore body developed at the surface.

2) The No 2 ore shoot is united with the west end ore shoot above 5 level and continues to below 20 level. Below 11 level the grade is less than 0.5 oz. Au/Ton and the shoot is only about 300 feet long, but it is persistent.

3) The No 3 ore shoot is similar to No 2 shoot but theye are separated by a narrow section of variable length. The shoot extends from 3 level to below 14 level for a vertical distance of 1,300 feet, and length of 600 feet.

4) No 4 ore shoot is a narrow discontinuous ore zone that occurs west of the 2 and 3 shafts. It extends for a vertical distance of almost 2,000 feet from 12 level downwards with a maximum drift length of little more than 500 feet. Below 24 level only small stopes were developed and at 29 level ore grade material is limited to a small uneconomic section.

92 AND 89 VEINS

The 92 and 89 veins occur several hundred feet within the foot wall of the Main vein and were exposed during the development period 1956 to 1959. Both veins have the same general strike as the main vein but their dips are flatter, 70 degrees and 65 degrees, respectively. Although the veins are 300 feet apart on the 20 level the dips of the

veins indicate they would unite about 29 level. On 20 level the veins are exposed, from the contact with the serpentine, for a length of more than 1,000 feet. The 89 vein terminates in a zone of narrow sub-parallel quartz filled shears. Drifting and raising on several sections of these veins indicate that for distances of 600 feet, these veins have an average width of 1 foot (89 vein) and 2 feet (92 vein). Over these sections the gold content of 0.3 oz. Au/Ton is obtained for a calculated mining width of 3 feet. The gold values are consistent but there is a marked increase in gold content of both veins as the serpentine contacts are approached.

Development on 25 level has exposed the 92 vein but here the vein contains no long sections of ore grade. Further exploration has failed to locate any strong vein structure in the projected position of the 89 vein. Development at lower elevations on the 29 level by the 16 cross-cut and drilling below the 29 level has failed to show any persistent vein structures or significant gold values.

27 VEIN The 27 Vein is a modified tension opening which occurs between the main vein system of faults. The 27 Vein strikes northeast and dips towards the northwest at an angle of 55 degrees. The vein is composed of several vein lenticles which are arranged with a slight overlap so that the vein appears as a continuous body. The vein is up to 20 feet wide in certain sections and it is formed by a tension opening.

The vein has been exposed from the 17 level to the 29

level and the strike development on 25 level is 1,600 feet. The vein is composed of a series of ore shoots which are limited to the individual vein lenticles. The ore in continuous on the upper levels but on the lower levels it is discontinuous and limited to certain ribboned sections. This vein is the main producing vein at the present time.

29 VEIN This is a foot wall branch which occurs at the north end of the 27 Vein. This vein has been developed from 20 level to 25 level for distances up to 580 feet but contains only a small ore shoot which occurs at the distal end of the drift.

WALLROCK ALTERATION

Wallrock alteration visibly extends 2 to 3 feet from the veins, but rock samples studied under the microscope show that it may extend much further. The microscopic effects are bleaching and general discolouration of the wallrock most readily observed in volcanic rocks because of the strong colour contrast. As the vein is approached the volcanic rocks show an alteration to dark or light brown or greyish colour. The sulphide content of the rocks increases towards the vein. The sulphides occur either as single euhedral crystals or as complex interpenetration twins of either pyrite or arsenopyrite up to 5mm in size. In some places intense alteration has produced a dense soft material containing secondary micas, carbonates, kaolin, and very small amounts of sulphides.

Irwin (1947:p.32-34) attributes the alteration of the Pioneer formation to the introduction of carbon dioxide, potash, sulphur, and arsenic. Alteration similar to that seen in the greenstone is present in the Bralorne diorite and Irwin concludes that the similarities in the alterations of the two rocks may be due to similarities of original composition. Thus, both rock types would be affected in the same manner by the "hydrothermal solutions" which gave rise to the gold quartz veins. The diorite and the greenstone originally contained albite, and hornblende (or chlorite). These minerals have been altered to a mass of 'sericite', carbonate, pyrite, and arsenopyrite, with some local silicification.

Quartz and albite are the main minerals in the more acid rocks, the soda granite and dykes. These minerals are altered to fine-grained masses of quartz, white micas, carbonates, and minor amounts of sulphides. The alteration is brought about by the introduction of carbon dioxide, potassium, sulphur, and arsenic, and by a decrease in the amount of soda and silica.

Irwin states that the alteration of soda granite and acid dyke rocks is less pronounced than that of the Bralorne diorite. He explains that the acid rocks are a late differentiate of the Bralorne intrusions and should have a composition similar to the final differentiates which are the theoretical hydrothermal solutions and the acid rocks would tend to be in equilibrium with the hydrothermal solution when compared with the basic rocks.

In the mine workings the degree of alteration appears to be strictly local and in the opinion of the writer it does not seem to be more pronounced in any single rock type.

Stevenson records that silicification is most common where granite is in contact with the veins. Where acid dykes are cut by a vein a platy quartz-sericite schist containing pyrite and arsenopyrite is developed. According to Stevenson areas of altered albite dykes may be megascopically distinguished from altered diorite, by the development of this platy structure, and may be distinguished microscopically by an abundance of quartz. The areas of granite and acid dyke rocks adjacent to the vein can be identified in their altered state by the presence of conspicuous quartz "eyes" which remain as relicts from the granite.

Irwin concluded that hydrothermal alteration of the various rocks in the mine occured in the vicinity of a system of open fractures. He considers that there was an introduction of carbon dioxide, potassium, sulphur, and arsenic and that soda and silica were partly removed.

MINERALOGY AND PARAGENESIS OF THE VEINS

GANGUE MINERALS

Quartz is the main gangue mineral of the veins, occuring in two main forms. The first variety occurs as massive, snow-white 'bull' quartz. This variety is common in the 27 vein where it may comprise the entire vein. This variety of quartz

generally contains only small amounts of gold although spectacular masses of gold are not unknown in it. The second variety of quartz occurs commonly in all veins in the valley and is called ribbon or banded quartz. The ribbon quartz is more precisely layered quartz, and is formed by parallel to subparallel layers of quartz which range from a fraction of an inch to several inches in thickness. These layers are separated from one another by thin films, streaks, and layers, composed of varying amounts of chlorite, "sericite", mariposite, gouge sulphides, and minor amounts of gold. This banded variety of quartz forms the bulk of the mine ore and generally has a higher gold content than the massive quartz.

Fractures in the quartz contain brownish white to white carbonates whose compositions range from calcite to ankeritic carbonate. In some sections of the mine carbonates may compose the main part of the vein.

Other minerals occur in the veins in only minor amounts but may be sufficiently distinct to be easily recognised. Previous reports written on the area describe the presence of scheelite, which in Pioneer forms part of a small shoot in the Main vein near the Pioneer No 2 shaft.

Mariposite has been identified by Irwin (1948) by its small negative 2v, less than 10 degrees, and refractive indices $\alpha = 1.57$ $\gamma = 1.60$. The mariposite is easily recognised by the bright green colour. It occurs as small flakes coating the slickensided surface of banded quartz or in isolated patches throughout altered soda granite and other altered host rocks.

Acicular crystals of black tourmaline in small radiating clusters are present in vugs and small cavities in the 27 vein.

Dolmage (1934:p.426) has recorded the presence of alunite and barytes within the veins of Pioneer mine.

METALLIC MINERALS

The mineralogy of the quartz veins is simple and the gold occurs in a free state. In general the metallic content of the veins is low and constitutes between 2 and 4 per cent of the vein content. The sulphides occur on the surfaces of the ribbon quartz foliations or in clusters and thin layers of isolated grains. The attitude of these sulphide layers may be independent of the attitude of the ribboning in the quartz.

Cairnes (1937:p.55-57) and Dolmage (1934:p.425) have adequately described the mineral assemblage and paragenesis. A brief resume of the minerals identified and paragenesis is given below.

GOLD Gold in economic quantities is generally confined to the quartz veins but may be present also in the host rock adjacent to the vein. The gold is associated with the sulphides on the slickensided surfaces of the ribbon quartz. The gold may also occur as spectacular masses within the unbanded quartz, with or without associated sulphides.

SILVER Native silver or any mineral of silver has not been recognised in the ores of Pioneer mine. Mint

returns show that the gold bricks contain about 6% silver. It is considered that the silver is in solution in the gold. Dana's system of mineralogy Vol. I p.91 states that gold may contain 10 to 15% silver in solid solution. Although it is not known which mineral contains the silver, it is suggested that the small amount of silver is contained in the gold.

PYRITE Pyrite is the most abundant sulphide mineral, occurring as disseminated crystals or grains throughout the veins and in the wall rock.

ARSENO-PYRITE Arsenopyrite occurs as massive irregular crystal clusters, as isolated well-formed dipyramidal crystals; or as minute to large acicular crystals. It occurs in both the vein and the more strongly altered wall rock, and is associated with the gold. Much of the smeared, slickensided, ribbon quartz surfaces are coated by arsenopyrite.

SPHALERITE AND GALENA Light brown sphalerite, and galena occur in the quartz as irregular isolated grains which are locally conspicuous. Most of the sphalerite is intimately associated with free gold.

OTHER MINERALS Pyrrhotite has been recognised at Pioneer, but it is rare. Other minerals recorded are chalcopyrite, tetrahedrite (?), stibnite, gold tellurides and millerite. Warren (1942:p.30) reports that the mill tailings of Bralorne contain small amounts of bornite, stibnite, chalcocite, covellite, and magnetite.

PARAGENESIS

The investigations of Cairnes and Dolmage indicate a paragenetic sequence which is summarised below.

1) Principal stage of vein quartz depostion with sparsely disseminated sulphides, chiefly pyrite.

2) Fracturing.

3) Chief stage of pyrite, arsenopyrite, and pyrrhotite deposition with, locally, considerable gold and calcite. Much of the sericite, and perhaps also mariposite, was probably formed at this stage. (this corresponds to the first period indicated by Dolmage)

4) Fracturing.

5) Chief stage of free gold deposition; commonly concentrated about the arsenopyrite and filling fractures in it. Other minerals formed principally in this stage include calcite, quartz, chalcopyrite, sphalerite, galena and gold tellurides.

6) Fracturing

7) Further deposition of gold together with acicular arsenopyrite; finely crystalline pyrite, calcite, and quartz. Any related stibnite mineralization probably formed at this stage.

The paragenesis given above shows that gold has been introduced in several periods and is mainly associated with arsenopyrite. Sphalerite and gold are found intimately associated, and because sphalerite is more easily recognised it is used as an indication of the presence of free gold in the veins.

RIBBON STRUCTURE IN VEIN QUARTZ

Ribboning in the Veins

Quartz veins throughout the mine workings are very similar in mineralogy and physical appearance, but the most

striking feature of the veins is their ubiquitous ribbon structure. This foliation is expressed both by platy inclusions and by closely spaced shear surfaces.

Platy or sliver like inclusions of highly altered wall-rock are common in the veins, and in some instances it may be seen that they have been wedged off the immediately adjacent walls. Many inclusions have striated surfaces coated with chlorite suggesting fault contacts.

In the Grass Valley region of California, several such inclusions in quartz veins have been described by Farmin (1938). These inclusions show features similar to those of the Pioneer veins. Farmin states that in several places the inclusions within the veins are fragmented, and these fragments are disorientated. For this disorientation, such as shown in figure 20, Farmin gives two explanations.

1) The specific gravity of the wall rock was near that of the quartz, which had not completely solidified, so that slow sinking of the inclusions occured. The smaller fragments settled at different angles but maintained approximately their former orientation. This explanation is not readily accepted by the writer, because the exact nature of the one bearing medium, whether it was a dilute aqueous solution, gas, or a crystal mush is debatable.

2) Dislocation of the inclusions occured when the solutions forming the vein became less "slushy and gelatinous", and before they stopped moving.

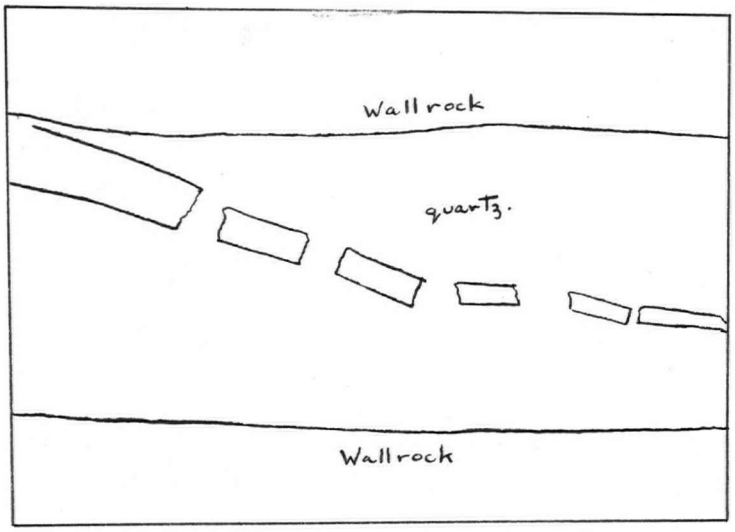


Figure 20. Diagram to show relative positions of inclusion fragments of a septa banding.

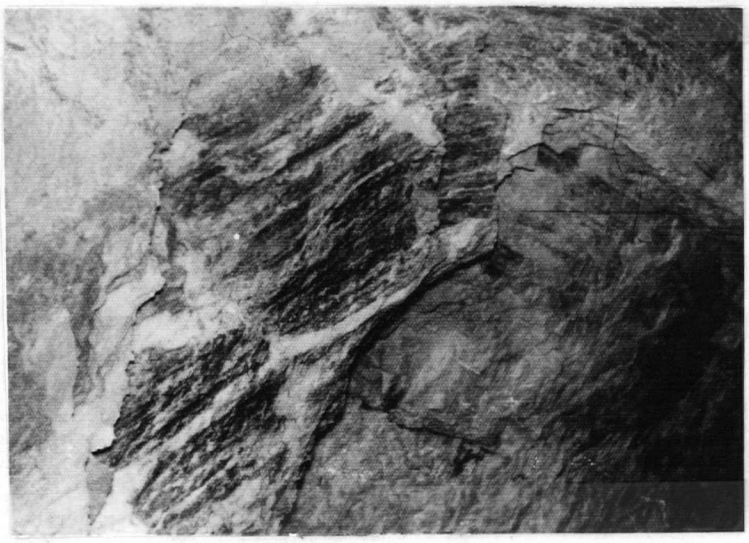


Figure 21. Photograph taken by 28-64 Raise showing the striations on the faces of ribbon quartz that indicate movement on the hanging wall has not been in a constant direction.

It appears to the writer that the most rational explanation for the disoriented fragments of inclusions is that there was crystallization of the quartz by the following mechanism - when the vein material was introduced, much dilation of the wall rock occured and thin septa were wedged from the wall and passed into the opening. Quartz then crystallised in the fissure. Later movements may have fractured both the quartz and septa resulting in slight disorientation of the septa fragments. These fractures were then annealed by quartz which was either derived from an external source, or by recrystallization of the pre-existing quartz. Some of this later quartz partly replaces the fragments especially along the broken surface, enlarging the previously small gap between individual fragments.

A second type of ribbon quartz is made up of parallel to subparallel layers of quartz varying from a fraction of an inch to several inches in thickness, separated by sheets, layers, or films of sericite, chlorite, gouge, or sulphides. In stope and drift backs these layers appear in section as distinct ribbons or bands. These layers were formed by the deformation of the original quartz veins. Deformation has produced a series of parallel shears whose surfaces were coated with sulphides.

In many stopes the ribbon quartz has been fractured and the fragments so formed are separated by an inch of white unribboned quartz. The surface of the sections of 'ribbon' quartz show striations which indicate that at some period the fragments were continuous, and the intervening white quartz is later than the ribboning.

The ribbon surfaces may be distinctly striated, or grooved with coarse striations and fluting thereby showing evidence of movement. The striations are present on the surface of ribboning of the 92, 89 and other veins of the main vein system. These striations pitch constantly to the east at high angles and on the main vein they parallel the rolls in the vein, which are clearly visible on superimposed level plans. The striations indicate that the fault movements were reverse. This movement direction is also shown by the displacement of the granite-greenstone contact.

The ribbon structure of the 27 vein was studied closely by the writer. The ribbon structures strike a few degrees more westerly than the strike of the vein, and they dip a little more steeply. Thus, in both plan and section the ribbons cross the vein acutely from footwall to hanging wall. (Figure 24 and Figure 25)

Striations and fluting upon the surfaces of these layers indicate that a reverse movement has occured on the 27 vein, at least in the final stages of deformation. Figure 21 shows striations on the hanging wall of the 27 vein in the area of the 28-64 raise. It can be seen that the striations are not entirely constant in plunge but some may even be horizontal.

SIGNIFICANCE OF RIBBON QUARTZ

It is obvious that the ribbon quartz and the striations result from movements produced in previously crystallized quartz. It is assumed that the initial quartz which filled the

vein was white "bull" quartz and its deposition was accompanied by the deposition of some sulphides. The septa of wall rock likely were incorporated in the quartz during the initial stages of formation of the vein, and alteration of the septa took place during these stages. The quartz probably crystallized from a dilute aqueous solution, or other medium. The banding of quartz in the main vein system is thought to have been caused by shearing within the vein.

During the period (1956 to 1958) an extensive investigation was made of all stopes in the 27 vein on the lower levels and also of isolated stopes in the upper levels of the 27 vein. Stope backs were mapped on a scale of 1 inch to 10 feet, and the results were plotted as a diagram together with the assay values for these backs. All the ribbon quartz was noted and plunge direction of the numerous striations recorded.

Figures 22 and 23 represent the various stope backs of 28-46 stope and of 26-108 stope, as seen in an up dip view.

The major points of interest to these figures are -

1) The attitude of the banding relative to the vein is constant.

2) Lineations and striations have the same dip plunge.

3) The ore shoots conform to the ribbon structure.

These features found in all stopes are considered to be ultimately related to stress environment which produced the vein fissures.

The 27 vein cannot be regarded as a simple shear fracture filled by quartz. It differs from the Main vein system in many

FIGURE 22 Stope back diagram of 28-46

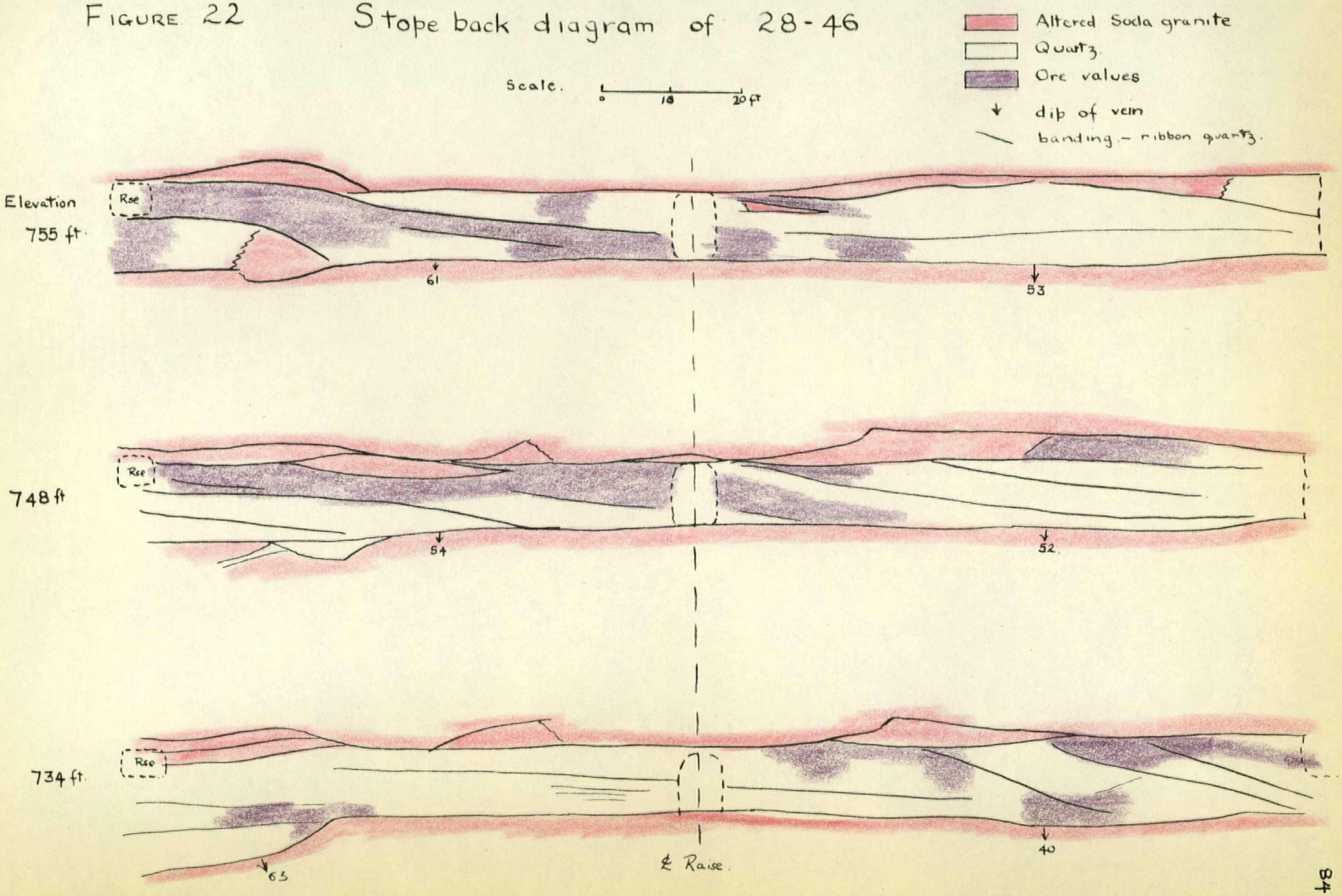
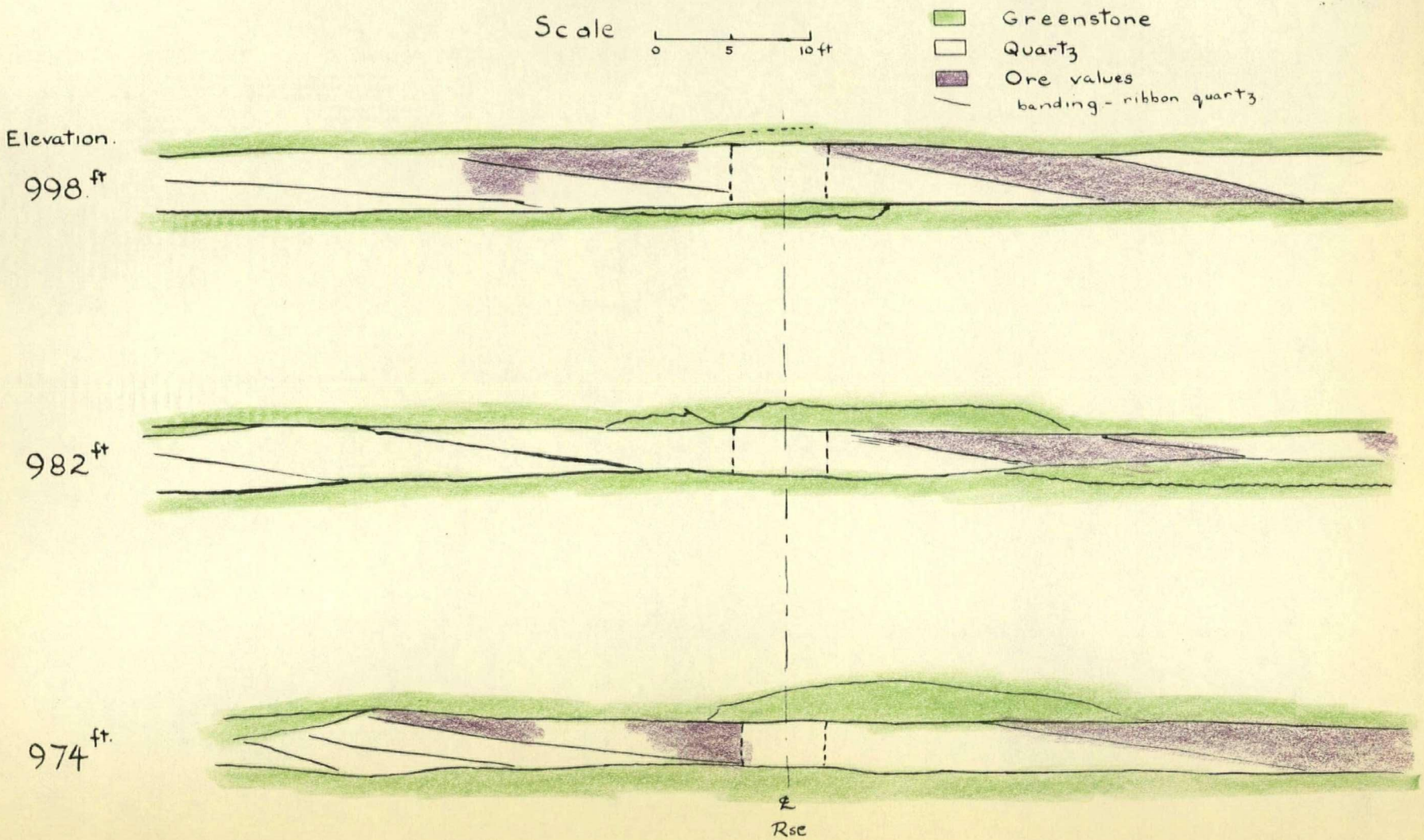


Figure 23 Stope back diagram of 26-108



respects. The veins of the Main vein system in Pioneer are fairly persistent, in strike and in dip direction. They are narrow, rarely over 3 feet in width, and are well ribboned. In contrast, the 27 vein is up to 20 feet wide, and banding is not everywhere present. Sections can be found where almost the entire width of the vein is composed of massive quartz, also the ore shoots are inclined, and the variations in the dip and strike of the vein are considerable.

Joubin (1948) tentatively considered the 27 vein to be a modified tension opening, or a "cross-over" vein corresponding to set C of his strain ellipsoid. The 27 vein branches from the main vein in a stringer zone and persists as a wide composite vein to the 131 vein near the argillite contact.

The 27 vein is composed of a series of small sigmoidal fractures which were probably formed at the same time as the Main vein system of fractures. The plan of the 27 vein shows that the individual vein lenticles are arranged en echelon with a slight overlap. They may simply join, or may assume one of the several forms listed by McKinstry (1948:p.314). These forms are described as a double link, chatter-like link, multiple or single cymoidal loops or curved shingles. The vein lenticles may be directly joined or connected by ramifying veinlets of calcite and milky quartz. The veinlets are commonly barren, contain no banding, and have irregular frozen contacts.

The vein lenticles are regarded as a series of overlapping sigmoidal veins containing ore shoots which are generally confined to the section of the vein lenticles that

do not overlap. In this manner the ore shoots appear as a continuous ore zone on each level. The vein lenticles are considered to have been tension openings and the brecciated wall rock at the northern end of the 27 vein is compatible with such an origin. Later shearing of the quartz which filled these tension openings, produced the ribbon quartz with which the gold is associated.

Movement has occured in the 27 vein and is expressed by the following features.

1) Striation, mullion, and large scale fluting in the vein walls pitching at 60° towards the south.

2) Ribboning of the quartz in the vein.

3) Striations upon the banding pitching at about the same angle as the striations on the vein contacts.

4) Displacement of the granite-greenstone contact.

The reverse movement on the 27 Vein has been calculated from the displacement of the greenstone-granite contact to be a total of 200 feet.

The stope back diagrams (Figures 22, 23) show that higher gold values are virtually restricted to particular parts of the ribbon quartz in each successive stope back. Some of the ore sections are restricted to one ribboned section but others pass from one ribbon section to another.

The 27 vein contains oval shaped tabular ore shoots, whose greatest dimension is in the dip direction of the vein. These ore shoots pitch at almost 90 degrees and they are limited horizontally by the extent of the vein lenticles. The upper limits of the ore are commonly determined by the physical limit

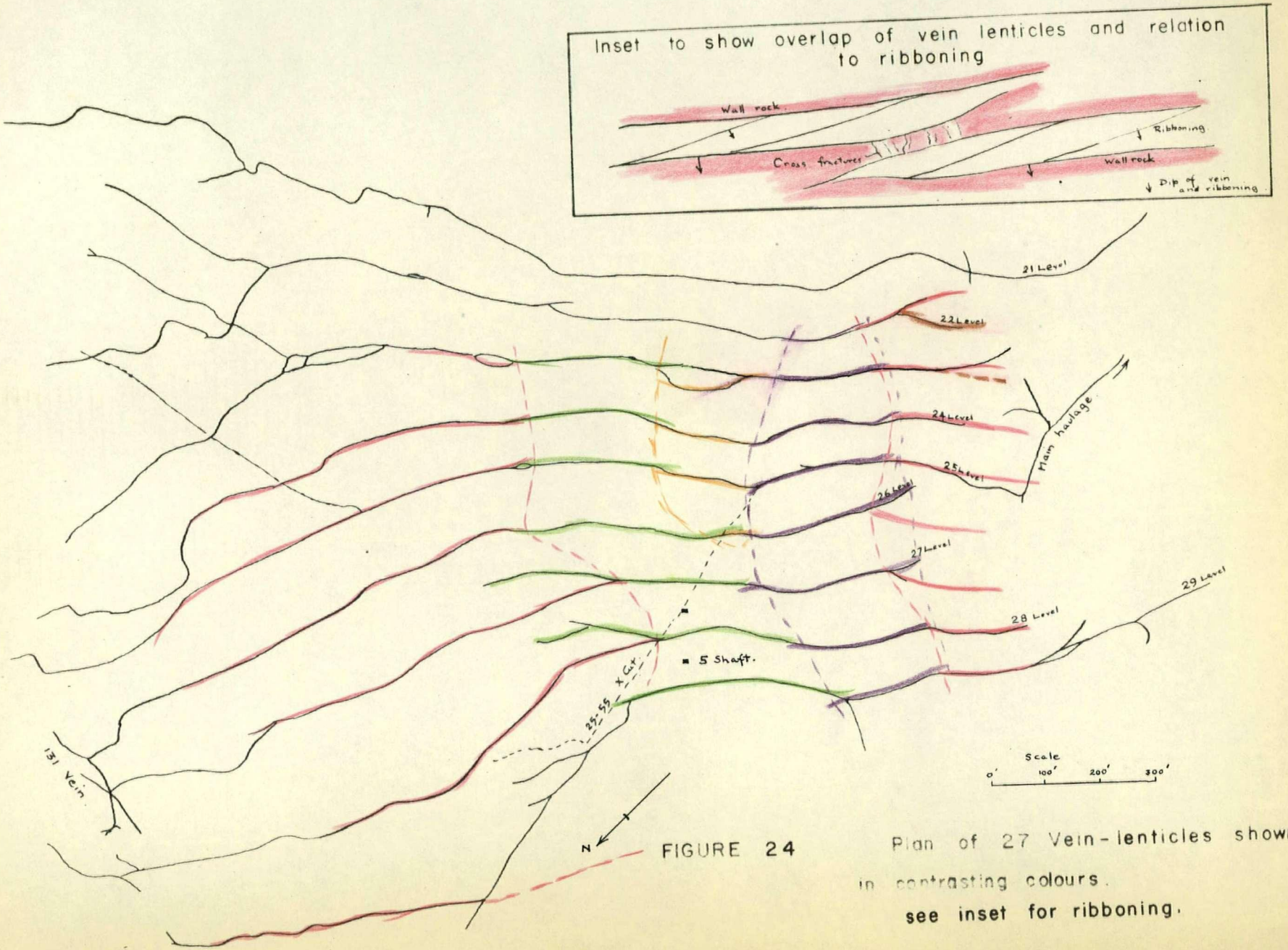


FIGURE 24 Plan of 27 Vein-lenticles shown in contrasting colours.
see inset for ribboning.

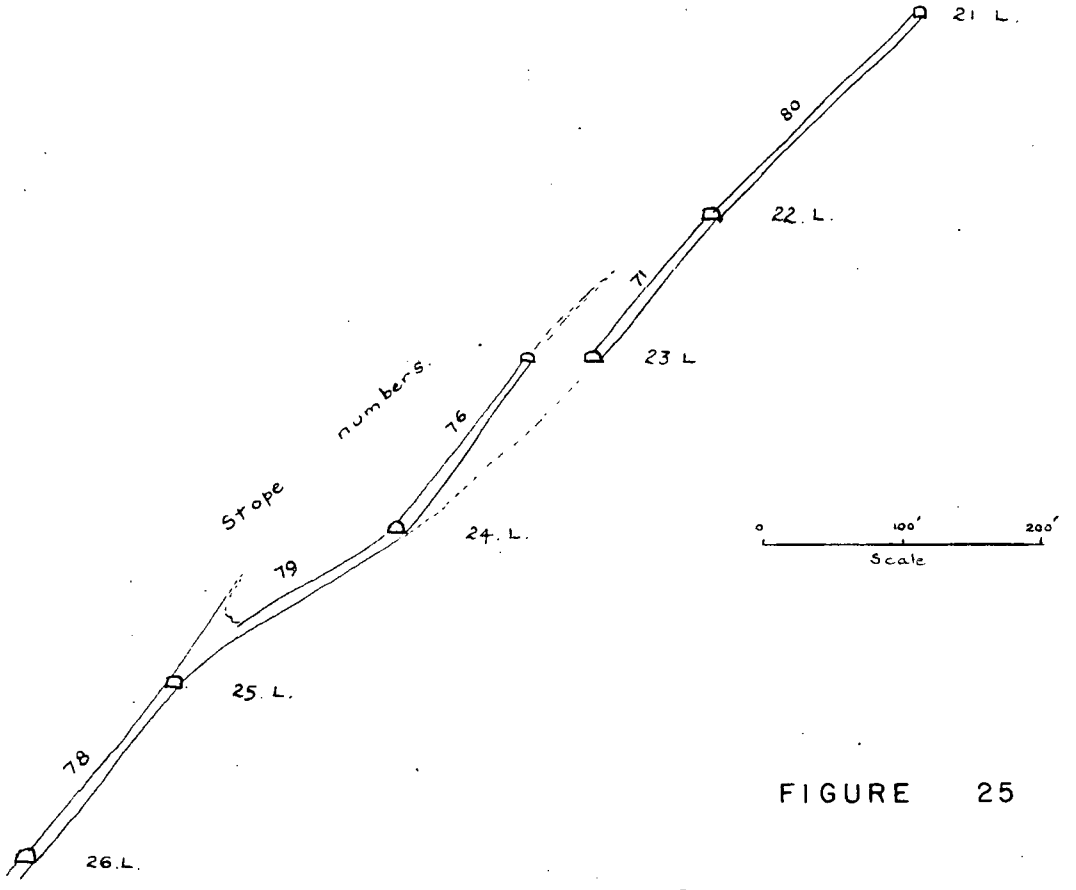


FIGURE 25

Cross section of the 27 vein showing overlapping vein lenticles (L = level)

of the vein lenticle but in depth the limits of the shoots are determined by assay values. There is a progressive decrease in gold values from 26 level downwards. In the northern section of the 27 vein the ore "bottoms" between the 27 and 29 levels. The section of the 27 vein south of 5 shaft has a continuous exposure of ore. This section of ore is composed of several ore shoots, each of which is confined to a vein lenticle. Each ore shoot contains good values on the level 27 and above, but the grade of ore decreases below the 27 level and on 29 level the ore becomes marginal. It would appear that, with the exception of a small shoot of ore near the 5 shaft, 29 level is at the bottom of the southern set of ore shoots. The individual ore shoots in the vein lenticles have within them high grade sections confined to the ribboning in much the same way that ore sections occur in the vein lenticles below the ore shoots.

The distribution of the ore indicates that the better grade sections are in the upper levels of the 27 vein and ore shoots are confined to the upper portions of the vein lenticles. Where the vein lenticles flatten in dip, as in the north end of the 29 level the gold content is low. This suggests that the best gold values are to be found in the steeper section of the vein lenticles.

The exact relation of ribboning to the gold content is not known. But the distribution of the gold on the surfaces of the ribboning indicates that the gold is later than the quartz. It would be necessary for the vein quartz to be fractured and the gold to be introduced along the fracture surface. The

relatively higher content of gold in the upper parts of the vein suggests that the gold ore bearing material was able to ascend only within the vein. The termination of suitable structures in the vein may have caused impounding of gold bearing solutions at the upper portion of the passage ways for the solutions. It is possible that the shear planes which form the ribbon quartz were suitable places for the deposition of minerals from that portion of the ore bearing medium that still remained mobile in the later stages of mineralization and after the crystallization of the quartz.

Mawdsley (1938) has discussed the implications of the late gold of other mining camps, and follows the explanations of Fenner. An alternative explanation for the presence of late gold has been made by White (1943:p.531). He considers that by a rational process of subtractive crystallization of non-auriferous minerals the gold present in the ore parent fluid in only minor amounts would become concentrated in the residual solutions. By virtue of its ability to diffuse readily, the residual fluid can collect in any section of the vein. Sheared surfaces would be easily permeated and the gold bearing ore readily deposited on the surfaces. Such an explanation could logically explain the distribution of the gold in Pioneer without recourse to several injections of ore bearing fluid implied by the paragenesis listed by Cairnes.

STRUCTURAL ANALYSIS OF THE VEIN FRACTURES

Cairnes (1937:p.51) states that a survey of a group of vein fissures revealed no consistent system of fractures. Mine development in the following years has shown that the distribution of quartz veins has a definite pattern as explained by Joubin (1948:p.46-48). Figure 5 of Joubin's paper reproduced here as figure 26 shows the interrelation of vein fractures and other structures in terms of the strain ellipsoid. It should be noted that the long axis of the ellipsoid is inclined to the southeast at minus 45 degrees and corresponds to that which Joubin has termed the "axis of elongation of the Bralorne intrusion".

The various fracture planes of the strain ellipsoid are designated as Set A, B, and C. These sets are related to the various veins and faults throughout the Bralorne and Pioneer mines.

Set A.....This is expressed by the northerly-striking faults that are unmineralized, with the possible exception of No. 2 Bralorne fault. All notable shears belonging to this set occur in Bralorne mine. The set strikes between due north and north 20 degrees west and dips range from 45 to 70 degrees west. The apparent horizontal component of movement on most faults of this set is dextral and amounts to 200 to 300 feet.

Set B.....This set is regarded as the complement to set A and is represented by the majority of economic veins in the area. These veins strike between 15 degrees north and south of

west, and dip from 55 degrees north to vertical, but have local steep reversals of dip. The horizontal components of movement are always to the left. The total movement on the veins is difficult to determine. James (1934:p.346) gives an upward movement of 400 feet for the Pioneer Main vein. Pronounced striations upon the ribbon quartz in the veins indicate that the final movements, at least, were reverse and to the left, for these striations pitch at steep angles towards the east.

Other veins in Pioneer which correspond to set B are the 89, 92, Taylor, Countless E, F, 28, and the numerous splits such as the Footwall, J, and Hanging wall veins which join the Main vein.

Set C.....This set is represented by openings which are found between the Main vein structures and considered to be tensional or 'cross over' structures. This set is represented in the lower levels of Bralorne mine by the 59, 73, and 79 veins, and in Pioneer by the 27 vein. These veins may curve westward as they approach the hanging wall of the Set B fractures.

Detailed work by the author on the structural relations of the 27 vein shows that this vein is not strictly the filling of a tension opening, for there is evidence that movement has occured subparallel to the vein walls.

It may be noted that Joubin's interpretation of the structure in terms of the strain ellipsoid takes no account of the 'Cadwallader Break' which is the most prominent structural

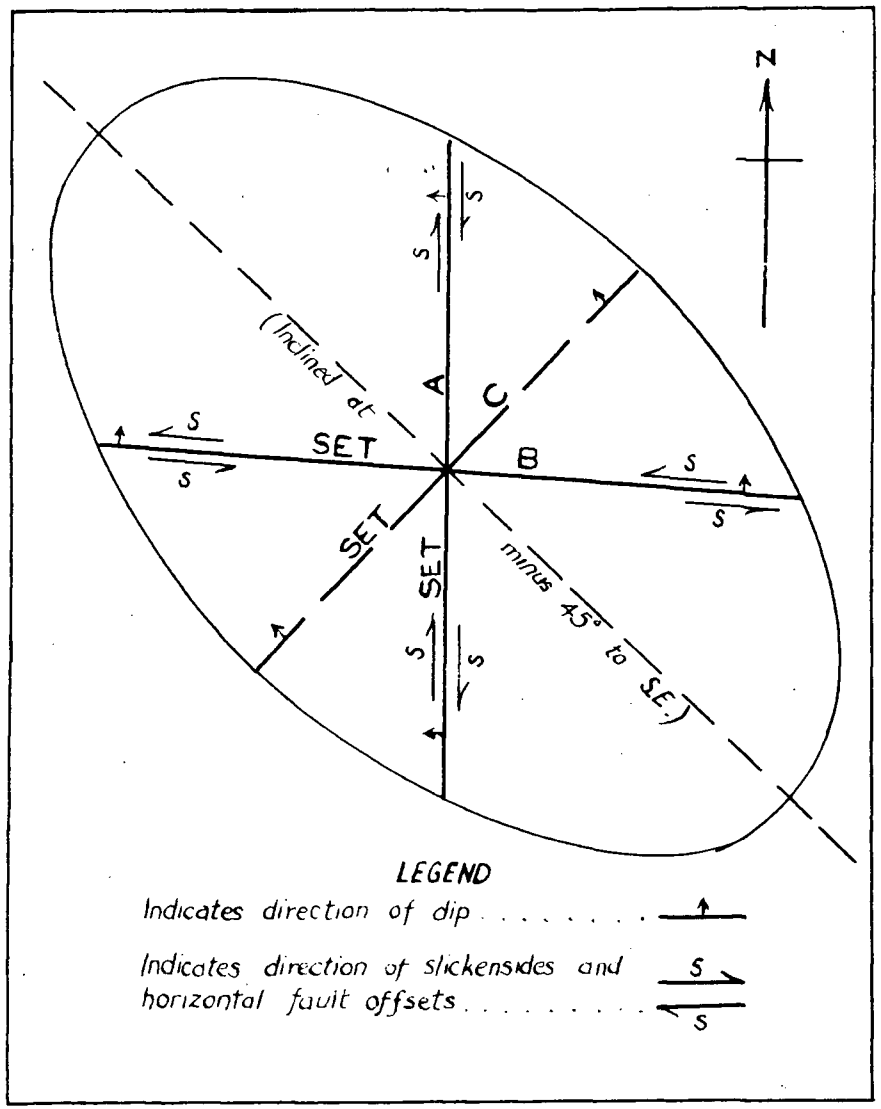


Figure 26 Strain Ellipsoid Diagram Reproduced from Joubin 1948 p 47

feature of the whole mining camp. It does not readily fit in with the strain ellipsoid concept.

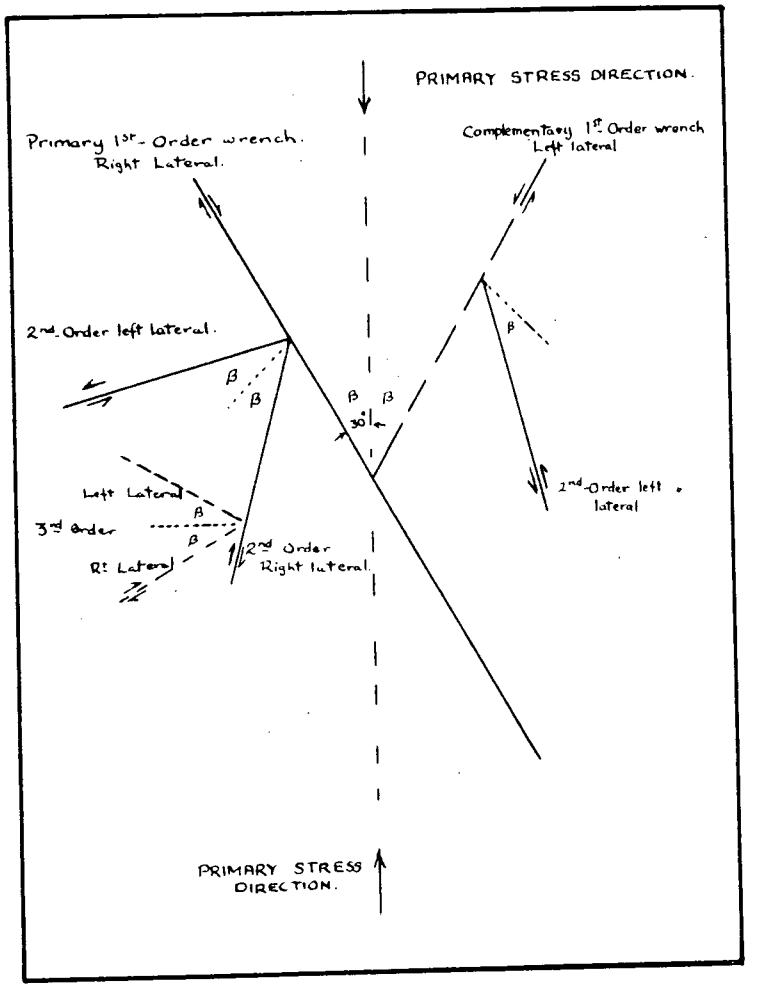
It is considered that the strain ellipsoid is a conventional way of describing the elastic strain known to have existed immediately prior to any permanent rock distortion. Leith (1937) has discussed the use of the strain ellipsoid concept and considers the strain ellipsoid is not a theory of rupture although it is possible to determine the nature of the pre-rupture strain.

Cloos (1955) performed experiments with clay cakes which were supposed to represent an homogeneous medium. He showed that the first shears formed are at 60 degrees to one another, and it is only upon further deformation that this angle is increased.

The writer will attempt to correlate all the major and minor fractures, including the "Cadwallader Break", known in the mine area.

An attempt will be made now to explain the distribution of these fractures in terms of the analysis of wrench fault systems recently made by Moody and Hills (1956). In order to make such a comparison, it must be assumed that the strain pattern of Moody and Hills would be valid not only for a smaller area but also for an axis of principal stress that is other than horizontal. In the case of Pioneer mine, for example, this principal stress axis must have been inclined to the east at some angle between 45 and vertical; and further, this axis may not have had the same orientation throughout the protracted

FIGURE 27 Comparison of system of Wrench Fault Tectonics proposed by Moody and Hills and the faults at Pioneer Mine.



PLAN OF WRENCH SYSTEM UNDER SIMPLE COMPRESSION.
MODIFIED FROM MOODY AND HILLS 1956.

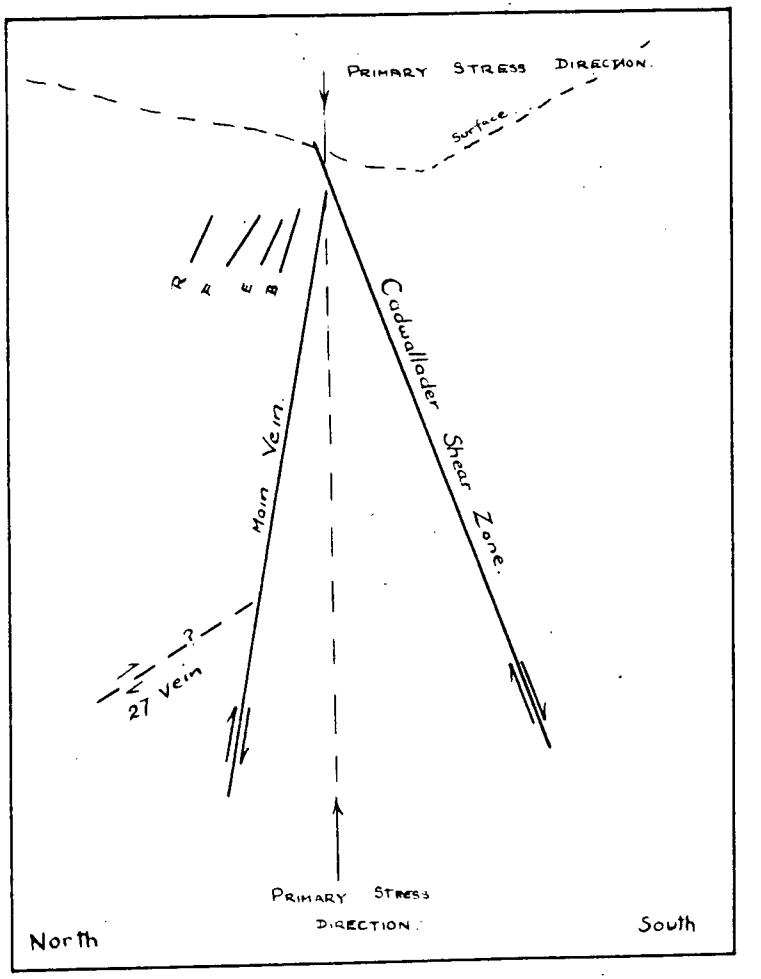


DIAGRAM TO SHOW RELATION OF CADWALLADER SHEAR ZONE AND THE VIEN FISSURES.

period of deformation.

Figure 27 compares the distribution of wrench faults resulting from a simple horizontal compression according to Moody and Hills with a distribution of faults of the Pioneer mine as seen in a vertical cross section. It must be assumed that in the latter example the principal stress axis is either vertical or highly inclined.

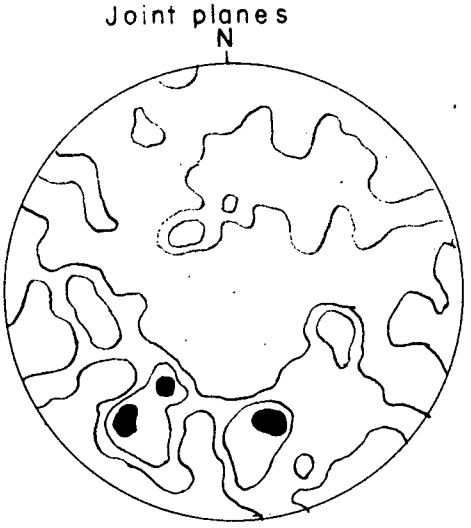
The primary 1st order fault of Moody and Hills would be represented by the "Cadwallader Break" which the writer has indicated previously to be a normal fault.

The complementary 1st order wrench faults would then be represented by a series of shears having the same strike as the "Cadwallader Break" but dipping at high angles towards the north, that is, in a direction opposite to that of the "Cadawallader Break". The 2nd order right lateral wrench faults of Moody and Hills would be represented by the Main vein system. The required complementary faults should develop at an angle of 60 degrees to the Main vein system, but such faults have not been recognised by the writer in that part of the mine with which he is familiar. However, Cairnes has recorded that in the upper levels of Pioneer mine a "....set of faults strikes about parallel to the main vein fissures, but dips northerly at a flatter angle (than the main vein) generally about 45°." It is possible that these faults described by Cairnes correspond to the complementary 2nd order faults.

The 27-vein, somewhat of a structural enigma, has the physical appearance of a tension fracture and was so designated

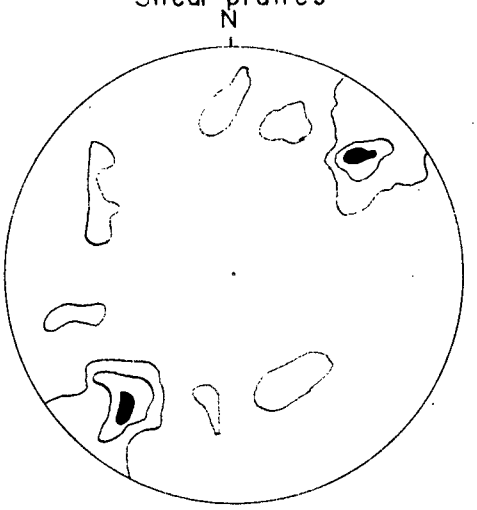
Stereographic Projection of Planes from 20-106, 135, 152 Cross cuts
(POLES PLOTTED)

Joint planes



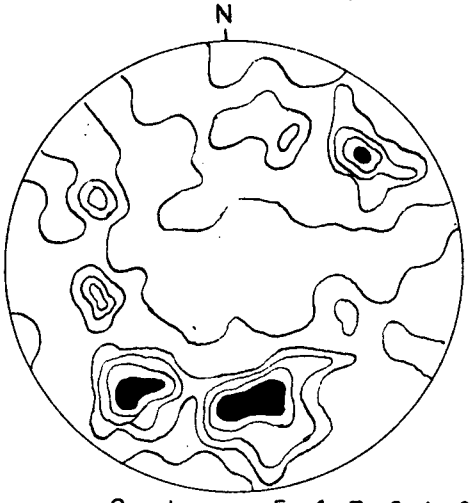
Contours 5, 3, 1 %
(78 readings)
FIGURE 28

Shear planes



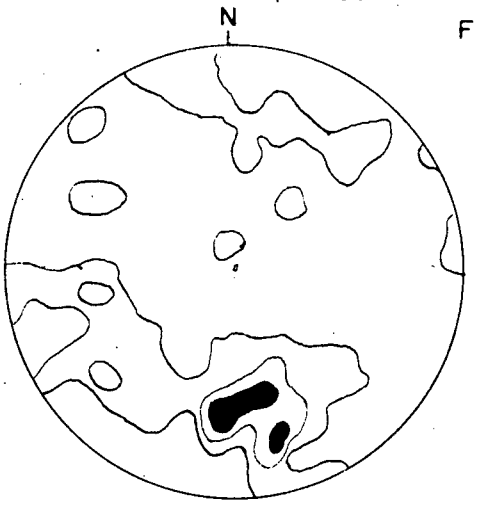
Contours 7, 6, 3 %
(67 readings)
FIGURE 29

Composite diagram



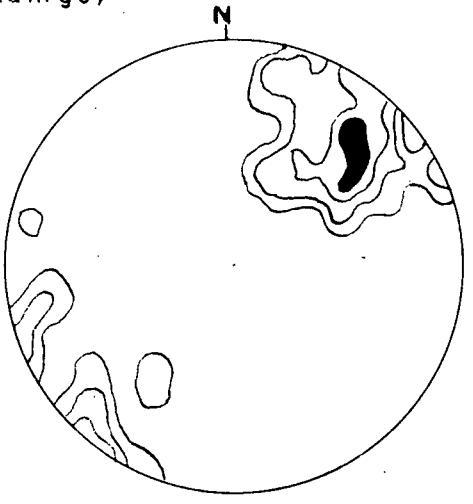
Contours 5, 4, 3, 2, 1 %
(220 readings)
FIGURE 31

Quartz filled planes



Contours 6, 4, 1 %
(75 readings)
FIGURE 30

Taylor Tunnel



Contours 8, 7, 3, 1 %
(60 readings)
FIGURE 32

by Joubin. It has, however, in places prominent ribboning that tends to cross the vein at a very acute angle, and that may represent planes of shear failure. The 27 vein may fit into the Moody and Hills concept as the tensional fracture complementary to the 2nd order shears, and the ribboning might then correspond to 3rd order right lateral shears.

Figures 28, 29, and 30 are the polar diagrams of shear planes, joint planes, and quartz veinlets that are present in the 20-106 crosscut, 20-135 crosscut and part of the 20-152 crosscut and that were mapped and measured by the writer. It will be noted that at least one maximum roughly corresponds in all three diagrams. This maximum is interpreted as the expression of the first order shear or its complement. By combining the three diagrams in Figure 31 it will be seen that there are two prominent maxima, one possible representing the 1st order complement and the other the 2nd order "right lateral" of Moody and Hills (i.e. the Main vein). Secondary maxima in the composite diagram probably represent complementary shears.

These maxima are not developed consistently throughout the mine and at any given point only are set may be developed. For example, figure 32 shows the plot of poles to all joints, and shears and quartz veinlets, in the Taylor Tunnel adit, and has only one maximum which corresponds to shear planes parallel to the "Cadwallader Break", a first order fault.

CATACLASTISM OF VEIN QUARTZ

Thin sections were studied of all varieties of quartz - massive quartz, ribbon quartz, and quartz which seemed to be later than the ribboning. Oriented specimens of massive and ribbon quartz (labelled A and B respectively in figure 37) were taken as close together as possible from the stope backs.

No unique features distinguishing one type of quartz from another could be found. Quartz was the main mineral in all thin sections studied with minor amounts of carbonate filling fractures and brecciated zone. One section contained abundant acicular crystals of arsenopyrite which appeared to be later than the main body of quartz.

The quartz in the thin sections examined contained myriads of inclusions. These inclusions and their significance are discussed in a subsequent section. The quartz in the 27 Vein of Pioneer mine shows several features of cataclastism which may have bearing on the deposition of the gold. It has been suggested that gold is late in the paragenesis and such zones of cataclastism could form channel ways for ore bearing media.

White (1943:p.250) has suggested that cataclastism is affected by temperature. In any environment below a certain temperature the vein quartz would only be pulverized. Above this temperature the quartz is capable of recrystallizing. The vein quartz of the 27 was investigated to see if any reorientation of the quartz grains could be found in the ribbon quartz.

Any reorientation may indicate the relative age of the quartz and indicate the presence of gold.

In the initial stages of cataclastism the straining of quartz produces undulatary extinction which is visible in thin sections as an extinction band that sweeps across the crystal grains. At a later stage in the process of cataclastism the extinction pattern becomes more definite and grains have a striking mottled effect in the extinction position. The edges of the grains in contact with other grain quartz were previously intricately sutured, but now a series of chains or clusters of small clear grains are formed. (Figure 33). These small grains are unstrained and contain no inclusions in contrast to the larger strained crystal of which they were once part.

White states that the cataclasism results in a completely new texture composed of small equidimensional grains of clear quartz. The specimens of quartz studied by the writer showed only small areas of fine grained clear quartz which was restricted to grain boundaries and zones of brecciation.

The development of strained vein quartz was discussed by Adams(1920:p.650) and the general process he postulated is given below.

Thin sections cut from unstrained quartz showed an aggregate of coarsely granular subhedral quartz grains which he considered to be the original crystals.

According to Adams the first effect of strain in crystals of quartz is the production of wavy or undulose extinction, and later mottled extinction. The mottled extinct-

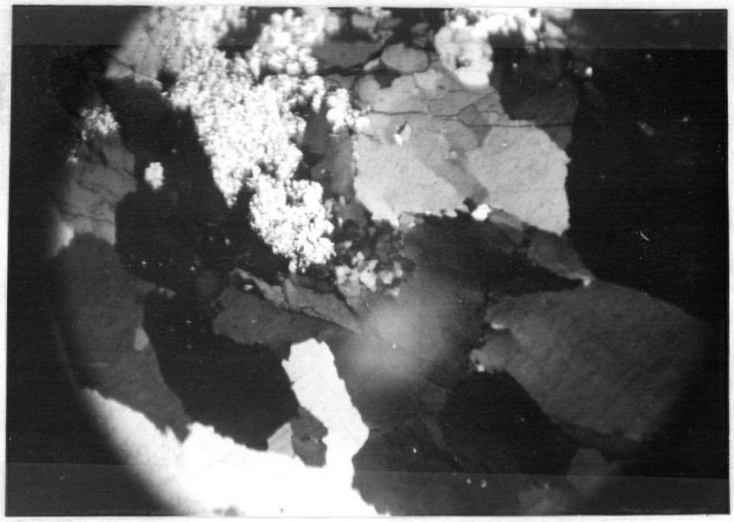


Figure 33. Photomicrograph of vein quartz. Crossed Nicols x 16. Note the mottled extinction and the formation of small clear grains at the contacts of large strained quartz grains.

ion is shown by small but definite areas within the larger crystals, and are caused by re-crystallization of the strained quartz. These areas increase in size under conditions of prolonged deformation.

Adams considers that ~~during~~ the final stages of strain produce interlocking aggregates of rather equidimensional unstrained quartz. A process for the granulation of quartz similar to that stated by Adams is outlined by Van Hise, (1890) in a discussion of metamorphic rocks. He states:

> "An individual, instead of extinguishing upon the whole as a unit is now composed of individuals which extinguish more or less independently although the positions of extinction are not far from each other, except the grain has been wholly destroyed".

The mechanism for such a process of "granulation" is obscure. However, several attempts have been made to explain a similar process which causes the breakdown and reconstitution of quartz in metamorphic rocks where the reconstituted quartz has a preferred orientation. This reconstitution of quartz is governed by the forces acting at some period, and much has been written in an attempt to explain the mechanics of this orientation.

In petrofabric studies it is usually assumed that the minerals did not possess any prefered primary orientation, unless it can be otherwise determined. - i.e. mica flakes in sedimentary rocks may be deposited so they are horizontal, and the C axis is vertical.

When directional forces cause movement the mineral grains

are rotated either mechanically or by redistribution of material taken into solution by contact pressure. The mineral grains of the metamorphic rocks will finally possess what is termed a directional fabric. This fabric is found by plotting the axes of the mineral grains, on the lower half of a stereographic projection. When the C axes of quartz in metamorphic rocks are plotted in this way several different fabric diagrams are obtained. The diagrams have been explained in several ways by different suthors. Turner (1948:p.265) describes several such fabrics and reviews the postulated mechanics of their formation. Experimental data to confirm any of the hypotheses are not available,for laboratory methods are not capable of a disrupting the strong space lattice of quartz, which has close interlocking silica tetrahedra, and it is difficult to interpret mechanical deformation in the crystallographic structure of quartz where planes of weakness are not easy to recognise.

Theories on the straining of quartz are mainly concerned with the recognition of a potential glide plane. These planes have been quoted as -

1) an unspecified face in the prism zone,

2) a unit rhombohedron, or other face,

3) a 2nd order pyramid $(11\bar{2}2)$

An explanation more feasible than those concerned with potential glide planes, was suggested by Griggs and Bell (1938). They consider that when quartz is deformed metamorphically it ruptures into needlelike fragments bounded by the unit rhombohedron, the basal plane, and irregular surfaces (not definite

prismatic planes) parallel to the C axis. These fragments are then drawn into a subparallel position so that their long axis are in the direction of movement. It is significant that shattering of quartz crystals into needlelike fragments has been obtained by experimental methods.

Recently, Bailey, Bell and Peng (1958) investigated strained quartz crystals from numerous environments. They used Laue photographs to show that asterism occurs. The formation of asterism is explained by the breaking of the quartz grains into a series of needle-like crystallites which are subparallel to the c axis of the initial parent grains. With continued deformation these crystallites are reorientated and then fuse together so that a new crystal is formed whose orientation is governed by deformation.

From the present work on the 27 vein it would appear that the quartz is broken down into small strained areas which are later recrystallized. The boundaries between these strained areas could easily be channel ways for ore bearing solutions.

The present studies show no relationship of the C axis of quartz grains to the megascopic structures in the area nor to the attitudes of the planes of inclusions. The studies indicate that the vein quartz has undergone very little recrystallization, and the fabric shown by the plotting of C axes to the quartz grains (Figure 34) is considered to be random.

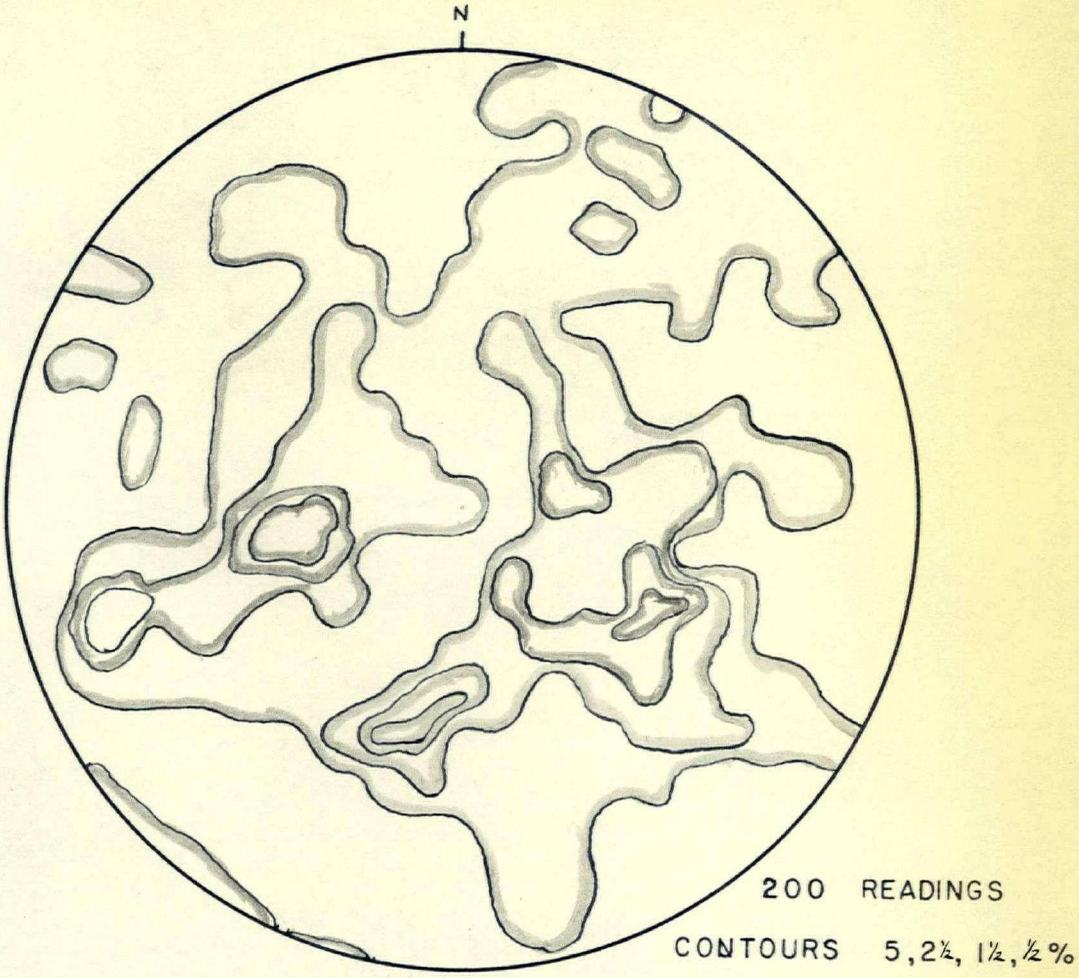


FIGURE 34

STEREOGRAPHIC PROJECTION OF C AXIS

OF QUARTZ GRAINS IN VEIN QUARTZ

THIN SECTION 28-46 A

PLANES OF LIQUID INCLUSIONS AND THEIR SIGNIFICANCE

Cairnes (1937:p.55) described inclusions that occur in quartz of all the principal veins of the Bralorne, Pioneer area, and also described inclusions within the quartz of the soda granite (1937:p.27). Cairnes suggested that such inclusions may be of significance in the search for further gold quartz veins.

Inclusions in quartz have been noted in other areas by several authors. Leech (1953:p.50) states that the vein quartz from the Elizabeth group in the Yalakom River area possesses myriads of dust like inclusions each of which contains liquid and a gas bubble. Other authors have described inclusions in quartz from magmatic and metamorphic rocks.

The presence of planes of liquid inclusions in quartz from vastly different environments indicates that they cannot be used to indicate the presence of gold. They are dependent upon the stress environment.

Thin sections form of vein quartz from the 27 Vein examined by the writer all contain myriads of inclusions. Some inclusions were carbonate material or sulphides and are considered primary and not discussed further. Other inclusions or vacuoles range in size from submicroscopic up to a few hundreds of millimeters in size. The shape of these inclusions is extremely variable and there are varieties from sheet like inclusions to inclusions with more regular shapes such as spheres, pearshaped, or ellipsoids. The larger inclusions are seen to contain a liquid and a small bubble, but the relative

properties of these phases did not seem to be the same for different vacuoles. The bubble is considerably smaller in comparison with the liquid but where the inclusions have been cut by the thin section the liquid has escaped and the vacuole may appear opaque.

These inclusions may be randomly distributed in the quartz, or occur in irregular patches, or in sinuous to flat planes. These planes generally vary in local attitude but their average attitude is easily recognised. The planes of inclusions may pass through grains irrespective of the crystal orientation. They may terminate at grain boundaries or pass on through the next grain without change in either attitude or continuity. (See Figures 35 and 36). These vacuole planes are always found in strained quartz and according to the criteria used by Tuttle are of secondary origin. The small recrystallized quartz grains that occur along grain boundaries contain no inclusions nor do the clear unstrained quartz grains in 'later' fractures. The conclusion is that the inclusions disappear during recrystallization.

Adams (1920:p.650) in discussing the crystallization of vein quartz states that in the original crystallized vein quartz the inclusions are randomly distributed. He concludes that with recrystallization these inclusions would be removed.

The exact mechanism for the formation of planes of inclusions is not well known. Three main hypotheses have been suggested.

Dale (1923) considered that the planes resulted from a

growth of phenomenon, and applied this theory to the formation of planes of inclusions in the quartz of granites. However he did recognised the existence of some planes of liquid inclusions which had a secondary origin.

The apparent lack of relationship between the planes of inclusions and the crystal axes and the extension of planes across grain boundaries do not indicate a primary origin for the inclusion planes in the Pioneer vein quartz.

Judd (1886) believed that the planes of inclusions were formed by solutions entering along planes of easy solubility. He considered that these planes along which solutions readily moved have a definite relationship to the symmetry of the crystal system, but he realized that such a relationship could not always be determined.

As early as 1884 Hicks proposed a fracture hypothesis in which he described planes that were of a seconday origin and were related to fractures in the primary quartz which were caused by deformation. These planes were later filled with secondary quartz. Tuttle (1949:p.334) elaborated on this theory by attributing the fracturing of the quartz to the same deformational forces that produce such structures as jointing, faulting, etc. He considered that the fracturing was followed by the filling of the fractures with a liquid which ultimately crystallized. According to Tuttle those parts of the fracture that were not annealed will occur as inclusions and the sizes and shapes of such inclusions will be indicative of the age of the fracture and the length of time taken for the annealing to

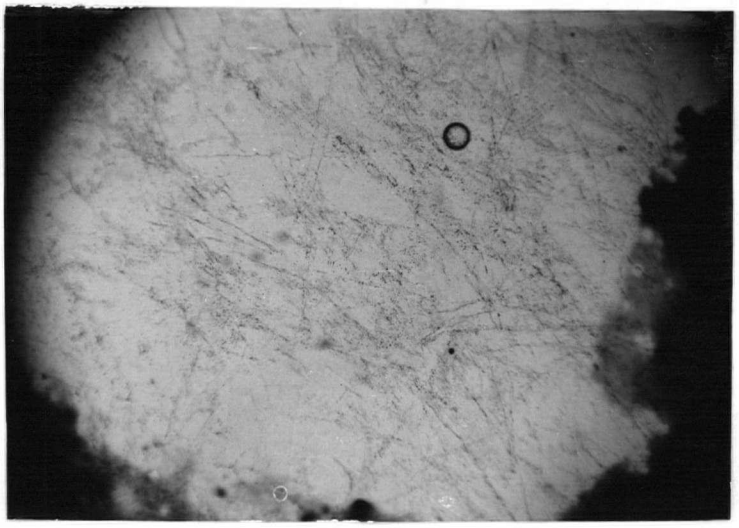


Figure 35. Photomicrograph showing planes of liquid inclusions in quartz. Plain light x 46. This section 26-112B.

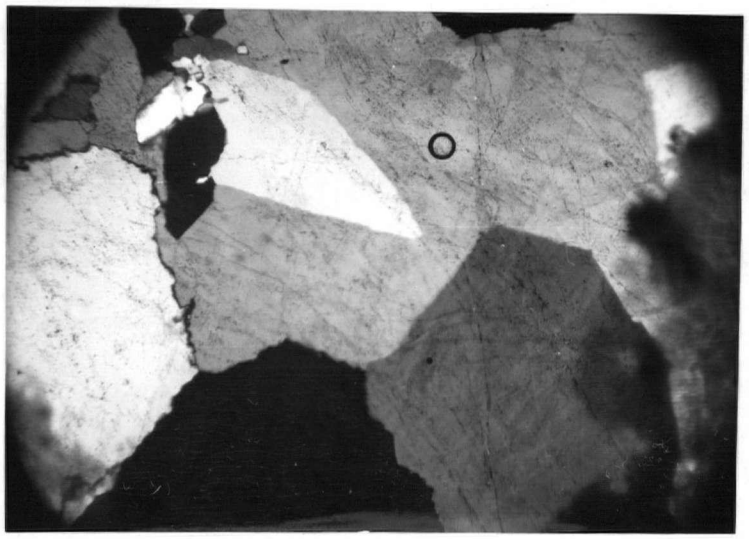


Figure 36. Photomicrograph showing planes of liquid inclusions. Polarized light x 46. Thin section 26-112B. The same section position as figure 35, showing the planes pass through grain contacts.

occur. He also considers that the progression of the annealing is seen by:

1) The formation of fractures seen as thin lines under the microscope.

2) The annealing of certain sections of the fracture, which results in the formation of vacuoles in areas not yet annealed.

3) The gradual apparent displacement of the vacuoles due to continued deposition of quartz. The vacuoles in the last stages do not occur in well defined lines.

The energy causing solution and deposition of quartz along these fractures can be mechanical or thermal and substitution and deposition were possibly affected by the 'Riecke' principle. TheRiecke principle is the effect of contact pressure on solution.

The exact mechanism of the formation of inclusions in quartz was stated by Tuttle to be the dissolving of material along surfaces of contact, which may have been followed by either deposition of dissolved material in areas of lower pressure or deposition upon pre-existing crystals, due to osscilations in temperature which results in the continued growth of pre-existing crystals.

Tuttle (1949) examined several quartz specimens from an area of 200 square miles in Washington, D.C. These specimens contained inclusions. Tuttle (1949:p.346) concluded that no microscopic structures could be found that could be directly re-

lated to the planes of liquid inclusions within the quartz, but that it was possible for some inclusions in vein quartz to be related to the megascopic structures. Furthermore, his statistical studies of planes of liquid inclusions in quartz, indicated that there was no control of the orientation of these planes by crystallographic directions in the quartz. Tuttle (1949:p.354) believed that the planes of inclusions are younger than the primary structures of the area and are not genetically related.

The writer studied several sections of vein quartz from the 27 vein of Pioneer. The oriented slides of quartz were placed on a Leitz 4 axis universal stage and the attitudes of the planes of inclusions were measured. Their poles then were plotted as a stereographic projection using the lower half of the sphere.

The way in which errors may result in the actual measurement of the planes have been described by Tuttle as -

1) These planes are undulose and the average direction must be taken. This will result in the loss of detail but should not affect the overall result.

2) The direction of the planes will affect the number of the readings recorded in a traverse of the slide and the statistical analysis will be in error.

To obtain optimum values for the statistical analysis Tuttle used one slide each cut at right angles to the plane of inclusion. He made determinations on them and combined the results. In the present work one horizontal and one vertical section were cut from each specimen of vein quartz. The

sections cut in the vertical plane are referred to as A', and B', and the results of the vertical section have been rotated into a horizontal plane. It was considered that any horizontal or sub horizontal planes of inclusions would not be recognized in the horizontal section, but would be seen in the vertical section, and no planes in the quartz would remain undetected.

The results of the measurements of planes of inclusions are expressed in figure 37 diagram 1 to 10, and for comparison the composite stereographic projection of the megascopic planes of failure in 20 level as reproduced as diagram 11.

The fabric diagrams of planes of inclusions indicate maxima which may be related to the maxima of the fabric of the megascopic structures. But in a similar manner to the megascopic features the maxima are not always the same in each diagram which indicates that there is a preferential development of planes.

The fabric diagrams indicate that over small areas and in certain environments the planes of inclusions may be directly related to megascopic structures of the area. In the case of Pioneer mine, the structures may all be related to the development of the "Cadwallader Break" or the Main vein system, with the complementary structures also developed.

ORE SHOOT CONTROLS

Although all the banded quartz veins throughout the mine contain traces of gold, there are only a limited number of ore shoots. The presence of these ore shoots may depend on the

grade or width of the vein, and the dimensions of these ore shoots are usually determined by assay values, rather than physical discontinuities.

The most important gold quartz veins in the Cadwallader gold belt appear to be associated with areas of Bralorne intrusions. This indicates a similar genetic origin for both the gold and the Bralorne intrusions.

The factors considered to be responsible for the formation of ore shoots are summarized below.

1) The most favourable feature is the presence of a rock which is able to sustain fractures. The distribution of the veins in the igneous rocks rather than the argillites and serpentine may be explained in terms of relative competency. It is significant that no great development has been made of any veins occuring in these serpentines and argillites, and it is considered that such rocks are distinctly unfavourable for the formation of ore.

2) With the formation of fractures and shears the presence of suitable ore solutions is essential, and a coincidence of appropriate temperatures, pressures, and chemical conditions would be required. The physical and chemical conditions at the time of vein formation are not known, and their exact nature can only be surmised.

3) The necessary openings for deposition of vein material would be found in the fissures at locations where changes in strike or dip occur. Such variations are reflected by the distribution and widths of the veins and may to some extent represent changes in the relative competences of the rock types in which the fissures formed. The exact locations of sections of relatively wide vein material would also depend on the direction of the movement. The more northerly striking sections of the main vein systems tend to be the pinched sections which represent the bearing surfaces of the movement. Such surfaces or planes would be compatible with a reverse sinistral movement.

4) Cairnes considered that an important factor for ore deposition is the presence of intra-mineralization shears. These shears are represented by the ribbon quartz in Pioneer mine. The presence of ribbon quartz sometimes indicates that the vein will contain better gold values than usually found, but this is not always true. The reasons for this variable relationship between the gold content and the banding has been discussed in the section relating to the banding as seen in the 27 vein.

5) The intersection of fractures and their minor splitting in certain sections have long been recognized

as potential locations of ore shoots. These intersections and splittings are not always conducive to ore deposition at Pioneer mine as can be seen by the contact of the Main and 27 veins on 22 level. At this position there is no increase in quartz widths and there is no increase in gold values.

The enrichment in gold of these intersections would depend on.

1) origin of the fissures
2) mineral history of these fissures
3) the relative positions of the fissures and the direction of movement of the ore forming medium.

6) The most outstanding ore control in the mine is the serpentine fault zone, which forms the southern limit of the mine workings. The fault dips at a steep angle to the south. The vein fissures dip to the north and their upper limits are determined by their contacts with this serpentine. These contacts plunge towards the west, and the ore shoots occuring below the serpentine have the overall form of curtains hanging from the serpentine contact. The serpentine is very incompetent and it is thought that it was unable to form or sustain an open fracture system during the period of vein formation so that it acted as an impermeable capping to the channelways formed by the vein fissures. This capping did not dam the 'vein'

solutions for there is no increase in the widths of the veins beneath the contact. The capping acted with a channelizing influence to concentrate the flow of vein material below it and caused an increase in the deposition of gold.

The overhang of local serpentine and of fault gouge along the greenstone-sediment contact to the north of the greenstone has resulted in the formation of minor ore shoots, none of which has been developed.

CHAPTER VI

ORIGIN OF THE GOLD QUARTZ VEINS

The positions of the ore shoots in the veins at Pioneer Mine appear to be dependent upon local conditions such as the positions and sizes of available openings which were coincident in space and time with the ore bearing medium. The appropriate temperatures and pressures and chemical conditions must have been constant over a vast area because the veins throughout the mining camp of Bralorne and Pioneer have an identical mineralogy which persists to great depths. The Main vein has been investigated to depths of almost 5,000 feet by underground development and diamond drilling.

The quartz of the Pioneer veins was considered by Cairnes and others to have been derived from the same magma that gave rise to the soda granite and Bralorne diorite. The evidence which suggests a genetic relationship between the Bralorne intrusions and the gold quartz veins is the fact that they occur in close proximity to one another. The association of gold quartz veins and albite rich rocks has been discussed by Gallagher (1940) who quotes the Bridge River district as an example of this association.

In the past decade many authors have questioned the hydrothermal origin of many ore deposits. Oftedahl (1958) has proposed an exhalative-sedimentary origin for many pyrite

deposits, and Sullivan (1948) has contended that ore deposits are not derived from the differentiation of magma but rather may be formed mainly from sediments and other rocks available in the soil at the time granitization takes place.

Sullivan (1948) has shown there is an association of gold and greenstone, which he considers may not be due to the physical and chemical properties of the greenstone. These properties supposedly make the greenstone more favourable for the deposition of gold than the sedimentary rocks because the greenstone can sustain open fractures in which gold-quartz veins can be located. He further implies that the greenstone may be regarded as the source rocks for gold in much the same way that shale is regarded as the source rock for petroleum. The nature of the mechanism for the extraction of the gold contained in the greenstone and of its concentration into economic deposits is not stated by Sullivan.

Boyles (1959:p.1523) who has described the Yellowknife gold deposits in the Northwest Territories of Canada suggests a mechanism for the concentration of gold from greenstone which is as follows:

> "1 The volatiles and other constituents of the deposits were derived by lateral and vertical secretion from a series of rocks in which they occur.
> 2 The energy necessary to mobilize various elements and concentrate them in deposits was in part due to dilatancy resulting from structural deformation."

Boyle bases his assumption upon geochemical studies of the rock types at Yellowknife. He finds that there is an in-

crease in volatile bearing minerals towards shear zones, and a corresponding decrease towards the granite.

The greenstone and the metamorphosed equivalents at Yellowknife do not appear to be unusual rock types and it would seem that the mechanism suggested by Boyle may explain the association of gold and greenstone.

At Pioneer mine there is no indication that a mechanism such as suggested by Boyle has been responsible for the formation of the gold-quartz vein material. Although it is impossible to determine the origin of the gold bearing solutions, it is reasonable to assume, on the basis of the present work, that the vein material was derived from a differentiating magma. The final acid phases of this magma were capable of causing albitization of the Bralorne intrusions and the adjacent greenstones. The gold-quartz veins of Pioneer mine may be classified as mesothermal and are associated with the final acid phases of the Bralorne intrusions, but they are later in time.

CHAPTER VII

CONCLUSIONS

The sedimentary and volcanic rocks of Pioneer mine are probably early Mesozoic in age. Although previous authors subdivided some of the sedimentary rocks of the Cadwallader creek area into the Hurley and Noel formations on the basis of the carbonate content, the writer considers that the carbonate has been introduced after deposition of the rocks. The writer, like Joubin (1948), concludes that the two proposed formations are actually the same rock unit.

The Bralorne intrusion is composed of Bralorne diorite of variable composition and texture, and soda granite. The intrusion has faulted contacts at Pioneer mine and the writer can find no evidence to support a granitization origin for it. The variable nature of the Bralorne diorite is possibly a reflection of the high volatile content of the original magma from which it was formed. There is no evidence for a 'contamination' origin for this rock.

The possibility of a replacement origin for the soda granite has been considered, but the writer concludes that the soda granite is of magmatic origin. Sodic solutions have caused some alteration of all the granitic rocks, and these solutions were responsible for the albitization of the Pioneer formation. The rock called greenstone diorite previously considered to be part of the Pioneer formation has been formed

by shearing of the Bralorne diorite.

The repetition of the Hurley-Noel formation and the Pioneer formation in the vicinity of Pioneer can be explained by movement on the 'Cadwallader Break'. The general structure is therefore likely a faulted homocline.

The distribution of the gold quartz veins of Pioneer mine can be related to the Cadwallader Break, and the system of faults formed by the vein fissures, megascopic fractures, and the Cadwallader Break is similar to that of a theoretical fault system proposed by Moody and Hills (1956).

Planes of inclusions in the quartz of the quartz veins have the same general attitude as the megascopic planes of rupture (joints, shear planes). The planes of liquid inclusions appear to be the microscopic affects of deformation.

The gold quartz veins are genetically related to the Bralorne intrusions. Although there is a possibility that evidence for a granitization process may exist at depth, the gold-quartz veins are considered to be hydrothermal, and are later than the acid phase of the phase of the Bralorne intrusions. These veins have a simple mineralogy and may be classified as mesothermal gold-quartz veins.

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