



GEOLOGY OF GYPO QUARTZ VEIN  
OLIVER, BRITISH COLUMBIA  
(82E/4)

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INTRODUCTION

Gypo quartz deposit is in the Okanagan Valley near the northern outskirts of Oliver, British Columbia about 43 kilometres (27 miles) south of Penticton (Fig. 102). Production of high-purity silica was continuous from 1955, when development was taken over by Pacific Silica Company, until August 1968 when the operation was closed due to caving of part of the quarry wall. During this 14-year interval from 20 to 35 persons were employed annually. Yearly production ranged from a low of 2,500 tons in 1955 to a high of 60,000 tons in 1960. From 1962 to 1966 inclusive, average annual production was about 46,000 tons. At the close of continuous quarrying operations in 1968 more than 20,000 tons of crushed material of variable quality existed in stockpiles at the quarry site. Small shipments have been made since 1968, both from stockpiles and limited sorting of slumped material from the quarry floor. Most concentrates produced had a purity of greater than 99 per cent silica.

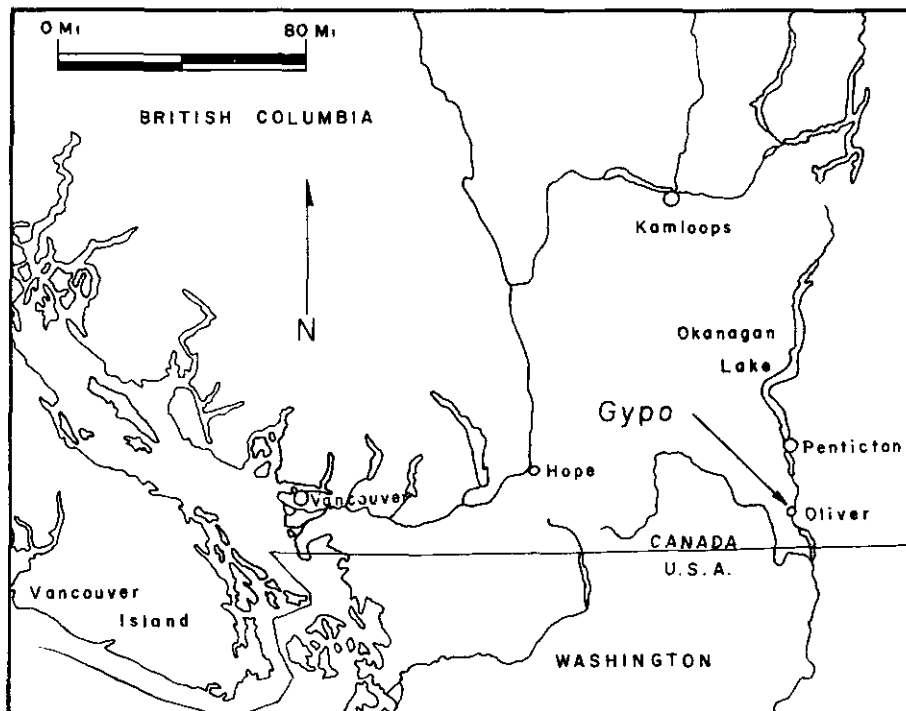


Figure 102. Location of Gypo deposit.

Production has been used mainly as decorative material in the building industry, especially as stucco dash. Small batches of concentrates have been used for a wide variety of purposes, including preparation of special cements, as a flux in the mineral industry, for patio aggregate, as poultry grit, in the production of ferrosilicon and silicon carbide, and others. Although Gypo vein has been quarried principally for quartz, a small amount of by-product fluorite has also been shipped from the deposit.

A number of other somewhat similar deposits occur in the general area. However, these are considerably smaller than Gypo deposit and were of interest in the past because of their precious metal contents. The nearest deposits of appreciable size are the Standard and Susie veins (Fig. 103), both of which have seen periodic reactivation in the past decade when gold prices have increased so dramatically.

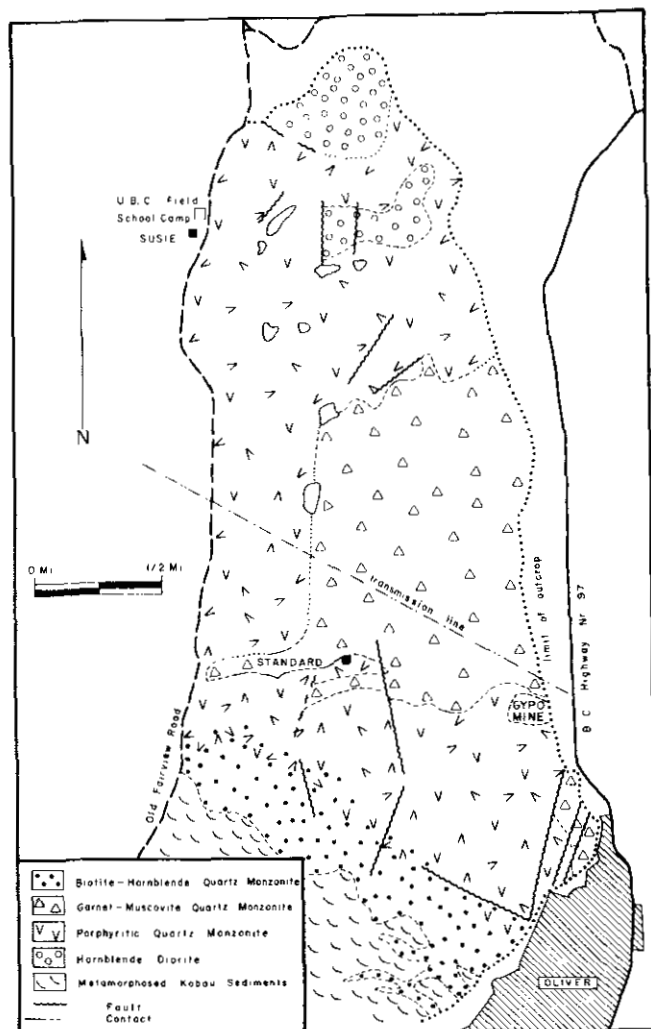


Figure 103. General geology of the Gypo deposit area.

Numerous small quartz veins and veinlets containing minor amounts of pyrite are known throughout the area. Morning Star and Stemwinder deposits of the Fairview camp (Cockfield, 1935) are in Kobau meta-sedimentary rocks several miles to the west.

### GENERAL GEOLOGY

The area surrounding Gypo deposit is underlain principally by medium-grained intrusive rocks that form what is here called the Oliver Plutonic Complex (Table 1). This complex includes rocks mapped previously as Oliver syenite and Oliver granite (Bostock, 1940). To the south the pluton cuts Kobau metasedimentary rocks of Carboniferous (?) age. On its northern margin the intrusive mass is in contact with Vaseaux Formation that probably is part of the Shuswap Terrane.

**TABLE 1**  
**MESOZOIC AND EARLY TERTIARY INTRUSIVE ROCKS NEAR GYPO DEPOSIT**

AGE	ROCK UNIT	ROCK TYPE	PREVIOUS TERMINOLOGY
EARLY TERTIARY	MAFIC DYKES	LAMPROPHYRE	
MIDDLE JURASSIC	OLIVER PLUTONIC COMPLEX	MUSCOVITE QUARTZ MONZONITE	OLIVER GRANITE OF BOSTOCK (1940)
		PORPHYRITIC QUARTZ MONZONITE	
		BIOTITE-HORNBLLENDE QUARTZ MONZONITE	OLIVER SYENITE OF BOSTOCK (1940)

Recent work (Fig. 103) shows that Oliver pluton is composed almost entirely of quartz monzonite (Richards, 1969). Three distinct phases can be recognized in the field. A central core of massive medium-grained garnet-muscovite quartz monzonite is surrounded by a porphyritic quartz monzonite containing about 1 to 5 per cent phenocrysts of K-feldspar up to 2.5 centimetres (1 inch) in maximum dimension. The contact between these units is commonly a narrow zone of quartz-feldspar pegmatite a few metres to 3.5 metres (10 feet) in width. However, at Gypo mine and at one locality along the northern margin of the core the contact is either sharp or gradational over several metres. Field examination indicates that the predominant mafic mineral in the porphyritic quartz monzonite is hornblende north of the core and biotite to the south.

The third phase of the pluton is a hornblende-biotite quartz monzonite located to the south of the other two units and previously referred to as Oliver syenite by Bostock (1940). A transition zone of up to 60 metres (200 feet) in width separates hornblende-biotite quartz monzonite from porphyritic quartz monzonite. Rocks in the transition zone are sub-porphyritic with smaller phenocrysts and a higher mafic mineral content than in the porphyritic quartz monzonite. The hornblende-biotite quartz monzonite contains numerous elongate mafic-rich inclusions that parallel a primary foliation of mafic minerals. Both of these features are most pronounced near the contact with Kobau metasedimentary rocks and the foliation, in general, seems to parallel the contact.

Relative ages of the three units have been determined from cross-cutting relations just west of the area shown on Figure 103. West of Old Fairview Road, immediately south of the powerline, dykes of garnet-muscovite quartz monzonite cut the porphyritic quartz monzonite. Similar relations are found further west. About 2.4 kilometres (1.5 miles) west of Old Fairview Road, along the general trend of the hornblende-biotite quartz monzonite unit, a thick dyke of porphyritic quartz monzonite cuts the hornblende-biotite quartz monzonite. Hence, on geological grounds relative ages of the three main phases of the Oliver pluton are: hornblende-biotite quartz monzonite (oldest), porphyritic quartz monzonite, and garnet-muscovite quartz monzonite (youngest). Modal analyses for specimens (see Table 2) of all phases are plotted on a feldspar-quartz triangular diagram (Fig. 104). A variety of dykes cut the pluton. Near the University of British Columbia geology field school is a swarm of fine-medium grained quartz monzonite dykes that cut hornblende-bearing porphyritic quartz monzonite. Similar but finer grained dykes are present in the southern part of the area. Along the northern margin of the core a small fine-grained muscovite-biotite-garnet-bearing dyke cuts both the porphyritic quartz monzonite and the garnet-muscovite quartz monzonite. Numerous dyke-like bodies occur in Kobau metasedimentary rocks along the southern margin of the pluton. Many of these are apophyses of the pluton but some are later dykes.

TABLE 2. MODAL COMPOSITIONS

SAMPLE NO.	1	2	3	4	5	6	7	8	9	10
Thin section no.	R68-2	GYPO 4	R68-1	567-15	R68-5A3	R68-5A1	R68-5A2	R68-SB3	R68-5A1	567-1
Hand specimen no.	R68-2	G-4	R68-1	567-15	R68-5A	R68-5A	R68-5A	R68-5B	R68-5A	567-1
General description	unaltered	unaltered	unaltered K-Fp rich	K-Fp alteration	K-Fp alteration	K-Fp alteration	K-Fp alteration	sericite alteration	muscovite alteration	muscovite alteration
No. of points counted	1 050	1 200	1 050	1 188	1 200	750	1 200	750	1 200	
<b>MINERAL</b>										
	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>	<i>per cent</i>
Apatite	0.4	0.1	0.2	0.4	0.5	0.2	0.8	0.3	0.3	-----
Clinozoisite	1.9	1.5	0.5	-----	0.1	0.1	-----	0.1	-----	0.5
K-feldspar	19.6	27.8	35.7	67.4	73.2	73.8	62.7	13.8	1.5	-----
Albite	34.0	17.3	33.2	-----	-----	-----	-----	0.3	-----	-----
Anorthite	8.5	6.7	8.0	-----	-----	-----	-----	0.1	-----	-----
Muscovite	0.7	-----	0.2	5.6	20.6	19.7	36.2	61.5	86.4	97.0
Biotite	7.5	4.9	5.3	-----	-----	-----	-----	-----	-----	-----
Pyrite	0.3	-----	0.2	0.4	0.6	0.1	0.1	2.3	0.2	2.5
Quartz	26.9	31.6	16.7	26.0	5.0	6.1	-----	21.6	11.5	-----
Sphene	-----	-----	-----	-----	-----	-----	0.1	-----	-----	-----
Calcite	0.2	0.1	-----	0.2	-----	-----	0.1	-----	0.1	-----
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

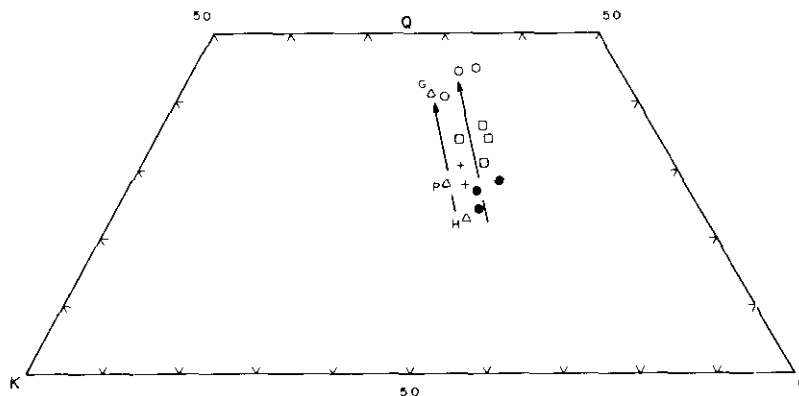


Figure 104. Mineralogical variations of principal rock units in the Oliver Plutonic Complex. Two trends are shown. Lettered triangles are averages of seven samples for each of the three principal rock types: H = hornblende-biotite quartz monzonite; P = porphyritic quartz monzonite; and G = garnet-muscovite quartz monzonite. This trend is compared with individual modes of specimens studied by Richards (1969).

Quartz veins containing small amounts of sulphides and precious metals are found in the Oliver pluton and surrounding rocks. Within the pluton large veins with some indicated economic potential are confined to the porphyritic quartz-monzonite phase. Quartz veins are cut by lamprophyre dykes that are highly variable in width and occur through the region. The largest known lamprophyre body is a near-vertical sheet about 15 metres (50 feet) wide that extends from Gypo mine southward for several thousand metres.

In the northern part of the area on Figure 103 are two large masses of medium to coarse-grained gneissic diorite consisting almost entirely of hornblende and plagioclase in variable proportions. These bodies resemble amphibolitic units of Vaseaux Formation to the north and probably represent large, partially assimilated masses of Vaseaux rocks.

The area has been faulted and fractured extensively. Contacts of the three main phases of the pluton have apparent offsets of 0.40 kilometre (one-quarter mile) or more, especially in the southern part of the area of Figure 103. Most of the region has been affected by hydrothermal alteration. In the northern part of the area where calcium-bearing minerals are most abundant the dominant alteration product is epidote which occurs in seams up to 2.5 centimetres (1 inch) in thickness. In the southern part of the region biotite is

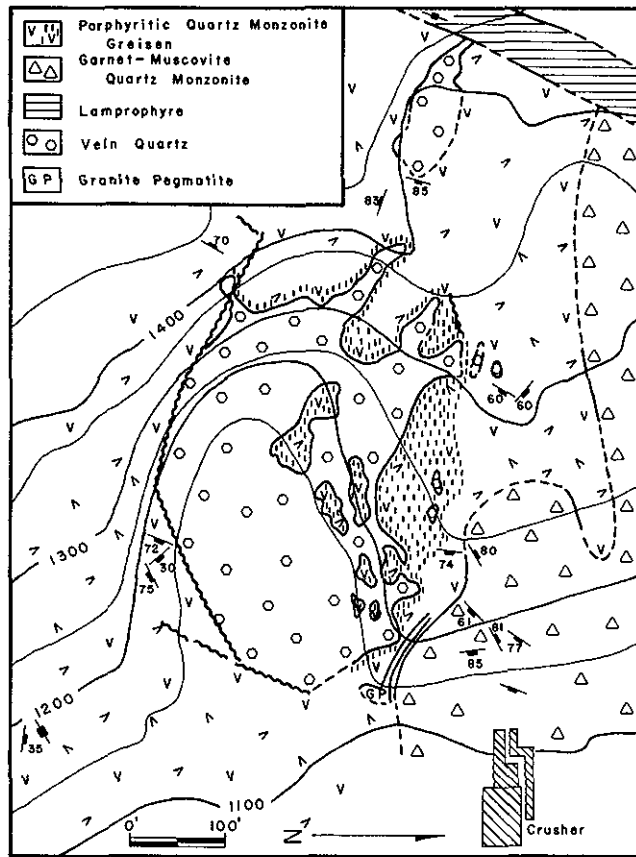


Figure 105. Detailed geology of the Gypo quarry and adjacent area.

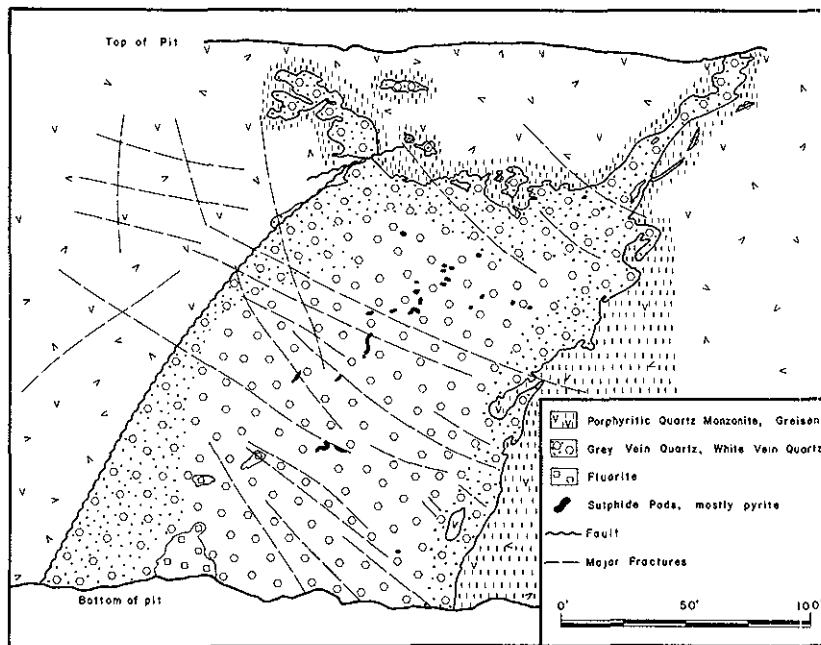


Figure 106. Projection of near-vertical quarry face onto a vertical N-S section essentially perpendicular to the strike of the vein.

the abundant mafic mineral and chlorite is the most obvious result of regional hydrothermal alteration. Whether or not the region has been subjected to more than one period of hydrothermal alteration is not known. However, some of the alteration postdated emplacement of lamprophyre dykes and the development of some faults. Many fault zones appear to be later than alteration effects. The eastern edge of the area under consideration forms the western wall of the Okanagan Valley; it has been affected by extensive faulting and close-spaced fracturing. These features have not been studied in detail here but they are one of the latest tectonic events in the area and one might speculate that they are related to the development of the Okanagan Valley, which further north has been shown to be the locus of intense faulting of regional extent (see Little, 1961).

## GENERAL FEATURES OF VEIN DEPOSITS IN OLIVER PLUTONIC COMPLEX

Numerous quartz veins occur within the Oliver Plutonic Complex all of which show a number of features in common. In addition, a few relatively large quartz veins are known in Kobau metasedimentary rocks, such as the Morning Star and Stemwinder deposits of Fairview Camp that were mined several decades ago for their gold contents. The following general account applies only to those veins within the Oliver Plutonic Complex, some of which are shown on Figure 103.

In general, all veins within the Oliver pluton are characterized by an abundance of quartz, almost to the exclusion of other minerals. Pyrite is, perhaps, the only other mineral common to all veins but in many cases can be observed only with close inspection; it forms a negligible proportion of vein material in terms of total volume. Other minerals have been recognized locally, including gold and silver tellurides, galena, sphalerite, and native gold at the Standard deposit. It is occurrences such as the Standard vein that have prompted the limited exploration conducted in the area. Recent high precious-metal prices have resulted in short-term re-opening or re-investigations of the Susie and Standard mines.

Quartz in all deposits has been subjected to varying amounts of post-mineralization fracturing, commonly to the extent that original textures are in large part destroyed. However, where relatively undeformed, all deposits show evidence that much of the quartz was deposited as fairly large crystals, generally 2.5 centimetres (1 inch) or more in cross-section and at least several centimetres in length. In places these crystals show a rough cockscomb texture. All deposits contain at least some early deposited grey quartz although the bulk of the quartz is generally white. Wallrock alteration is not normally a pronounced feature of most of these deposits but all veins show at least a thin zone of sericitization along their margins. Large veins are restricted to the porphyritic quartz monzonite although smaller veins up to a few centimetres in width are found in both the core phase and the southern marginal phase. All quartz veins show some evidence of wallrock replacement but in most cases it is clear that the depositional process has been principally one of open-space filling. Most veins are very small, about 0.3 metre (1 foot) or less in width and extend laterally for distances of a few metres up to 30 metres (100 feet) or so. The so-called large veins are variable in thickness, commonly from 0.6 metre (2 feet) to 3 metres (10 feet) or more with strike lengths of several hundred to a thousand feet (300 metres) or so. Veins are mostly moderately to steeply dipping with variable strike direction.

In general, the similarity of features of quartz veins associated with the Oliver Plutonic Complex suggest that they have had a common origin that is somehow related to the pluton itself. Many of the features referred to are shown by the Gyppo deposit, but on a much more grand scale than is general throughout the area.

## DETAILED GEOLOGY OF GYPO VEIN

Gyppo deposit is a large quartz vein in porphyritic quartz monzonite near the contact with the core phase (Fig. 103). The deposit strikes east-west with a southerly dip of 55 to 60 degrees (Figs. 105 and 106). It is

approximately 45 metres (150 feet) in true thickness at the quarry site and has a known strike length of about 150 metres (500 feet). A thinner extension from the main vein continues at least another 90 metres (300 feet) to the west. On the hangingwall (south) side the deposit is bounded by a thin shear zone 5 to 7 centimetres (2 to 3 inches) wide, occupied by gouge. At the west end of this fault apparent offset is small as is shown by continuity of protrusions from the vein on either side of the fault. The movement picture is not at all clear near the quarry entrance. Character of the footwall is in sharp contrast to that of the hangingwall zone. The footwall has been altered intensely for distances up to 30 metres (100 feet) from the vein, forming a greisen consisting predominantly of muscovite with lesser amounts of quartz. Furthermore, abundant relict patches of partially greisenized wallrock occur within the vein near the footwall.

The deposit has been cut by a near-vertical lamprophyre dyke that strikes roughly north-south near the western exposures of the quartz vein. Lamprophyres are common in the general area but this particular dyke is the largest yet found, with a width of about 15 metres (50 feet) and a strike length in excess of 700 metres (2,000 feet). The dyke contains about 45 per cent ferromagnesian minerals (olivine, augite, and biotite) in a K-feldspar matrix (35 per cent) with lesser amounts of apatite, plagioclase, and magnetite. Heat from this intrusion metamorphosed small pods of pyrite in the quartz vein, transforming them to pyrrhotite.

## MINERALOGY

**QUARTZ:** Three stages of quartz mineralization are recognized in Gypo deposit. Early (Stage I) quartz is grey in colour and is confined to country rock, alteration zones, and marginal parts of the vein. It is massive in character and the colour fades gradually over a distance of a few metres from the vein wall where it gives way to white quartz (Stage II) that makes up more than 95 per cent of the vein material. An explanation for the colour difference between these two types of quartz has not been sought in detail at Gypo deposit. Holtby (personal communications, 1972) did a trace-element study of white and grey quartz from the nearby Susie deposit and found there that grey quartz had a much higher manganese content than did white quartz. Distributions of the two types are shown on Figure 106.

The white quartz at Gypo deposit is principally in the form of giant crystals up to 0.3 metre to 0.6 metre (1 to 2 feet) in diameter and 2 metres (6 feet) in length (*see* Matson, 1959), hence the deposit qualifies as a quartz pegmatite. These crystals are observed intact only rarely, in part because most have been mined, but principally because the deposit has been fractured intensively with the production of numerous closely spaced smooth joint surfaces. These joints have given rise to the local name 'cleavage quartz' and commonly exhibit a rhombohedral form. We have examined this rhombohedral joint pattern in crystals at the quarry and others now used as decorative pieces in gardens in Oliver. In many cases, the joints parallel rhombohedral crystal faces but this is not the case everywhere. In some crystals as many as six fracture directions are apparent and invariably some of these joints, although not necessarily the best developed, are parallel to rhombohedral crystal faces. Some smooth joints can be traced from vein quartz into adjacent wallrock. Etch tests with hydrofluoric acid suggest the quartz was deposited as the low temperature polymorph.

Small amounts of quartz (Stage III) occur as thin delicate boxworks that cut earlier minerals, especially fluorite.

**FLUORITE:** Apple-green fluorite occurs in a series of irregular pods up to 2 metres (6 feet) or more in average diameter, distributed sporadically along a zone that is of more or less uniform distance from the hangingwall (*see* Fig. 106). The fluorite is intensively fractured and even fresh-looking specimens are extremely friable.

**MUSCOVITE:** Muscovite occurs in two distinct sizes. It forms very coarse-grained books up to 2.5 centimetres (1 inch) in diameter that occur intermixed with vein quartz near the footwall but medium-grained, massive muscovite that is characteristic of altered wallrock is much more abundant.

**SULPHIDES:** Sulphides form less than 1 per cent of the vein material. They are concentrated in small pods up to a few centimetres in diameter restricted to a thin zone in the central part of the vein (*see* Fig. 106). Pyrite is the principal sulphide but it has been metamorphosed to pyrrhotite adjacent to a lamprophyre dyke in the western part of the vein. Small amounts of chalcopyrite and molybdenite have been observed in polished sections. Minor amounts of marcasite are present as an alteration of pyrrhotite. Sulphide pods stand out clearly because all are limonitized and contrast sharply with white quartz on the quarry face. Small cubes of pyrite are a minor but ubiquitous component of altered country rock.

**APATITE:** Small amounts of apatite have been recognized in thin sections of altered rock, both greissen and feldspathized rock, in the footwall zone. The mineral has not been seen megascopically.

**CALCITE:** Small amounts of white to colourless calcite occur as thin veinlets and seams in quartz and locally forms small drusy cavities.

**MANGANESE STAIN:** Black stains, commonly with well-developed dendritic pattern are present on some crystal faces, on joints in quartz and wallrock, and as earthy material in weathered wallrock. These minerals have not been studied in detail.

#### MINERAL ZONATION AND PARAGENESIS

A well-defined zonation of mineral varieties occurs within Gypo vein as illustrated on Figure 106. A relatively thin marginal grey quartz zone grades into white quartz occupying the interior of the vein. Regularly distributed within the white quartz are two separate zones, one characterized by large irregular pods of fluorite fairly close to the hangingwall and a second consisting of small sulphide pods more or less centrally located in the vein. Small grey quartz veins up to 0.30 metre (1 foot) in thickness are common around the margin of the main vein. These veins are cut by thin seams of muscovite whereas white quartz is not. The implied age relationship is consistent with order of deposition in the main vein. Position of fluorite and sulphides in the paragenetic sequence is less certain. Sulphides are centrally located in small cavities that indicate they were probably one of the last effects of hypogene mineralization. Fluorite distribution pattern suggests that it was deposited for a relatively short period within the interval of white quartz deposition. The Stage III quartz that cuts fluorite might simply be a continuation of Stage II quartz.

#### WALLROCK ALTERATION

**FIELD ASPECTS:** Wallrock alteration has been extensive about the Gypo quartz vein, particularly along the footwall side (Fig. 106). The host, porphyritic quartz monzonite, has been altered almost completely to a friable mass of muscovite with minor amounts of grey quartz and, in places, a few relict 'horses' of host. In detail, these 'horses' are also altered by feldspathization upon which has been superimposed intensive muscovite alteration. The resulting alteration product is akin to a greisen, although some common *greisen minerals* such as topaz and cassiterite have not been recognized. This extensively altered zone grades rather abruptly into wallrock that is only slightly altered. It was collapse of this greisenized footwall zone in August 1968 that piled debris on the quarry floor and resulted in shutdown of mining operations. Field relations indicate that 'greisenization' occurred prior to extensive quartz deposition. The greisen is cut locally by early grey quartz veinlets up to a few centimetres wide and with sharp contacts. In places, however, such as the quarry entrance, thin replacement seams of muscovite extend through grey quartz and feldspathized zones. One of the striking features of the alteration is its apparent asymmetry — no extensive greisen zone occurs on the hangingwall (south) side of the vein. Further attention will be directed to this peculiarity in a later section.



Useful insight into the alteration processes can be had by investigation of small well-defined alteration envelopes about thin grey quartz veins adjacent to the main vein. Such an example is shown diagrammatically on Figure 107, a tracing of a photograph taken on the south side of the quarry entrance. Here, relatively flat-lying quartz veins, each a few centimetres to 0.30 metre (1 foot) in thickness, contain on their lower side a massive muscovite zone. The combined quartz and muscovite zones are surrounded by a pink alteration envelope consisting predominantly of K-feldspar and having a thickness comparable to that of the quartz vein. This alteration zone grades fairly abruptly into relatively unaffected wallrock. In places one finds thin seams of muscovite a fraction of a centimetre thick that cut the K-feldspathized zone. These seams are products of metasomatism that extend into otherwise unaltered wallrock and apparently are fracture-controlled. This relationship establishes relative ages of alteration types-K-feldspathization followed by greisenization. A similar age relation can be seen in the large intensity greisenized footwall zone where feldspathized masses of wallrock have been replaced irregularly by greisen.

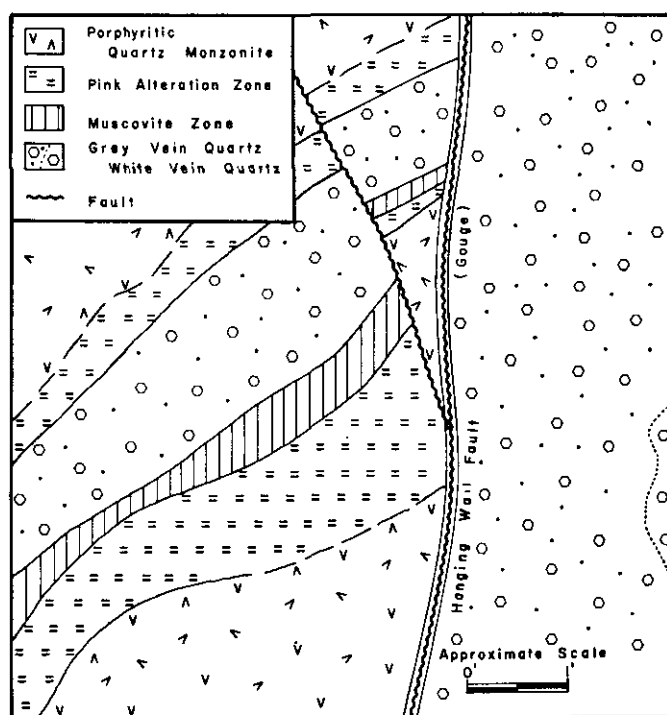


Figure 107. Details of mineralogical zoning in and around a 4 to 6-inch-wide grey quartz vein at the margin of and in fault contact with the main vein. South side of quarry entrance.

**PETROGRAPHY:** Modal analyses of unaltered wallrock and the two extreme types of alteration, based on approximately 1 100 points per thin section, are listed in Table 2. Mineralogically the two types of alteration are distinct. One is predominantly K-feldspar (at least two-thirds by volume) with much smaller and variable amounts of muscovite and quartz. The other, greisen, is almost exclusively muscovite with small amounts of quartz. Pyrite occurs as an accessory mineral in both types and appears somewhat more abundant in the greisen than in the K-feldspar alteration.

In general, alteration products are medium-grained and massive and, with their distinctive mineralogies are easily recognizable in the field. As mentioned earlier, typical accessory minerals in greisen such as topaz and cassiterite have not been identified although fluorite is a minor constituent, as are apatite and molybdenite.

**EXCHANGE OF ELEMENTS DURING ALTERATION:** Wallrock alteration has been effected by extensive metasomatism involving the complete making over of original country rock. Although this probably took place principally within solid rock, there is some indication that open-space filling played a significant part in the process of greisenization. For example, on the hangingwall (south) side of the vein, small seams of muscovite (identical with large massive patches of greisen) have formed by replacement of fracture walls. Similarly, on the footwall (north) side, within the zone of intense greisenization veinlets of medium-grained muscovite cut relict patches of feldspathized wallrock.

The investigation of element transfer during metasomatic processes presents problems because of the uncertainty as to what might represent a standard feature of reference that remained unchanged during metasomatism. Various underlying assumptions have been made as a standard for calculations, including: constant volume (Lindgren, 1918), constant cation percentages (Barth, 1952), constant oxygen atoms (Barth, 1952), and constant silica tetrahedra (Poldervaart, 1953). Calculation of element exchange, using all the foregoing assumptions, requires chemical analyses that were not available to us. However, it is possible to calculate chemical compositions approximately from detailed modal analyses, providing that chemical compositions of constituent minerals are known fairly precisely. We had tested this approach previously by comparing such calculated chemical compositions with actual chemical analyses for specimens from the Copper Mountain area (Montgomery, 1967) and found surprisingly close agreement between the two methods. Consequently, we proceeded to calculate chemical compositions for unaltered rock, K-feldspathized samples, greisen samples, and several transitional rocks using a computer program patterned after that of Dietrich and Sheehan (1964). Calculations are based on average mineral compositions for rocks of similar geological settings taken from Rankama and Sahama (1950).

Using the calculated chemical compositions as a base, we then proceeded to investigate the four methods mentioned earlier for examining exchange of major elements during metasomatism. Qualitatively, all methods showed essentially similar trends for individual elements but quantitatively they differ somewhat one from another. For purposes of presenting the results, we use the method of Barth (1952) based on an assumption of constant numbers of oxygen atoms during metasomatism of silicate rocks. Results are shown on Figure 108 and are summarized briefly below.

The most pronounced chemical changes resulting from metasomatism are shown on Figure 108a and involve obvious decreases in silicon and sodium and increases in aluminum, hydrogen, and potassium, all by a factor of about two or more. These chemical variations are apparent whatever method is used to estimate chemical exchange, and whether average or ideal mineral compositions are used in estimating the chemical composition from modal analyses.

Chemical variations of the less abundant elements are shown on Figure 108b. Because of low abundances, estimated amounts of these elements are more susceptible to variation depending on the particular mineral compositions used in calculations. Nonetheless, the trends shown are consistent regardless of the standard reference state chosen for metasomatism. Of this group only calcium decreases consistently. Other elements such as iron, magnesium, and sulphur appear to decrease in the initial stage of alteration and then increase during greisenization. Iron is of particular interest — it is present mainly in biotite (and chlorite) in unaltered rock, is drastically reduced in the feldspathized zone which is almost devoid of mafic minerals, and then increases drastically in the greisen zone due to its fixation with sulphur as pyrite. Other elements, such as phosphorus, titanium, manganese, and carbon (or CO<sub>2</sub>) show no particular change, although this could be more apparent than real because of their low abundance and the relatively low accuracy in making estimations.

On the average, unaltered wallrock contains 234 silica tetrahedra per cubic centimetre as compared with 175 silica tetrahedra per cubic centimetre of greisen. Assuming no loss of silica tetrahedra, the tetrahedra originally distributed through 1 cubic centimetre of unaltered wallrock now must be distributed in 1.42

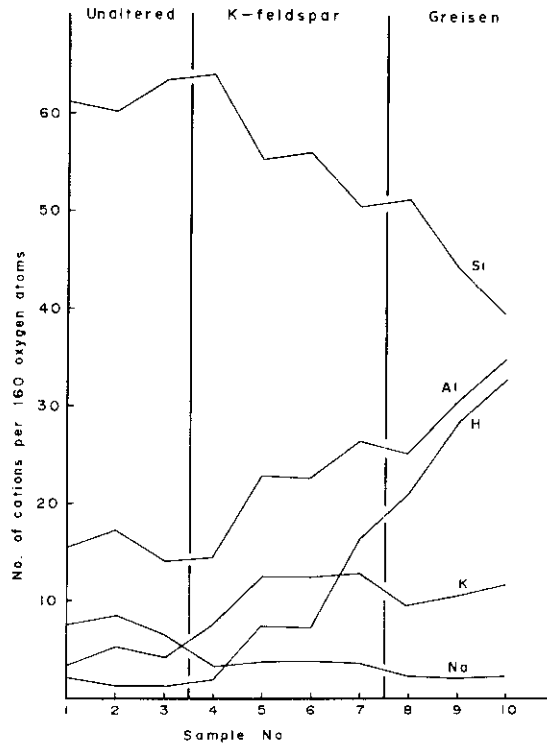


Figure 108a. Graph showing relative exchange of major elements during metasomatism, using Barth's standard cell of 160 oxygen atoms as a reference.

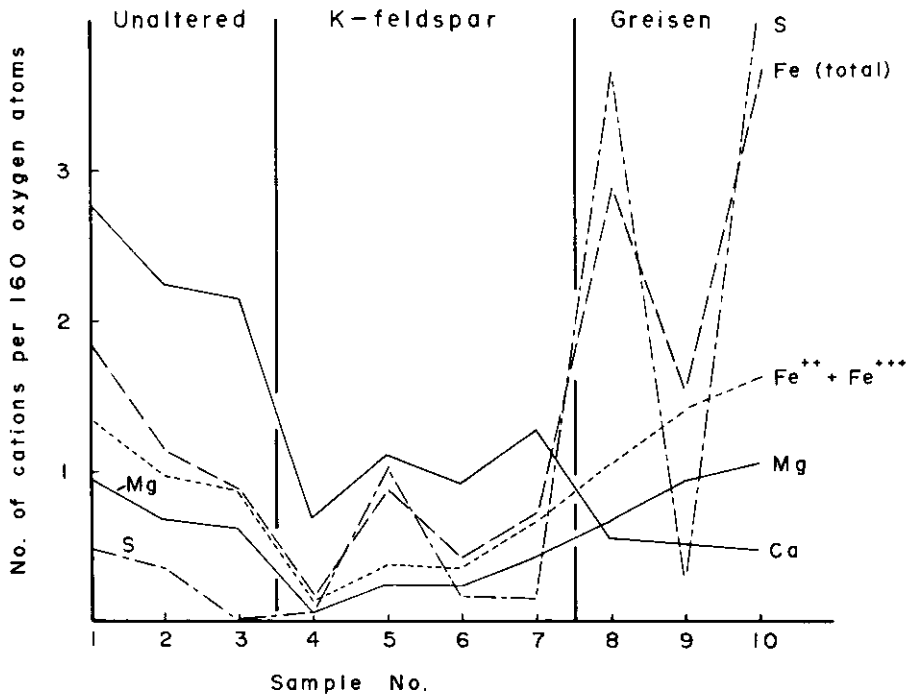


Figure 108b. Graph showing probable relative exchange of some minor elements during metasomatic wallrock alteration, using Barth's standard cell of 160 oxygen atoms as a reference.

cubic centimetres of altered rock, implying a volume increase of about 34 per cent. Although one cannot attach significance to the precise figure, the major conclusion to be derived from this calculation based on the assumption of constant numbers of silica tetrahedra is that a substantial increase in volume has occurred as a result of metasomatic changes. Ames (1961) has suggested that replacement in a closed system involving an increase in volume will continue until all voids in the rock undergoing replacement are filled. This process seems to provide an adequate explanation for thin greisen seams that have developed along joints at Gypo deposit. In general, however, it appears unlikely that metasomatism occurred entirely, if at all appreciably, in a closed system. The indicated volume change, for example, requires a considerable open space into which the altered rock could expand. Whatever the fundamental nature of the processes producing this space (that is, fracturing or chemical dissolution) an open system is implied. Fracturing, for example, suggests through-going channel ways, as does complete removal by chemical dissolution. The argument of an initially open system is further supported by mass balance calculations which show that  $\text{SiO}_2$  released during alteration could account for only about 20 per cent of quartz now existing in the vein (Moore, 1970). Consequently, one must assume that the remaining 80 per cent of quartz in the vein is truly epigenetic and was introduced in the form of dilute aqueous solutions. The tremendous quantity of solutions that would have been required preclude a closed system.

Greisen veinlets and masses commonly show sharp contacts with quartz and, in fact, cross-cutting relations prove that some greisen formed later than some of the grey quartz. On the other hand, greisen is inter-mixed intimately with grey quartz. No such relations exist between greisen and white quartz. It seems probable that greisenization preceded white quartz deposition but was contemporaneous with at least the early part of grey quartz deposition.

However, textural data suggest that a small proportion of the muscovite, in particular the very coarse-grained variety, precipitated from the same solutions from which quartz was deposited. In small flat-lying veins the result is akin to that produced by crystal settling, producing an asymmetry of the muscovite zone. Such an origin might account, in part, for the asymmetry observed in the main vein.

## SPACE PROBLEM

Both open-space filling and replacement processes were operative in the development of Gypo deposit. The extensive footwall greisen zone provides ample evidence of replacement, whereas the presence of giant quartz crystals whose termination point towards the centre of the vein suggests a dominant role of open-space filling. Both processes seem to require an open system. These conclusions lead to a problem in explaining how space was produced for the development of the vein. Mass balance calculations indicate that a maximum of about one-fifth of the total vein volume could have been produced by quartz formed as a result of metasomatism of wallrock. The remainder of the volume must be accounted for by the presence of pre-existing open spaces.

The problem has not been solved as a result of field and laboratory work and one is led to speculate on possible mechanisms. The peculiar shape of the vein in cross-section, that of a tilted rectangular block with upward extensions from each of the top two corners, suggests a plausible means of developing openings. The writers suggest that a centre of intensive fracturing existed at the site of the present vein, leading to extensive alteration. Rock thus weakened, foundered with continuing tectonic activity to produce a large opening in which quartz deposition continued. This hypothesis has the advantage that it provides an explanation for the unusually great width of the vein in the area of the quarry, as well as for the thin vein extensions both upward and to the west. However, it requires that the vein bottoms at some unknown depth, down dip at the top of the foundered block(s). This hypothesis also provides an explanation for asymmetry of the greisen zone (compare Fig. 107), that is, the 'missing' greisen zone on the hangingwall side (vestiges of which are present as discussed in the section on field aspects of alteration) is part of the foundered block.

## RADIOMETRIC DATING

Unpublished rubidium-strontium isotopic dating of the Oliver Plutonic Complex provides an age of emplacement at about 160 Ma, that is, mid-Jurassic (R. L. Armstrong, personal communication, 1981). Potassium-argon ages summarized in Table 3 are all substantially lower than the rubidium-strontium date. Muscovite potassium-argon data for the garnet-muscovite quartz monzonite and the Gypo greisen zone group at about 140 Ma suggesting either a thermal event at that time or a high heat flow from 160 Ma to 140 Ma. Biotite ages are much less, perhaps due to variable local resetting during the Tertiary thermal event represented by the biotite-augite lamprophyre dated at 52 Ma.

TABLE 3  
POTASSIUM/ARGON MODEL AGES FOR  
IGNEOUS ROCKS AND WALLROCK ALTERATION NEAR OLIVER  
(After White, *et al.*, 1968, with additions)

UBC NO.	UNIT	ROCK TYPE	AGE (Ma)*
W65-1	Kruger syenite	Quartz monzonite (Horn Silver mine)	Pyroxene-hornblende 152±8
W65-2	Fairview granodiorite	Granodiorite	Biotite 111±5
W65-3	Oliver Plutonic Complex	Hornblende-biotite quartz monzonite	Biotite 118±4
W65-4	Oliver Plutonic Complex	Porphyritic quartz monzonite	Biotite 82±3
W65-5	Oliver Plutonic Complex	Porphyritic quartz monzonite	Biotite 103±4
W65-6	Oliver Plutonic Complex	Garnet-muscovite quartz monzonite	Muscovite 139±5
W65-7	Gypo, footwall greisen zone	Muscovite-quartz alteration	Muscovite 140±6
W66-2	Mafic dyke, Gypo deposit	Biotite-augite lamprophyre	Biotite 53±2
W66-5	Oliver Plutonic Complex	Garnet-muscovite quartz monzonite	Muscovite 144±6
W67-1	Susie, wallrock alteration	Sericitized porphyritic quartz monzonite	Sericite 114±5
W67-2	Standard, wallrock alteration	Sericitized porphyritic quartz monzonite	Sericite 117±5

\*Error is laboratory reproducibility (one standard deviation).

## CONCLUSIONS

Gypo quartz vein developed in the porphyritic quartz monzonite phase of the Oliver Plutonic Complex about 160 Ma ago, shortly after consolidation of the host. A genetic relationship almost certainly exists between Oliver Plutonic Complex, Gypo quartz veins, and other smaller nearby quartz veins. At Gypo, wallrock replacement has been fairly extensive but the bulk of the vein quartz must have been deposited from hydrothermal solutions in an open system. Origin of the opening in which Gypo vein developed is uncertain but might have formed by foundering of a large fault-bounded block of partly greisenized country rock.

At an early stage in development of the vein the adjacent country rock was extensively feldspathized, probably contemporaneously with deposition of early grey quartz. Small grey quartz veinlets in the surrounding rock formed at the same time. Concurrent with continued deposition of grey quartz and some muscovite, there was a period of intensive greisenization. Foundering of a weakened central block of country rock might have occurred principally at this time or perhaps somewhat earlier to provide a large open space in which white quartz was deposited. Fluorite was precipitated during a short interval within the period of white quartz deposition. Small pods of sulphide located centrally in the vein were the last hypogene mineralization. The calcite might, in part, be the result of late-stage hypogene mineralization, but it has a regional occurrence and is probably largely due to a later superimposed regional hydrothermal alteration. This could, in part, have been related in time to a period of Early Tertiary lamprophyre dyke emplacement but is also, in part, younger. Lamprophyre dykes metamorphosed nearby pyrite to pyrrhotite.

Fracturing affected the deposit and the area several times after vein formation. One period of fractures predates and another postdates regional hydrothermal alteration. The abundant major faults and joint

systems that cut rocks in and near the vein are probably related to a Late Tertiary tectonic event that produced much of the fracturing apparent in the Okanagan Valley and caused the development of so-called 'cleavage' in Gypo quartz.

Later mineralizing effects include deposition of black manganese stain in and near the vein, alteration of pyrrhotite to marcasite, and the production of limonite from both pyrite and pyrrhotite.

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