VANADIUM-BEARING INTERLAVA SEDIMENT FROM THE CAMPBELL RIVER AREA, BRITISH COLUMBIA

BY

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ABSTRACT

Vanadium is concentrated in laminated, black carbonaceous, siliceous sedimentary rocks at Menzies Bay and Quadra Island, Campbell River area, British Columbia. The vanadiferous rocks are intercalated with amygdaloidal, porphyritic basalts, andesites, and spilites, many of which are pillowform. The writer has correlated the Menzies Bay, Vancouver Island, flows with the Upper Triassic Texada formation volcanic rocks of Quadra Island.

A limited petrographic study of the Texada flows in the area has indicated that pumpellyite is copious and widely distributed. Amygdaloidal greenockite is present in trace amounts. The identification of pumpellyite, regarded as amphibole by earlier writers, marks its first occurrence in British Columbia.

In a detailed study of the mineralization associated with the vanadiferous sedimentary rocks, the first British Columbian occurrences were noted for tenorite, brochantite, and cyanotrichite. Malachite and bronchantite were found to be the most abundant supergene copper minerals in the laminated seams. Nearly all the supergene vanadium is present as volborthite, a hydrous copper vanadate common in the Colorado Plateau ores but formerly unknown in Canada.

A blue, well-crystallized mineral, thought to be a hydrous copper sulphate, occurs in the Menzies Bay vanadiferous seams in small amounts. This mineral is believed to

be a new species.

Trace quantities of several other unidentified supergene minerals are present. Among these is a water-soluble vanadate with an x-ray powder pattern similar to that of fernandinite.

A previously unidentified opaque material constituting as much as 40 per cent of the laminated rocks has been recognized as an inorganic, volatile carbon substance containing copper and traces of vanadium. The carbonaceous matter is largely epigenetic in the Menzies Bay seams and syngenetic in the Quadra Island sediment. X-ray powder photographs and diffractograms, semi-quantitative spectrographic analyses, and polished thin section studies have delimited the primary vanadium source to the carbonaceous substance.

In conjunction with the vanadium problem, an x-ray powder diffraction study was carried out on many type copper and vanadium minerals. Partially the result of this study is an appendix consisting of a compilation of all the known non-uraniferous vanadium minerals. The strongest x-ray powder lines are listed for most of these minerals.

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Mr. Thor Pederson of Campbell River, B.C., was a most generous host during the duration of the field work and provided, without charge, the services of an outboard boat by which access was gained to the Quadra Island and Steep Island workings. Messers. N. Lothrop of Vancouver, and G.A. Dirom of American Smelting and Refining Company, provided maps and directions to the Menzies Bay claims.

The laboratory work was conducted under the supervision, encouragement, and generous assistance of Dr. R.M. Thompson of the Geology Department. Robert Butters of the Metallurgical Department performed all the x-ray fluoroscope examinations required in the problem. The fossil identifications were made by Dr. W.R.Danner.

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The writer is greatly indebted to many of his

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Several type specimens of vanadium and copper minerals were made available from the Royal Ontario Museum through the courtesy of Dr. J.A. Mandarino, Associate Curator of Mineralogy.

INTRODUCTION

This paper perhaps represents only another stepping stone in the study of the vanadiferous sediments of the Campbell River area. For the nearly thirty years following the first recorded discovery of the peculiar sedimentary rocks which host the vanadium, the study has intermittently continued to the present (Ellsworth and Gunning (1932), Gunning (1932), Carlisle (1944), Gunning and Carlisle (1944). Despite the volume of literature published on so small a geologic feature, there has been a notable deficiency of data concerning the nature of the vanadium within the sediment and the fund of knowledge pertaining to the mineralogy of the deposits lay essentially barren.

The combination of the distinctive sedimentary rocks and vanadiferous mineralization makes the deposits rather unique, and indeed, as far as is known they are unparallelled by any other vanadium occurrence. Most of the previous studies of the Campbell River deposits were carried out by persons who were at some time associated with the University of British Columbia and consequently many of the original thin section and rock specimens were preserved and intermittently dusted off for further examination. Among this material was a polished section of a black sediment which was known to contain an unidentified golden tan[1] "mineral".

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1 The colour described is that observed in reflected light; the substance is actually black.

The writer was first introduced to this same "mineral" in the spring of 1958, when several polished sections of the sediment were presented for laboratory study in connection with an advanced mineralogy course being conducted by Dr. R.M. Thompson. The unknown substance once again eluded identification, but the writer sought refuge by reporting the presence of several other unknown minerals. Among these was the "yellow stain" described by Gunning and Carlisle (1944) as being indicative of the presence of vanadium.

The scope of the problem thus passed beyond that which was originally intended and was continued as a Master's thesis. The principal objects of the study were to identify the "golden tan" and "yellow stain" minerals and determine the mineralogical form in which the vanadium exists. Field work in connection with the problem was intermittent in nature, but extended throughout the university winter sessions from 1958 to 1960. During this period, approximately three weeks was spent in the field examining the deposits and gathering several hundred samples for laboratory study. Nine polished thin sections, 52 thin sections, and over 200 polished sections were examined. The small quantities and powder form of many of the minerals made necessary the liberal use of x-ray powder methods for both confirmation and identification of mineral species. In this connection, 248 powder photographs were taken.

CHAPTER I

GENERAL FEATURES OF THE AREA

LOCATION AND ACCESSIBILITY

Vanadium is concentrated in a black, carbonaceous, laminated, siliceous sedimentary rock in two principal localities to the north and northwest of Campbell River. The accompanying geological map (in back pocket) illustrates the location and geological setting of the vanadium deposits.

The most intensively prospected and best exposed outcrops of the sedimentary rock are west of Menzies Bay on Vancouver Island, and north of Gowland Harbour on Quadra Island.

The Menzies Bay sediment is exposed in an adit and a series of trenches and prospect pits which extend for a distance of approximately two thousand feet. These workings, which are readily accessible by automobile, lie adjacent to, and on both sides of an excellent logging road which intersects the western side of the Island Highway (Number 19) at approximately 11¼ road miles from the north end of the bridge across Campbell River.

The main showing on Quadra Island is a sixty foot trench, the location of which is known only from descriptions available in the literature. It is described as being approximately 1½ miles north of the north end of Gowland

Harbour and about 600 feet above sea level (Ellsworth and Gunning, 1932; Carlisle, 1944; Gunning and Carlisle, 1944). Having an island location, the deposit is slightly more difficult to reach. Boats, however, can be rented at Campbell River and a maze of logging roads on the island serve as good walking trails.

The writer repeatedly traversed the area, but the search for the Quadra trench proved fruitless. However, a number of smaller pits and diggings were encountered and sampled. Some of the latter workings contained exposures of irregular films of the black sediment which is similar to that present in some pits at Menzies Bay.

HISTORY

The attention of prospectors was perhaps first directed to this area because of the widespread occurrence of copper mineralization in the volcanic rocks of the Texada formation. As early as 1907, Bancroft (1913) described much of the development work which had been done on the mining claims in the vicinity of Gowland Harbour and on Steep Island; it is indeed surprising to find, even today, many of the tunnels, shafts, and trenches which he so clearly described.

The writer is not aware of how long the existence of the vanadium-bearing sediment has been known, but Clothier (1932) states that the black sediment was known for many years previous to his writing.

Considerable attention was first focused on this unique sediment in the years 1930-1932 when R. Crowe-Swords of Vancouver reported the presence of a soft, greenish yellow material which was subsequently identified as carnotite (Ellsworth, 1932)[1]. Examination of the Gowland Harbour occurrence by officers of the Geological Survey of Canada and the resulting publications gave much impetus to prospecting in the area, and some years later, sediment similar to that occurring at the original showing was discovered in the Copper Cliffs area and at Menzies Bay.

Although considerable development work in the form of exploration by trenching was done, the lack of sufficient quantities of the vanadium-bearing[2] sediment has resulted in the deposits generally being classified as uneconomical. Nevertheless activity in the vicinity has recently be renewed. In 1954, the Menzies Bay deposits were taken over by Argus Consolidated Mines, Limited, and two men were employed to carry out surface work on the chalcocite showings. No further mention to date has been made in the Annual Reports of the British Columbia Minister of Mines, but Geojimal Mining Company has apparently taken over the claims and is currently tunneling along the interlava sediment.

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1 No additional "carnotite" has been found in the area. The writer is given to understand that the "carnotite" may have been deposited by non-geologic processes.

2 The maximum reported value of V_2O_5 in the sediment is "over 3 per cent" (Ellsworth and Gunning, 1932).

TOPOGRAPHY, VEGETATION, CLIMATE

The Quadra Island and Menzies Bay region lies within the Coastal Trench physiographic division of British Columbia. The topography of the area, in contrast to the flanking mountainous regions, is relatively subdued. Elevations in the immediate vicinity of the deposits range from nearly 800 feet to sea level. In detail however, the hummocky nature of the lavas has resulted in a ruggedness which is not indicated by the range in vertical relief.

The climate of the area is mild, with warm dry summers and cooler, wet winters. Although the annual mean temperature is only about 50 degrees, a monthly mean temperature below freezing is exceedingly uncommon. The average annual total precipitation at Campbell River is less than 56 inches, with more than 80 per cent falling during the October to March period.

The vegetation of the area was originally a dense, but patchily distributed heavy timber forest. The open, unforested areas are usually occupied by barren extrusives at higher elevations. The lower country and valleys were originally well-forested, but many of the larger trees have been removed or destroyed by fires and commercial logging operations. The underbrush in the forested areas is rather dense.

With the exception of the sea life, a few small rodents, and a thriving deer population, the paucity of fauna is a marked contrast to the luxuriance of the flora.

CHAPTER II

GENERAL GEOLOGY

The oldest and most abundant rocks exposed within the map area are a great thickness of Triassic volcanic rocks first described in detail by Dawson (1887) and named by him the Vancouver series. The series is intruded by the Jurassic or later Coast Range granitic rocks and is unconformably overlain to the south by Upper Cretaceous clastic sediments of the Nanaimo series.

The later subdivision of the Vancouver series by numerous workers has resulted in considerable confusion in stratigraphic nomenclature. The lowest part of the series has, for example, been variously described as the Texada group (LeRoy, 1908), Valdes group (Bancroft, 1913), Texada porphyrites (McConnell, 1914), and the Karmutsen volcanics (Gunning, 1931). In order to prevent unnecessary confusion by using several names for the same formation, the stratigraphic succession listed below will be used throughout this paper. The terminology used is that of LeRoy (1908) which is in current usage by the British Columbia Department of Mines (Mathews, 1947, 1957; Brown, 1958).

TEXADA FORMATION

The Texada formation, as found within the map-area, consists of about 3000 feet (Brown, 1958) of basalts,

basaltic andesites, and spilites. These are predominantly massive flows, but many pillow lavas, breccias, and tuffs are intercalated.

Table 1

Table of formations

Upper Cretaceous.	NANAIMO SERIES: shale, sandstone, conglomerate, coal. Unconformably overlies the Texada formation in the southern part of the map-area.
Jurassic or later	COAST INTRUSIONS: granodiorite, hornblende diorite, undifferentiated granitic rocks.
Upper Triassic	MARBLE BAY LIMESTONE: limestone, skarn, marble, some volcanics, greenstone dykes, etc.
	TEXADA FORMATION: basaltic, andesitic, and spilitic flows and pyroclastic rocks, pillow lavas, breccias, etc. (Includes the vanadiferous sediment and its associated rocks).

The extrusives are fine-grained to aphanitic and vary in color from grey to green with black and purple shades locally present.

The weathered surfaces of the lavas are characteristically hummocky or rounded, and northerly-trending vertical cliffs are common. Although vertical quadrangular jointing is often well developed, hexagonal columns are vague or absent. Minor faulting has taken place, but in most cases

has not resulted in any significant displacements. Small slickensides and mullion are remarkably common.

Although there is a lack of consistency regarding the direction, all writers agree that the angle of dip of the extrusives is low, generally 20 degrees or less. Attitude determinations are hampered by the rolling character of the lava tops and general similarity of successive flows. Brecciated beds, pillowform structure, and intercalated sediment help to distinguish between the individual flows.

Pillow structure is poorly developed or absent in the majority of the volcanics. Though deficient in volume, good examples of pillows do exist in the area. Bancroft (1913) reports that pillow structure is beautifully developed in one of the flows on the northern shore of Hyacinth Bay. Some good examples are also found at Menzies Bay, where loaf and balloon-shaped forms were observed.

Many of the lavas are vesicular and amygdaloidal. The amygdule material is usually quartz, pumpellyite, chalcedony, zeolites, calcite, epidote, and chlorite. In many cases chalcocite, bornite, native copper, and azurite may be present. Many of these minerals also fill fractures and irregularities between flows.

Toward the contact with the Coast Range intrusions to the east, the angle of dip of the Texada flows increases from less than 20 degrees to about 70 degrees northeast at the contact. The degree of recrystallization of the flows

also increases as the intrusive contact is approached and plagioclase and augite, the original principal components of the lavas, give way to a plagioclase-hornblende combination. The darker color and loss of amygdaloidal character of the flows is the macroscopic manifestation of this change.

In a thin section study of several specimens of the Texada flows from Quadra Island, Steep Island, and Menzies Bay, it was found that the rocks ranged in composition from spilites to augite andesites and basalts. The majority have been somewhat altered; in many cases the original minerals are so fine-grained or so extensively transformed that they are barely discernible.

The rocks appear to have originally consisted largely of plagioclase, augite, and volcanic glass, with disseminated opaque "iron ore" and a few grains of apatite and sphene. The texture in all the rocks is porphyritic or glomeroporphyritic, with the phenocrysts in both cases being augite and plagioclase.

The plagioclase phenocrysts range in size from 0.2 mm to over 3 mm. The larger-sized crystals or groups are occasionally visible in the less altered hand specimens. The plagioclase grains in the glomeroporphyritic clusters are usually much larger than the feldspar phenocrysts which occur as individual grains, and these in turn are invariably larger than the augite phenocrysts. The latter, many of which are euhedral, range in size from 0.1 to 0.9 mm and

are less abundant than plagioclase phenocrysts. These two minerals are frequently combined in subophitic intergrowths.

The rocks were originally merocrystalline, hyalopilitic, commonly insertal textured, and frequently holocrystalline. The groundmass consists of devitrified glass, augite, and microlites and laths of plagioclase. Subophitic intergrowths of the augite are common. Although their proportions vary greatly in successive flows, the feldspar is usually considerably more copious than the augite. Numerous were the cases noted in which the plagioclase laths are radially grouped, forming a variolitic texture. These varioles usually occur in the vicinity of amygdules.

The greenish colour of most of the volcanics in the area is the outward expression of their widespread alteration and replacement by pumpellyite, chlorite, and epidote. The groundmass of many of the flows, particularly the finer ones, is usually partially, and commonly wholly replaced by felted aggregates and myriads of minute (0.01 mm) grains of these minerals. Even in some of the coarser flows, large plagioclase laths have been completely replaced. In some cases the original feldspar outlines are visible in plain light (Plate I,A), but under crossed nicols the pseudomorphs blend in and become indistinguishable from the remainder of the altered rock (Plate I,B). In some sections leucoxene is fairly copious as an alteration product associated with the opaque minerals. Augite is usually partially replaced but

remains relatively unaltered in comparison to the plagioclase. Replacement has been selective to such a degree that in some cases the pyroxene has remained essentially intact whereas the accompanying feldspars have been completely obliterated.

The most abundant minerals filling the amygdules are quartz, pumpellyite, chlorite, prehnite, and epidote. The quartz occurs principally as large, irregular, inclusion-riddled grains which have no discernible sharp contacts with the surrounding rock; as single "clean" grains which fill the vesicles and conform to the vesicle borders; as narrow coatings on the vesicle walls, the cores of which consist of another mineral or additional quartz; and quite commonly, as fillings in which a quartz core is surrounded by a thin sheath of chlorite which separates it from the thin quartz lining on the vesicle wall.

Chlorite in amygdules is usually fibrous and commonly in rosettes. Prehnite has a similar habit but is much less widespread. Calcite, in addition to filling vesicles, occurs as disseminated anhedral grains which favour an interstitial position between plagioclase laths - apparently a replacement of the insertal glass. The carbonate also replaces augite irregularly and along cleavage traces and grain boundaries.

The strongly pleochroic green pumpellyite is also a major amygdule constituent. It occurs most commonly as radiating felted groups which have occasionally completely

PLATE I

1.47 mm

(A) Glomeroporphyritic volcanic flow from Menzies Bay. Clusters of plagioclase phenocrysts and the groundmass are highly altered, but augite remains essentially intact.

(B) Identical photo, but with crossed nicols. The groundmass and phenocrysts are indistinguishable. The large amygdule at the bottom of the photo serves as a good reference point. Scale identical in both photos.

filled the vesicles, but more frequently are crustifications on other minerals, principally quartz. Conversely, where the pumpellyite is present as crustifications on the vesicle walls, quartz, and prehnite, have filled the voids and are thus present as the cores of the amygdules (Plate II,A).

Pumpellyite was also commonly observed as small veinlets consisting of aggregates of randomly-oriented small (up to 0.02 mm) leaf-shaped or fibrous grains. The veinlets irregularly traverse the groundmass and occasionally cut across plagioclase phenocrysts. However, the typical mode of occurrence in the feldspar, as mentioned previously, is as a myriad of minute disseminated felted aggregates.

The widespread distribution of pumpellyite is indicated by the fact that it was found in varying amounts in every thin section of the flows examined. In a few of the specimens, it comprises up to 50 per cent of the rock. Prehnite, chalcocite, and native copper, as amygdule fillings, are widespread in small amounts; analcite, heulandite, and greenockite are of rare occurrence.

The identification of pumpellyite is based on x-ray powder diffraction patterns obtained from material picked from thin sections under the microscope. These patterns are identical to that obtained from a pumpellyite specimen from Sonoma County, California. This data also agrees with that obtained by Coombs (1953) for material from the same locality.

PLATE II

(A) Pumpellyite in a Quadra Island flow rock. Quartz (Q) forms the amygdule core into which radiating, fibrous pumpellyite crustifications project. Prehnite (p) and remnant augite make up the remainder of the rock.

B) Amygdaloidal pumpellyite in a Quadra Island flow rock. Crossed nicols. Scale: from top to bottom of photo, approximately 0.9 mm.

The amygdule fillings of "greenish blue to straw yellow amphibole" (Ellsworth and Gunning, 1932) and "fibrous green amphibole" (Gunning and Carlisle, 1944) are probably pumpellyite.

Structure

Brown (1958) reports that "... in the southwest of Quadra Island the Texada flows dip northeastward and the over-all pattern is that of a north-east dipping monoclinal arch...". The writer agrees with Gunning and Carlisle (1944) that in the area to the north of Gowland Harbour and at Menzies Bay the flows are inclined toward the south. This perhaps serves to emphasize the difficulty in determining attitudes and shows that there is much room for additional studies. There is little doubt, however, that the structure of the Texada formation, whatever its form, is relatively simple.

Age

Fossils from the lower Texada formation found by W.H.Mathews in 1945 on the west shore of Texada Island have been identified as Paratropites sp., Hannaoceras sp., Coenothyris sp., Pecten sp., and crinoid stems of the Karnian stage of the Upper Triassic (McLearn in Mathews, 1947). The areal limits of the Texada formation have been extended northwards from Texada Island and correlated with the volcanics on Quadra Island so that Bancroft's Valdes group is now part of the Texada formation.

It is within the flows of the Texada formation on Quadra Island that the thin carbonaceous, vanadium-bearing siliceous sediment is found. In 1958, the writer collected fossils from a small limestone lens overlying the siliceous sediment at Menzies Bay on Vancouver Island. These fossils were identified by Dr. W.R.Danner as most resembling Spondylospira sp., and Psiodea sp. (Spiriferina), brachiopods of Upper Triassic age. The volcanics in the vicinity of Menzies Bay will henceforth be referred to by the writer as being part of the Texada formation.

MARBLE BAY LIMESTONE, COAST INTRUSIONS, NANAIMO SERIES

Since these rocks bear no discernible relationship to the vanadium problem, they shall be discussed only briefly.

MARBLE BAY LIMESTONE

The Marble Bay formation consists of argillaceous, black, granular, fetid limestones, thin-bedded quartzites, and argillites which conformably overlie and are interbedded with the top flows of the Texada formation. The age is recognized as being Upper Triassic.

Thin dykes and sills, ranging in thickness from a few inches to a few feet, are common. The dip of the bedded rocks is predominantly northeast, but at the contact with

the Coast Intrusions the limestone and its included flows, dykes, and sills are severely compressed into isoclinal folds overturned toward the southwest. Folds of a type that may result from rock flowage also occur and the included volcanic rocks are commonly squeezed into boudinage forms.

Skarn development near the granitic intrusions is manifested by the development of garnet, tremolite, pyroxene, and other silicates. Metallic mineralization consists principally of magnetite, pyrite, pyrrhotite, and chalcopyrite.

COAST INTRUSIONS

The Texada and Marble Bay formations are cut by the Coast intrusions of probable Upper Jurassic or later age. These intrusions are usually quartz diorite or granodiorite, but in the vicinity of Open Bay, Brown has distinguished granodiorite and a hornblende diorite.

The granodiorite at the above locality is quartzose and commonly shows a foliation which is subparallel to the northwesterly strike of the Marble Bay rocks. The foliation dips steeply southwestward near the contact and more nearly vertical or northeastward away from the contact. Minor aplitic and pegmatitic phases are present at the margins of the granodiorite and some dykes which intrude the older rocks are porphyritic.

The hornblende diorite is found as small bodies and dykes near the contact and as a moderate-sized body that extends over half a mile from the contact.

In contrast to the granodiorite, the hornblende diorite is not noticeably foliated. Both, however, contain large and small inclusions. Some of the smaller hornblende diorite bodies are intruded or fragmented by the granodiorite, but the largest body of the former has a gradational contact with the granodiorite. The contact of the Marble Bay formation and Coast intrusion is irregular in detail but in general the granitic rocks follow a relatively straight northwesterly line which intersects and truncates the Marble Bay formation to the north so that it does not completely extend across the Island.

NANAIMO SERIES

South of the area around Campbell River and in the southwest portion of the map area, the Triassic volcanics are unconformably overlain by sandstone, shale, and conglomerates of the Upper Cretaceous coal-bearing Nanaimo series.

QUATERNARY SEDIMENTS

Much of the map area is covered by a thin mantle of glacial and alluvial materials.

Pleistocene glaciation, although apparently controlled largely by the pre-existing local topography, modified the land forms to their present rounded, subdued character. Glacial striae are common on many of the hummocks; in the Quadra Island area these indicate a northwesterly trend of ice movement.

Glacial till is widespread in the valleys and depressions, but everywhere the deposits appear to be very thin. The till contains boulders of volcanics, foliated and non-foliated acid intrusives, and much less commonly, boulders of red quartzite. Granitic and volcanic erratics are moderately common near the tops of some hillocks. These are usually only a foot or so in diameter, but a rounded granitic boulder over five feet in diameter was encountered near the Menzies Bay deposit.

Stratified sands are exposed in road cuts north of Campbell River and white "earth" deposits form the prominent cliffs at the south end of Quadra Island.

CHAPTER III

GEOLOGY OF THE MENZIES BAY AND QUADRA ISLAND DEPOSITS

As mentioned previously, vanadium is contained in a thin, carbonaceous, siliceous black sediment[1] which is found between the volcanic flows of the Texada formation. Only two localities are known in which the sediment has accumulated to any significant thickness, that is, at the prospect in the vicinity of Menzies Bay on Vancouver Island, and secondly, in the open cut north of Gowland Harbour on Quadra Island. The sediment does not exceed a thickness of five to seven inches at either locality.

Examination of the many prospect pits on Quadra Island and Steep Island indicates that the vanadium-bearing sediment is of widespread distribution. It is also apparent that the sediment is not necessarily a single layer, but rather, may appear as two or three thin seams, each separated by one or more extrusive flows. Even in such cases, however, the sum thickness of the sediment is less than six inches and is generally much less than half an inch.

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1 The sedimentary rock containing significant quantities of vanadium is very finely laminated. Conformably above and below the laminated rock is a similar, but essentially non-laminated sediment which is almost completely devoid of metallic minerals and probably does not contain appreciable quantities of vanadium. Unless specific mention is made, the terms "sediment", "siliceous black sediment", "carbonaceous black sediment" etc., refer only to the laminated, vanadium-rich rock.

As far as it is known the seams are restricted in occurrence to a very narrow horizon in the flows.

The character of the sedimentary rock may vary at different outcrops, but it is always dark gray to black and laminated.

QUADRA ISLAND

In the Quadra Island area outlined in the accompanying pocket map, many of the Texada volcanics are mineralized with sulphides, principally chalcocite. The sulphides are most commonly present as fillings of vesicles and as concentrations along small fractures and shears in the lavas. In addition, however, the black sediment has also been a locus of chalcocite deposition and prior to the initial discovery of vanadium on the island, much of this sediment was exposed by prospectors following the copper mineralization. These outcrops clearly illustrate the character and distributional nature of the vanadium-bearing seams.

Probably the most northerly exposures of the sediment on Quadra Island are those found in the open cut first described by Ellsworth and Gunning (1932). This deposit could not be located by the writer, consequently the following description has been taken from Carlisle (1944).

"The open cut...is about sixty feet long in a north-south direction and about six feet deep. The east wall exposes three lava flows dipping about ten degrees south-east

with very poorly developed pillow structure, the upper and the lower flow continuing from end to end of the cut. The middle flow is represented only in the southern...two thirds of the cut, terminating in the pillow-like shape about 18 feet from the north end. The middle and upper flows are normal amygdaloids, fairly dense and greenish-grey in colour, but the lower flow is highly brecciated where observed and is more intensely chloritized.

The vanadiferous sediment is an irregular, finely laminated, black or dark grey seam between the upper and middle, and middle and lower flows, varying in width from paper thin up to six inches. In the thicker parts and particularly near the end of the middle flow, the seam is crenulated and appears to have been forced between incipient pillows."

The sediment present in this pit was again described by Gunning and Carlisle (1944). In correlating the sediment found by the writer with the material described above, it must be pointed out that Gunning and Carlisle state they were unsuccessful in a search for similar sediment within several hundred yards of the open cut. There is no doubt that the material found by the writer is similar, however, particularly since thin sections and rock specimens from the Quadra open cut were available from the University collection for comparison. In addition, Carlisle (1944) states that a vanadiferous sediment is present in the vicinity of Copper Cliffs, Gowland Harbour.

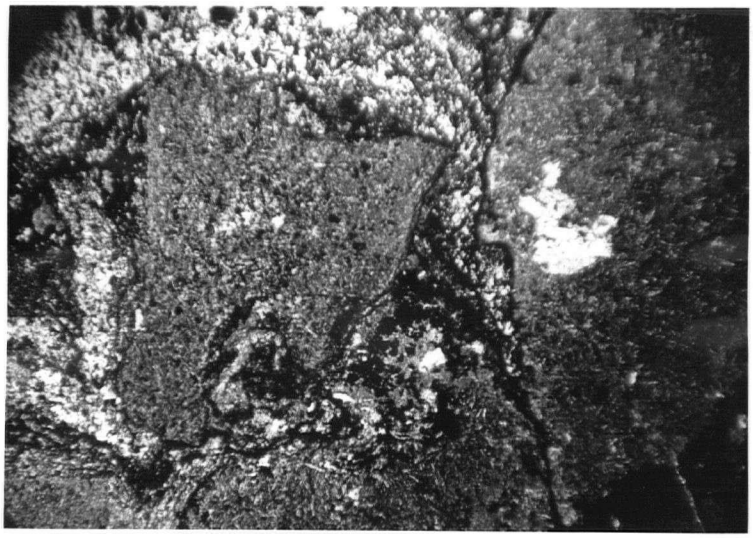
The black sedimentary coatings throughout the area are only about one quarter of an inch thick for the most part, but there is invariably at least one portion of each exposure in which it appears that the sediment has possibly been rolled or squeezed into irregularities between the flows so that it is at least one half inch and up to one inch thick. In some cases it appears as if the encroaching lava had slid or skidded over the sediment so that a single layer is bisected or branched, with a portion being retained under the flow and the remainder being spread over its top.

Recognizable volcanic breccia was found associated with the sedimentary rock in two pits; in both cases the breccia underlies the sediment. In another occurrence, a portion of the sediment is present as the matrix of a brecciated flow (Plate III).

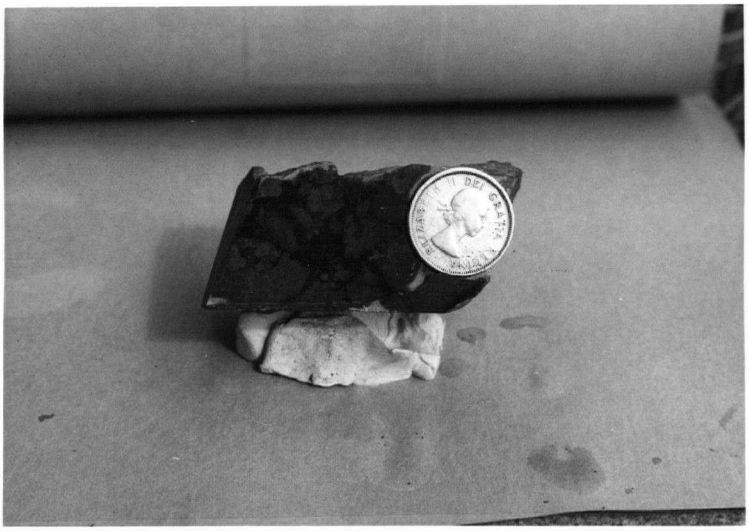
The vanadiferous sediment is a dense, extremely hard and tough, dark grey to black rock which is generally found as discontinuous, irregular coatings interlayered between the lavas. Although fine laminations are conspicuous in thin sections of the sediment, they are rather difficult to discern in most hand specimens examined in the field. However, the laminae may appear on strongly weathered surfaces of some of the sediment as thin, wavy lines. In addition, some of the rock will part into thin layers which were found to approximately parallel the laminated structure.

In polished thin sections, quartz and the "golden tan" carbonaceous substance are revealed as the principal

PLATE III



(A) Quadra Island fine-grained flow rock breccia. The fragments are in a matrix consisting of the laminated vanadiferous sediment and small amounts of the fragmented rock. Microphotograph, transmitted light. Scale: from top to bottom of photograph approximately 4 mm.



(B) The hand specimen from which the above thin section was made. The vanadiferous sediment is black, the volcanic fragments grey. The coin is twenty five cents.

components of the sediment. Chalcocite is relatively sparse in comparison to the quantity in the Menzies Bay rock.

Since the sediment contains copper minerals and vanadium, the exposed surfaces are usually coated with supergene green and blue copper minerals and commonly lightly stained with a canary-yellow powder which is the hydrous copper vanadate, volborthite.

Although the vanadiferous rock is extremely thin, irregular, and discontinuous, its distribution within the outlined area is widespread. Only traces are present in many of the workings, but the exposed seam or seams appear to be thicker and more common in the central and northern portions of the area.

Steep Island

Several open cuts and pits were made on copper showings in the southern part of the island prior to 1907. Mineralization is present as disseminated amygdaloidal chalcocite and as chalcocite smears along numerous small fractures and shears. Traces of the black sediment are interbedded with the amygdaloids. The appearance and irregular nature of the sediment are similar to that outlined for the Quadra Island occurrences.

THE MENZIES BAY DEPOSIT

The Menzies Bay deposit is on Vancouver Island, some ten miles northwest of the Quadra area showings.

At Menzies Bay the sediment is intercalated between green and grayish green amygdaloidal flows which are considered to be part of the Texada formation. The volcanics at both sites are similar for the most part, but at Menzies Bay pillow structure and step-like topography is much more common whereas flow breccias were not encountered.

The best developed pillows are generally ellipsoidal or loaf-shaped and are two to four feet in length. Larger bodies up to seven feet long and four feet thick have been observed, but these are less well-formed. It appears that the pillow outlines and features become more vague as the size of the body increases.

In some cases it appears as if the pillows did not wholly come in contact with each other. These spaces are only a few inches wide and are presently filled with highly altered gritty and flaky brown or gray material which is of the same character as the altered envelopes around the ellipsoids. The envelopes probably represent remnants of the fine-grained margins around the pillows.

The outer edges of the massive flows and pillows occasionally contain concentrations of irregular or spheroidal-shaped amygdules (Plate VI,B). Elongate or pipe-like vesicles were not observed. The amygdules, which generally

have a diameter of less than one quarter inch, commonly make up ten to twenty per cent of the rock. Quartz, pumpellyite, chlorite, and epidote are by far the most abundant minerals in the amygdules. Calcite is normally the most abundant mineral filling irregularities between flows.

The nature and extent of the open pits and other workings in the locality are shown in the insert of the map in the folder. The general picture is that of a thin sediment conforming to the tops of the underlying flows and dipping at low angles to the southeast. The layer is thickest and best displayed at the tunnel site and in the southernmost open cut.

The tunnel and accompanying main pit

These workings are currently being developed by Geojimal Mining Company. This company has exposed the sediment in a twenty foot diameter open pit at the portal. The tunnel, driven into the volcanics along the sedimentary horizon, exposes an additional twenty feet of the seam.

At the extreme eastern portion of the pit the sediment is less than an inch thick. It is extremely irregular, and thickens, thins, and conforms to irregularities on the surface of the underlying flow. Westward, in the vicinity of the portal and along the tunnel walls, the contact is essentially flat and the black sediment is two to four inches thick. Rather surprisingly, the seam shows no sign of either pinching out or, conversely, appreciably thickening.

This is not meant to imply that the sediment is thickest where the surface of the underlying flow is smooth or flat, for no such generalization is warranted. Flat,regular contacts between the sediment and flows have in some cases been observed to have less sedimentary material than the tops of nearby swells.

The underlying flow at the base of the sediment is only partially exposed in the workings, but it appears to be no different from the overlying flow. The schematic diagram below illustrates the strata succession.

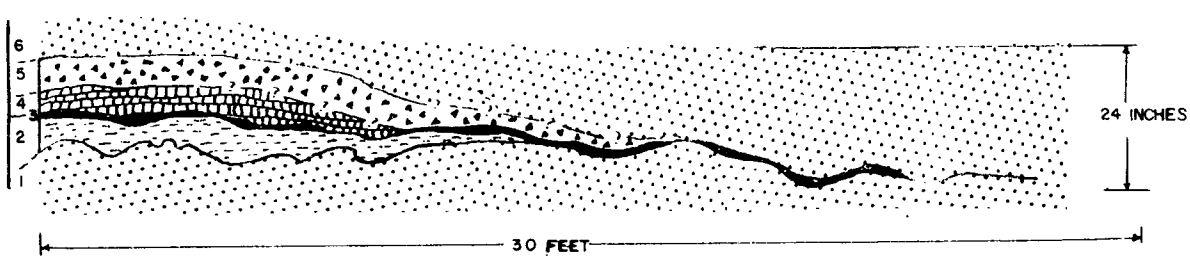


Figure 1. Schematic diagram illustrating the succession of the sedimentary rocks exposed at the Menzies Bay tunnel site.

(1) The underlying volcanic flow.

(2) 0-7 inches thick: dark gray to black, microcrystalline, "non-laminated" rock: contains few pyroclastic fragments; some laminations present, but these are few in number and relatively poorly developed in

comparison to those present in the overlying sediment. Probably similar in composition to the overlying laminated sediment; mineralization meager to absent.

(3) 0-6 inches thick: very finely laminated vanadiferous sediment, most of which is only 2-3 inches thick. Heavily mineralized with chalcocite. In places may be overlain by up to 7 inches thickness of rock identical to (2). Contains a few pyroclastic fragments.

(4) 0-5 inches thick: dark gray, fossiliferous, microcrystalline limestone. Contains numerous pyroclastic fragments which become increasingly abundant toward the top of the bed.

(5) 0-5 inches thick: dark gray, microcrystalline, recrystallized cherty rock with a few replaced fossils and up to 40 per cent pyroclastic fragments.

(6) the overlying volcanic flow.

The aforementioned bedded sequence is overlain by a relatively thick greenish flow which is crudely pillowform. At the contact with the sediment, the flow has a chilled margin up to an inch thick. The selvedge consists of a thin (1/10 inch) aphanitic dark green border which grades inward to a slightly coarser and lighter green portion comprising the remainder of the margin.

This chilling effect in places is also a recognizable feature of the flow underlying the sediment. Specimens of this particular rock also contain marked concentrations of large, irregularly-shaped amygdules at the places where the "normal", coarse-grained part meets the finer, intermediate-grained portion (Plate VI,B).

Both the upper and lower flows which straddle the sediment have sharp (not diffuse) contacts with it.

The vanadiferous sediment

The vanadiferous sediment in these workings has been heavily impregnated with chalcocite which commonly constitutes 25 to 35 per cent of the rock. Deposition of the sulphide was controlled chiefly by the bedding (Plate IV,A).

Some of the tunnel site sediment is dense and thus macroscopically similar to the Quadra Island sediment. However, unlike the latter rock, most of the Menzies Bay sediment has good fissility along the laminae planes (Plate V,A). Furthermore, the Quadra sediment consists essentially of microcrystalline quartz and fragments and laminae of the golden tan carbonaceous substance. In thin sections, the Menzies Bay sediment is light brown in colour and consists largely of cryptocrystalline quartz. The golden tan carbonaceous matter is present as small blebs, irregular grains, veinlets, intergranular material in quartz masses, and as the opaque fossil cores.

The carbonaceous matter does not form thick, distinct laminae as in the Quadra rock. The laminae are wavy and blend in with each other. Their darker portions appear as diffuse streaks rather than distinct, separable units.

In addition to chalcocite, irregular masses and veinlets of hypogene quartz are common. Small amounts of pyroclastic material are dispersed throughout the rock and minute (0.07mm) fossil remnants are numerous.

Banding in the tunnel sediment is usually made up of three units, with the central laminated member being straddled

by laterally discontinuous units of similar, but massive rock (Plate V,B) which may reach thicknesses of 5 to 6 inches each.

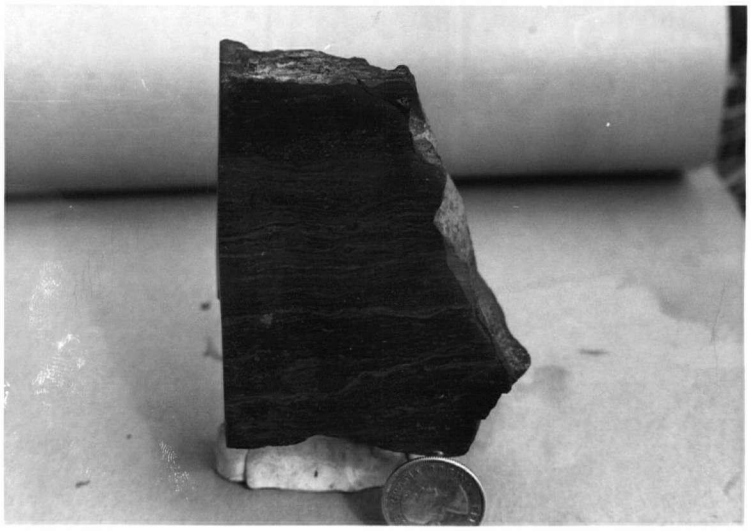
The change from the laminated sediment to the massive rock can be seen in thin section to be gradational. The laminae become less distinct and for the most part only a faint suggestion of lineation remains. In some cases, non-laminated, massive sediment alternates with strongly lineated sediment or groups of poorly-formed laminae.

The disappearance of the laminated structure is accompanied by a corresponding decrease in the opaque constituents, both chalcocite and carbonaceous(?) matter. Although the massive rock is so fine-grained that the individual minerals are barely discernible, quartz was identified as a major constituent. Probably the bulk composition of the massive rock is somewhat similar to that of the laminated vanadiferous seam. However, the differences between the two, such as the smaller amount of opaque materials in the massive rock, are apparently of prime significance. A specimen of the massive rock underlying and in contact with the laminated seam was tested for vanadium with the x-ray fluoroscope. The sample contained the metal only in very small amounts, probably in the order of 0.01 to 0.1 per cent.

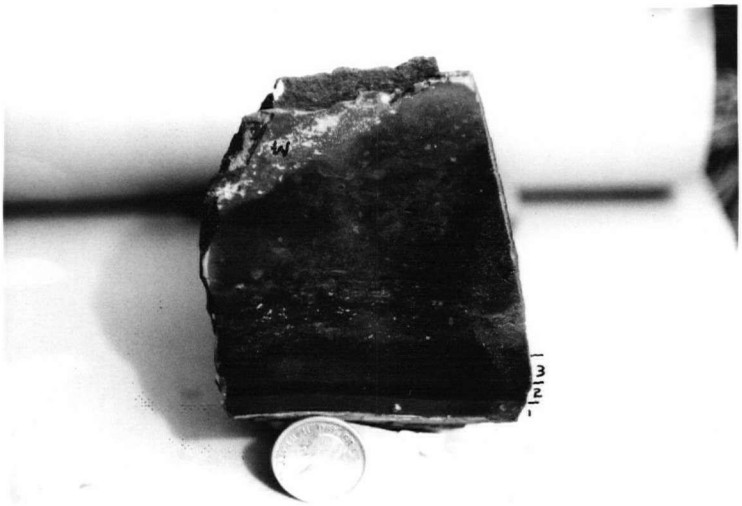
The limestone

Conformably overlying the laminated or massive

PLATE IV



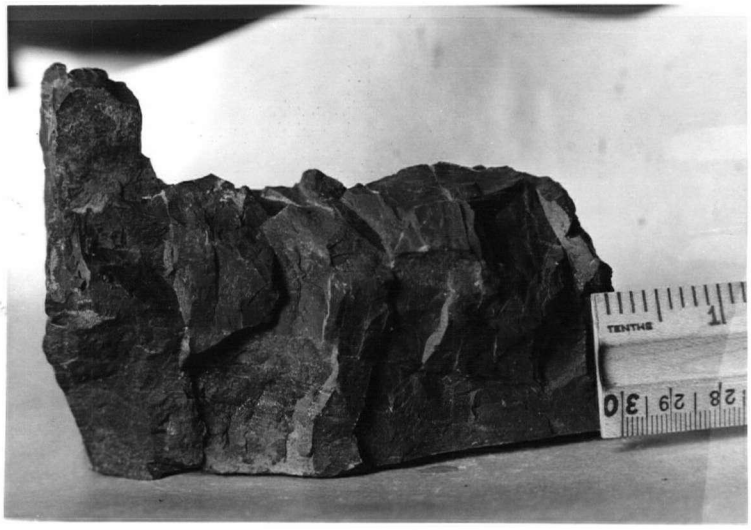
(A) The laminated vanadiferous sediment from the Menzies Bay tunnel site. The grey wavy lines are chalcocite which follows the laminae. The top half inch of the rock (black) is the poorly mineralized, "non-laminated" massive sediment. Coin is twenty five cents.



(B) The laminated vanadiferous sediment from the Menzies Bay southern trench. Note the presence of three distinct layers in the vanadiferous sediment, each layer consisting of many many laminae. Units one and three are heavily mineralized with chalcocite and are thus lighter-colored. Unit two consists of thicker laminae and is relatively poorly mineralized. Note the weathered portion (W) in the overlying fossiliferous limestone. Coin is twenty-five cents.

PLATE V

(A) The vanadiferous sediment from the Menzies Bay tunnel site. The rock is fissile along the laminae, Weathered surfaces are coated with malachite, brochantite, and volborthite. Scale in inches.



(b) The massive siliceous rock overlying the vanadiferous sediment at the tunnel site. Scale in inches.

siliceous rocks is a dark, grey fossiliferous, microcrystalline limestone which is similar to that exposed in the large open cut to the south. It is laterally discontinuous in exposures and varies from three to five inches in thickness.

Most of the limestone has not been weathered. Visually, the fresh rock resembles the underlying massive siliceous sediment, but even in the field the two are easily distinguished since the siliceous rock is not scratched with a knife nor does it react with dilute acid.

In thin section, the change from the underlying rock can be seen to be gradational, but within a very limited thickness. The approach of the limestone is marked by a decrease in the opaque constituents and a corresponding increase in the distances between laminae. The laminae themselves gradually lose their regularity and become wavy and discontinuous as the rock becomes increasingly calcareous. Scattered throughout the limestone are angular devitrified fragments of porphyritic, amygdaloidal flow rock which are commonly 3 to 4 mm and as large as 7 to 8 mm in size. Near the top of the bed, the fragments become more abundant and are accompanied and exceeded by small angular plagioclase particles. The impact of some of the larger pieces of the pyroclastic debris has visibly depressed the underlying carbonate matrix with which they have come in contact. This effect is particularly evident where there are concentrations of the abundant calcareous fossil material which is dispersed throughout the bed.

The limestone is in turn overlain by a similar thickness of dark grey cherty rock which consists largely of volcanic fragments and microcrystalline quartz. The groundmass and feldspar laths of the pyroclastic material have been replaced by coarse-grained quartz. However, the augite phenocrysts have resisted replacement and remain as essentially unaltered relicts surrounded by large quartz grains. Fossil material is moderately copious and has been completely replaced by the silica.

Depositional environment of the sediments

That the sediments formed under submarine conditions is unquestionable. In addition, however, the laterally discontinuous nature of the sediments and the lense shape of the bodies indicate that the strata probably accumulated in small basins or basin-shaped irregularities in the underlying flows. The laminated nature of the sediment and changes in lithology of the overlying beds suggest deposition took place in an environment which was intermittently but gradually being slightly modified. The fossil material, characteristic of the shallow Upper Triassic seas, is found throughout the sequence. Similarly, pyroclastic material occurs in varying amounts from, and including, the laminated sediment to the cherty rock. It thus appears that there was a rather continuous eruption of volcanic material throughout the time the sediment was accumulating; the increase in the amount of fragments in the upper beds possibly represents the increased

activity which signalled the advent of the flows which overlie the sediments.

Other prospect pits

Several other pits in the vicinity of the tunnel contain exposures of the black siliceous, laminated sediment. However, in these occurrences the seams are extremely thin and relatively poorly mineralized. On the whole, they are identical in appearance with the seams on Quadra Island.

The southernmost large open cut

This open cut is a bulldozed trench about twenty feet wide and seventy feet long in a southeasterly direction. The western wall of the cut exposes thin seams of the black sediment which are similar to the Quadra sediment in occurrence and appearance and hence will not be discussed further. The eastern wall exposes a vanadiferous sediment and limestone sequence which is similar to that exposed at the tunnel site approximately thirteen hundred feet to the northwest.

The volcanics associated with the sediment are pillow-form and massive flows which are individually less than three or four feet thick. A yard or so below the sediment, a discontinuous light grayish-green aphanitic sill, traceable for about 40 feet, roughly parallels the seam. The sill is only a few inches thick at the north end of the trench and disappears to the south in overburden. It apparently temporarily pinches out, reappearing in the flows a few feet further

south in a gently tapering shape which, over a distance of twenty feet, reaches a maximum thickness of about a foot and a half before terminating in a bulbous form. The flows above and below the sill have been irregularly impregnated with pumpellyite, quartz, chlorite, epidote, prehnite, and chalcocite. At the bulbous termination, the overlying flow is light greenish-grey for several inches as a result of being completely saturated with these minerals.

The accompanying sketch illustrates the configuration which the black siliceous sediment and limestone assume. The wedge shape of the body is the result of thickening of the limestone to the north where most of it abruptly terminates against an elevated portion of the flows.

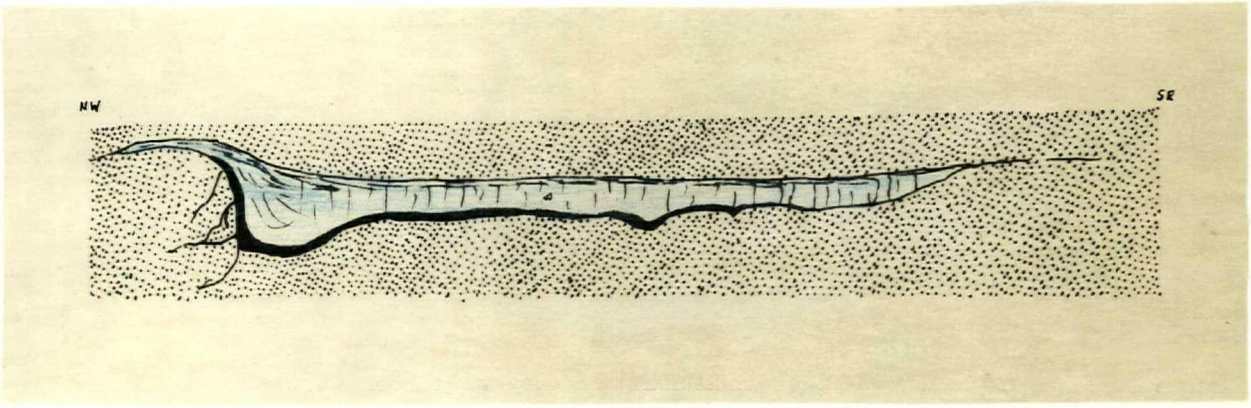


Figure 2. Sketch of the eastern wall of the southernmost large open cut at Menzies Bay. The laminated sedimentary rock (black) is overlain by a wedge of dark grey, fossiliferous, jointed limestone (blue). The fractures at the extreme left of the sketch, in the volcanic flow rocks (stippled), contain thin seams of the laminated rock. Scale: length of sketch approximately 20 feet, width approximately 6 feet. Thickness of laminated sediment is exaggerated.

The vanadiferous sediment

The black siliceous sediment forms a thin layer, one to four inches thick, which is continuous beneath the limestone but pinches out and is only intermittently present on both sides of the wedge. Beyond the position shown in the sketch above, where the sediment rises abruptly on the flank of the elevated portion of the flow, the single relatively thick layer of the sediment diverges into several extremely thin fractions which are so irregular and discontinuous that they are no longer recognizable as seams. Small patches of vuggy, highly weathered fossiliferous limestone are present as remnants within this confused mass.

Farther to the left (north) of this chaotic mixture, the sediment reappears for a few feet as a single paper-thin seam at about the same horizon as the base of the wedge.

The sediment at the tapered end of the wedge becomes noticeably thinner before disappearing into overburden. The next exposure reveals that the sediment dies out in a manner similar to that further north - the single layer apparently branches into two, possibly three, seams which rapidly thin out and disappear.

Thus, the length of the sedimentary layer in this trench is about forty feet. For about fifteen feet the sediment averages a thickness of two inches and reaches a maximum of four inches; in the remainder of the length the thickness is only a fraction of an inch and it eventually becomes difficult to distinguish the sediment from the

weathered and rotting contacts of the pillows and flows.

The most striking feature in the appearance of hand specimens of the vanadiferous bed in this trench is the fine, amazingly continuous parallel banding (Plate IV,B) which is traceable for as long as 20 feet. The structural form of the seam has had little effect on the continuity of the bands, for they remain uniform even where the sediment rises abruptly at the elevated flow. The constancy of the bedding and lack of deformational structures indicates that the sediment was probably fairly well consolidated before being gently folded.

The banding is made up of a maximum of five units. The top and bottom units consist of the hard, massive, non-laminated rock identical to that which occupies the same stratigraphic position at the tunnel. For the most part, this rock is absent or poorly developed. The remaining three layers (shown in Plate IV,B) exemplify the control the sediment has had on chalcocite mineralization, the replacement having taken place chiefly along the more finely laminated units.

On the whole, the fissility of the rock is poorly developed; the parting is principally between the units and occasionally along laminae.

PLATE VI

(A) The laminated sediment at the position shown in the sketch (p.36) where the seam rises abruptly on the elevated portion of the flows. The sediment pinches out a short distance upwards from the base of the hammer handle. Traces of the seam are present in the joints below and about four inches to the left of the hammer, and at the positions where the roll in the underlying flow flattens out.

Note the sheared appearance of the limestone in the upper left of the photo.

(B) Concentration of amygdules near the chilled margin of the flow rock underlying the vanadiferous sediment at Menzies Bay. The aphanitic portion of the specimen above the amygdules is darker. Specs of native copper give the amygdaloidal quartz a pinkish colour.

The limestone

The black, siliceous sediment on the northeast side of the trench is overlain by dark grey limestone which reaches a maximum thickness of two feet before pinching out at the northwestern and southeastern ends of the open cut. The limestone contains numerous fossils, among which are abundant brachiopods and a few snail-like gastropods. The brachiopods, as mentioned earlier, are tentatively identified as Spondylospira sp., and Psiodea sp. (Spiriferina), indicating that the rock is probably of Upper Triassic age.

Most of the limestone has been severely weathered so that it now is light gray, extremely porous, vuggy, soft, and crumbles readily. This contrasts markedly with the properties of the original limestone, which is dark gray, microcrystalline,relatively hard, extremely tough, and has a good conchoidal fracture.

The weathering of the rock is less complete near the base so that in many places the fresh limestone can be seen in conformable contact with the underlying vanadiferous sediment. Remnants of unaltered limestone, absent in the upper half of the bed, become progressively more abundant from the middle to the base of the bed. In a plane view the remnants appear as angular fragments (Plate VII); however, with a little digging it is possible to see that some of the larger ones are actually projections which are connected to the fresh limestone at the base. The "fragmental" appear-

ance is thus simply the product of unequal weathering of the rock.

The complete limestone bed is traversed by closely-spaced joints which have broken the rock into rectangular and triangular blocks a few inches in width.

An examination of 10 thin sections, representing a cross-section of the limestone, revealed that no tuffaceous beds are present. Traces of volcanic debris were apparently originally present, but have been almost completely replaced.

The limestone is not laminated, nor is good bedding apparent. A crude diffuse banding, the result of concentrations of the lighter-coloured fossils in some parts of the rock, is evident on cut and polished surfaces. Elongate fossils, principally echinoid spines and brachiopod shells, for the most part parallel the banding. In thin sections, a few discontinuous darker bands are also apparent. These are essentially the result of the presence of small amounts of intergranular opaque material which imparts a brownish colour to the surrounded carbonate grains.

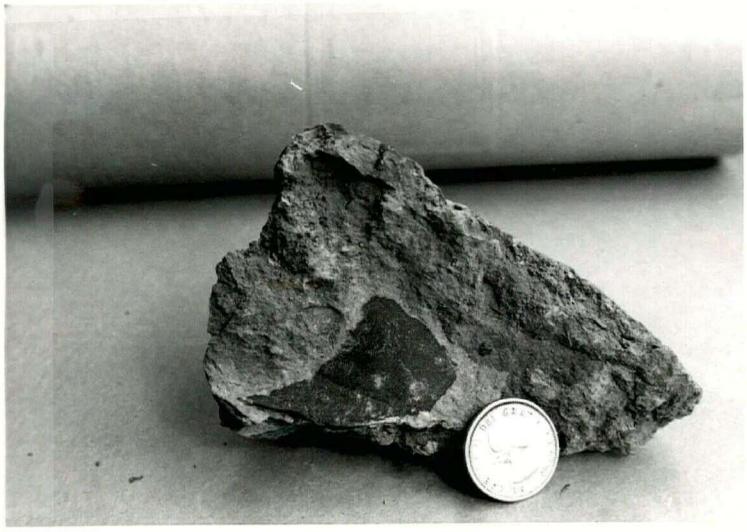
The amount of disseminated quartz, epidote, and other minerals which characteristically fill amygdules, increases toward the top of the limestone. Disseminated specs of chalcocite and native copper are found throughout the bed.

A specimen of the unweathered limestone immediately overlying and in contact with the vanadiferous laminated sediment was crushed and submitted for an x-ray fluoroscopic analysis. No more than a possible trace of vanadium was detected.

PLATE VII

(A) "Fragmental" appearance of the limestone resulting from differential weathering. Note the large unweathered block (F) to the left.

The laminated vanadiferous sediment is at the base of the hammer.



(B) Specimen of the light grey, porous, fossiliferous, weathered limestone containing a remnant of the fresh rock.

Coin is twenty five cents.

CHAPTER IV

MINERALOGY OF THE DEPOSITS

Introduction

Since the central theme of the thesis alludes to a discussion of the vanadium mineralization, only those minerals which are associated with the laminated seams will be discussed. The amygdaloidal metallic mineralization consists chiefly of chalcocite, with minor native copper and traces of bornite and chalcopyrite. Fractures, shears, quartz veinlets, and irregular white quartz masses in the volcanics also contain chalcocite and its alteration products. Dykes were not observed in the area.

Hypogene metallic mineralization in the laminated siliceous sediments consists almost exclusively of chalcocite which, in some cases, notably at the tunnel site, may constitute as much as 30 to 40 per cent of the rock. Only in the overlying limestones is native copper conspicuous, but even here the quantity of copper sulphide greatly exceeds the native metal.

Oxidation of the copper and vanadium has produced a great variety of colorful supergene minerals, of which brochantite and malachite are the most abundant and widespread. The hydrous copper vanadate, volborthite, is the principal supergene vanadium mineral.

Vanadium content of the sediment

As to the vanadium content of the sediment and surrounding rocks, Ellsworth and Gunning (1932) report the following results from a chemical analysis of an average sample of the Quadra Island vanadiferous sediment:

	%	Comments (Ellsworth and Gunning)
SiO_2	75.31	--Microscopic examination and chemical tests indicate that most of the silica is present as quartz.
FeO	2.29	
Al_2O_3	3.70	
TiO_2	0.15	
MnO	0.10	
CaO	4.08	
MgO	0.53	
Cu	2.88	--Copper is present as chalcocite, malachite, and probably also in small amount as sulphate and silicate
V_2O_5	2.16	
S	0.72	--Some of the sulphur is apparently present as SO_3
P_2O_5	trace	
H_2O	2.61	
U,Cr	not detected	
C,CO_2	present	--Carbon about 5 per cent by calculation. No hydrocarbons detected.

These authors also state that one sample yielded over 3 per cent V_2O_5.

An assay by the British Columbia Department of Mines on a chip sample of 12 inches of black sediment collected at the same open cut yielded 1.96 per cent V_2O_5. Carlisle (1944)

states that the Menzies Bay sediments were found to contain vanadium in amounts up to 1.10 per cent V_2O_5.

No other rocks in the area contain quantities of vanadium which approach the values present in the black laminated sediment. According to Carlisle, the vanadium content of the lavas ranges from 0 to 0.30 per cent V_2O_5. The amygdaloidal materials, including chalcocite and native copper, contain no vanadium. The fossiliferous limestone was spectrographed by Carlisle and found to contain only a trace of vanadium. A similar value was obtained by the present writer by x-ray fluorescence analysis.

The sedimentary horizon in which the vanadium is present in substantial quantities can possibly be even further delimited. The black, "non-laminated", massive rock commonly straddling the conspicuously laminated sediment apparently does not contain appreciable amounts of vanadium. Additional analyses would, of course, be necessary to verify this, particularly since the content of the overlying laminated rock was not checked.

It was stated earlier that one of the principal objects of this paper was to identify the mineralogical form in which the vanadium exists. A description of the mineralogy and the possible origin of the vanadium follows.

DETAILED MINERALOGY

The following minerals were found in association with the vanadiferous seams from Quadra Island, Steep Island, and Menzies Bay. The minerals are listed under each heading in their decreasing order of abundance.

Native Minerals	Sulphides	Oxides	Carbonates
native copper	chalcocite covellite bornite chalcopyrite	cuprite tenorite	malachite calcite azurite

Sulphates	Vanadates	Silicates
brochantite unidentified hyd. copper sulphate cyanotrichite	volborthite fernandinite-like mineral	heulandite

Others	Carbonaceous Matter
Mineral A B C D	"golden tan"

In addition to the above minerals and the carbonaceous substance, several non-metallic species have impregnated the sediment during the hypogene mineralization. Of these, quartz has pervaded both the volcanics and sediments in vast quantities. Megascopic and microscopic lenses, veinlets, blobs, and irregular masses are ubiquitous within the laminated sediment.

In common with chalcocite, quartz deposition appears to have taken place in two indistinct phases which are manifested by amygdule zonation and cross-cutting veinlets.

The latter have filled fractures which are probably contemporaneous with the slight deformation which resulted from the flowage movement of the overlying lava during extrusion. Quite likely the two phases are simply "peaks" of deposition within a single, brief, but continuous period of deposition.

Native Copper: Cu

Although native copper is found commonly in the amygdules of the flows and in the limestone lenses, its quantity is rather paltry. In polished sections of the limestone, some of the mineral is present as a few disseminated isolated grains, but most is closely associated with chalcocite. The two minerals exhibit either a mutual boundaries texture or the copper coats the wall of the vesicle and chalcocite forms the core.

Scanty amounts are also present as widely dispersed uncombined anhedral grains within the hypogene quartz in the vanadiferous sediment.

The nature of the occurrences is suggestive of hypogene deposition. Etching with ammonium persulphate did not produce textures characteristic of supergene copper (Carpenter and Fisher, 1930).

Chalcocite (Cu_2S) and Covellite (CuS)

These two minerals are so intimately associated that it is difficult to describe them individually.

The nature and occurrence of the chalcocite has been repeatedly mentioned, but to reiterate, it is distributed throughout the area as amygdule material and fillings of fractures and shears. Deposition in the laminated sediment has been extremely intense for the most part, particularly at Menzies Bay.

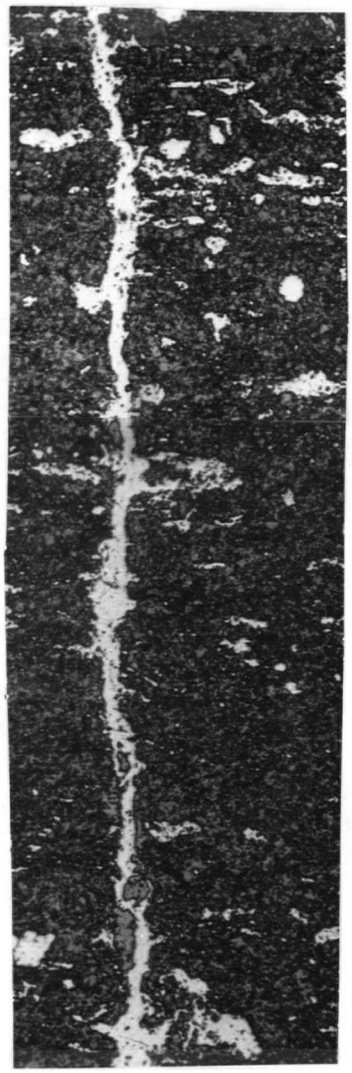
Bedding and compositional differences in the sediment exhibit a rather spectacular influence in the control of sulphide deposition. Mineralization is concentrated chiefly along the finer laminae. Veinlets for the most part conform to the bedding regardless of the amount of undulation or contortion which existed in the sediment. The veinlets exhibit either sharp or diffuse contacts with the wall rock. In the latter case, the chalcocite at the borders of the veinlet gradually decreases, leaving highly irregular margins which gradually diffuse into numerous small blebs.

The second principal mode of occurrence of the chalcocite is as thousands of closely-spaced blebs (Plate VIII) which also tend to be concentrated along the bedding. This texture is characteristic of the finer-grained, less well laminated but conspicuously banded sediment of the southern trench at Menzies Bay.

Where quartz is abundant as large masses, chalcocite simulates the appearance of amygdule fillings and may exhibit "atoll" texture as a result of the amygdule zonation. Crystal development of the chalcocite in quartz masses is quite marked. Prismatic and elongate prismatic forms are common;

PLATE VIII

(a)



(b) top of this photograph is the continuation of (a)

Microscopic view of changes in the form of the chalcocite mineralization. Photograph (a) shows the bleb form characteristic of the heavily mineralized bands in the Menzies Bay southern open cut sediment (Plate IV,B). The veinlet cuts across the sulphide-poor middle band at right angles to the bedding.

x 72

stout prisms and pseudohexagonal outlines are very rare. Quartz prisms projecting into vesicles filled with chalcocite were observed many times.

Large, poorly-formed, solitary chalcocite crystals are dispersed throughout the sediment. These may conform to the bedding, but more frequently they cut across and replace the rock without distorting the laminae. Pyroclastic material is commonly enveloped by a thin chalcocite coating which has penetrated the fragments and replaced the margins of the plagioclase phenocrysts. This marginal replacement has very rarely progressed inward to the extent that the feldspar laths are pseudomorphed. Similarly, fossil material may be either marginally or completely replaced by the chalcocite.

Small quantities of the copper sulphides are contained in narrow fractures which cut across the bedding at high angles (Plate VIII). These transverse veinlets terminate by ramification or by turning into the bedding and degrading into the 'emulsion' texture.

Alteration of chalcocite to covellite is substantial in some sections; in others the hypogene mineral has been completely unaffected. Minor replacement by veinlets and emulsion blebs of covellite has taken place along grain boundaries and cleavage traces. Quantitatively much more important is indigenous massive replacement and, secondly, complete replacement in which the covellite pseudomorphs consist of thin parallel units which simulate polysynthetic twinning. The latter feature coexists only with the massive-

ly replaced grains; the texture is not apparent in the vicinity of unaltered chalcocite nor are chalcocite-covellite or chalcocite-digenite exsolution relationships observed.

Chalcopyrite ($Cu_2Fe_2S_4$) and Bornite (Cu_5FeS_4)

In common with native copper, these minerals occur disseminated within amygdaloidal quartz masses.

OXIDES

Cuprite: Cu_2O

Supergene cuprite, as confirmed by x-ray powder photographs, ranges in colour from light orange-yellow to orange, and scarlet to deep red. It is found principally as thin powdery coatings in cavities and along joint surfaces in the flows both above and below the vanadiferous sediment. The distribution is sporadic and the quantities minute.

One small vug was found to contain a capillary variety (chalcotrichite) which, under the microscope, consisted of a fibrous to matted aggregate of needle and hair-like crystals up to 0.03 mm. in length.

Tenorite: CuO

It is difficult to estimate the quantity of tenorite present because of its similarity to the surrounding environment. There is not much doubt, however, that the amount is quite small. Flat surfaces, yielded by splitting the sediment along the laminae, commonly reveal the tenorite on

chalcocite as coatings which are so thin that no depth is observable even under the high power binocular microscope. The colour of the mineral is black with a distinctive bronzy-brown cast. Scrapings examined in immersion oil under the petrographic microscope were pulverent and without distinctive habit.

The mineral was not observed in any of the polished sections. Even the best tenorite hand specimens, when polished, do not reveal the mineral. Its identity was confirmed by x-ray powder photographs.

Tenorite appears to have formed by incipient surface alteration of the chalcocite.

CARBONATES

Malachite: $Cu_2(OH)_2(CO_3)$

Malachite is ubiquitous throughout the area and is, together with brochantite and volborthite, one of the principal forms in which the supergene copper has been precipitated in the vanadiferous sediments. Small amounts are widely distributed in the volcanics, but the greatest concentrations of malachite are found on weathered surfaces and along laminae partings of the sediment. A multiplicity of habits are present: massive incrustations; small botryoidal; needle-like crystals; large groups of fibrous rosettes; single or groups of hemispheres consisting of rosette cores with lighter-coloured outer zones; rosettes with massive or lighter pulverent shells; and circularly zoned radial fibrous groups.

Malachite or brochantite is evident in polished sections as replacements of chalcocite and covellite grain boundaries. Some of the alteration has occasionally progressed along cleavage traces (Plate IX,A).

Calcite: $CaCO_3$

Most of the carbonate solutions apparently combined with copper, and consequently, calcite is not found within the sediment. It does appear as light gray coatings on the weathered surfaces of the overlying limestone; as white, coarsely crystallized masses associated with malachite, on limestone joint surfaces; and is common in amygdules.

Reddish-brown medium-grained calcites also coat a few joint surfaces in the volcanics at the tunnel site. The peculiar color is due to intergranular specks and films of scarlet-coloured cuprite.

Azurite: $Cu_3(OH)_2(CO_3)_2$

Azurite is found only in small quantities which have a limited distribution. Most of it is associated with the limestone, but small amounts are also present in the laminated sediments and amygdules. The habit is chiefly tabular, bladed prismatic, or less frequently, divergent acicular groups. Within the sediments, dull, earthy habits predominate.

SULPHATES

Brochantite: $Cu_4(SO_4)(OH)_6$

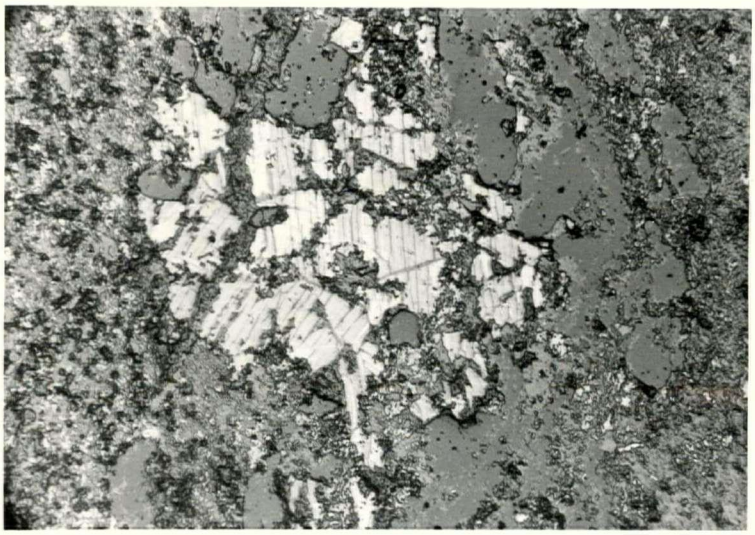
Green copper stains on the surfaces and along the parting planes of the vanadiferous sediment may be brochantite or malachite. The mineral is present as massive crusts, powdery coatings, groups of emerald-green elongate prismatic or bladed crystals, dark green crusts of stout prismatic to acicular crystals, and radiating fibrous aggregates with massive spherical nuclei. Brochantite and volborthite are intimately associated and on rare occasion may be present as alternating layers making up a single crust.

Unidentified blue copper sulphate:

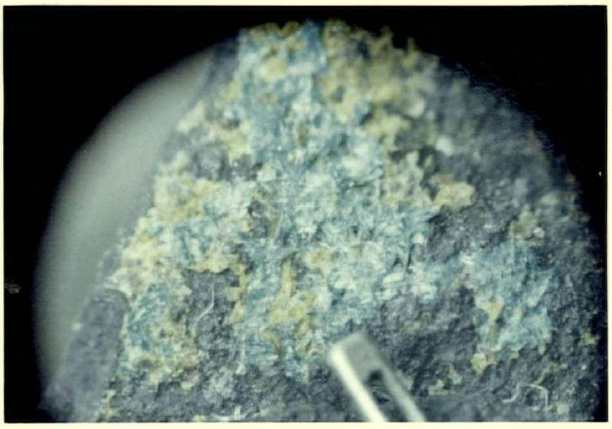
This mineral is found only with the vanadiferous sediment at Menzies Bay. It is moderately common on surfaces of laminae partings, and is very rare on weathered surfaces.

Habit: Always extremely thin, bladed acicular or tabular, usually in groups and associated with volborthite. Commonly in small coalesced clusters, with a patchy distribution on the rock surface. More abundantly as masses of needle-shaped, razor-thin crystals, some with pedial or pinacoidal terminations. Occasionally divergent; rarely radiating, or with macroscopic crude herringbone texture of small blades along a medial lath.

PLATE IX



(A) Chalcocite, in an amygdule, altering to covellite and replaced at the grain boundaries and along cleavage traces by brochantite or malachite. Scale: top to bottom of photograph 0.7 mm.



(B) Unidentified blue copper sulphate, with volborthite. Natural colour. Scale: width of needle approximately 0.4 mm.

Twinning: Lamellar twinning parallel to the length is fairly common, occasionally in combination with polysynthetic twinning resembling herringbone texture.

Physical properties: Cleavage parallel to length, possibly a pedial cleavage at 115° to length. Brittle. Soft; hardness probably $3\frac{1}{2}$. Specific gravity low (est. 2.6). Lustre vitreous. Colour light blue, less commonly greenish blue. Streak white. Translucent.

Optical properties: Extinction of the laths varies from parallel or nearly parallel to 25°. Length fast. The mean index of refraction in the plane of the laths is about 1.69. Pleochroic, light to darker blue.

Microchemical tests: For vanadium, negative; Cu and SO_4 positive, strong. Hydrous, turns black on gentle heating in closed tube. Insoluble in water at room temperature, but rapidly soluble in dilute acids.

X-ray powder diffraction pattern: Identical patterns were obtained from crystal material on three attempts.

X-ray powder diffraction pattern of unidentified blue mineral. Copper radiation, nickel oxide filter. Cutoff approximately 9.41 A°.

Intensity	d	Intensity	d
VS (100)	6.97	MW	2.132
VW	5.28	M (38)	2.014
F	4.90	W	1.949
VF	--	MWd	1.870
VF	--	VF	1.814
S (70)	3.507	VW	1.771
F	3.326	F	1.740
F	3.209	W	1.661
W	2.805	VF	1.618
M (32)	2.706	W	1.588
M (30)	2.607	M (36)	1.547
MW	2.501	Wd	1.512
M (40)	2.423	Fd	1.459
W	2.327	Fd	1.449
W	2.265	Wd	1.391
F	2.191	Wd	1.352
		MWbd	1.305

S, strong	W, weak	d, diffuse
M, medium	F, faint	b, broad

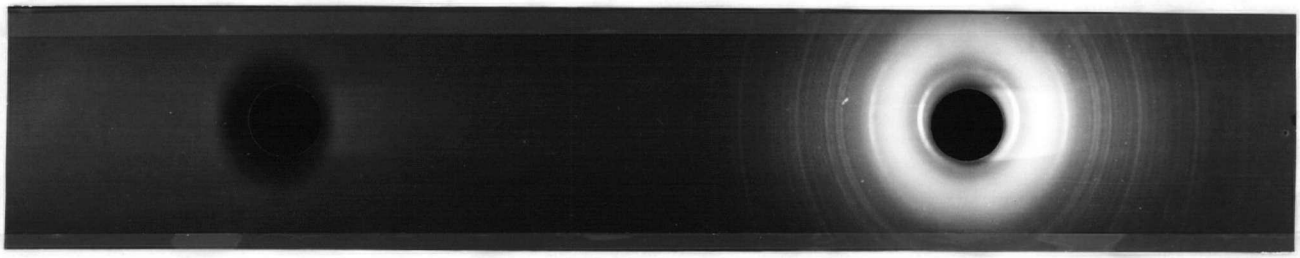


Plate X: x-ray powder diffraction pattern of unidentified mineral.

If the chemical tests are independently verified, it it suggested that this mineral may be a new species.

Cyanotrichite: $Cu_4Al_2(SO_4)(OH)_{12} \cdot 2H_2O$

Cyanotrichite occurs as soft, sky-blue coatings on brochantite incrustations. Small quantities of the mineral are present on many of the Quadra Island volcanic and sedimentary rocks, but none was found at Menzies Bay. The identity of this rare mineral was confirmed by comparing its x-ray powder pattern with that of a known cyanotrichite from Mason Pass, Nevada.

VANADATES

Volborthite: $Cu_3(VO_4)_2 \cdot 3H_2O$

The distinction between volborthite and calciovolborthite, $CuCa(VO_4)(OH)$, is not well established, and it has been suggested that calciovolborthite is only a calcian variety of volborthite (Strunz, 1939, in Dana, 1944). The problem is further discussed in the appendix.

One of the truly astounding features of the volborthite in the Campbell River area is the vast array of colours and habits which the mineral assumes. The following descriptions briefly summarize most of the occurrences:

--dark green to yellowish green massive, compact, with good cleavage; yellow, ochre yellow, golden, brownish yellow, greenish yellow, yellowish green, light gray-green, olive green, dark green, light brown, yellowish brown, coppery, blackish brown, earthy, commonly fibrous to sub-fibrous, flocculent with varnish-like coatings; radiating fibrous and circular in outline, singly or in groups, with or without

a small massive core; scaly crusts and rosette-like, honeycombed, or boxwork-like aggregates; scales with triangular or hexagonal outline, occasionally with impurities some distance from the centre arranged to form a hexagonal outline; scaly yellow incrustations on massive or cleavable dark green hexagonal cores; massive; botryoidal; spherulitic. (Plates XI, XII, XIII, XIV).

Physical Properties: Perfect cleavage parallel to the plates. Brittle; dark green botryoidal material was easily depressed with a needle. Hardness about 3. Lustre vitreous to pearly on the cleavage; waxy and irridescent on botryoidal material. Streak yellow to greenish yellow; light brown on blackish-brown material. Translucent to subtranslucent.

Optical Properties: For the rosette-like aggregates from Menzies Bay (Plate XIII,B), yellow in transmitted light and very faintly pleochroic. Biaxial negative; $n\gamma$ less than 1.84, approximately 1.837. This is not in agreement with Dana (1944), where $n\gamma$ is 2.02 (See appendix).

Chem.: Hydrous, yields abundant water in closed tube. From x-ray diffractograms and semi-quantitative spectrographic analyses, Cu and V are major constituents, Si and Al minor.

Locality	Habit	Method	Major	Minor	Important Tr.
Menzies Bay	Flocculent	Spec.	Cu,V	Si,Al	Ca
Menzies Bay	Flocculent	Spec.	Cu,V	Al	Si,Ca
Menzies Bay	Scaly xls.	Spec.	Cu,V	Si	Al,Ca,Mg
Menzies Bay	Flocculent	Diffract.	Cu,V		
Menzies Bay	Hexagonal core	Diffract.	Cu,V		

Occurrence: Minor quantities of volborthite coat weathered surfaces, but it is most abundant on laminae partings of the Menzies Bay sediments. The Quadra Island seams contain only very scanty amounts on weathered surfaces and the mineral is essentially absent along the laminae. The deficiency is probably a reflection of the fact that the compact, non-fissile mature of the Quadra sediments makes them much less amenable to weathering than those at Menzies Bay.

Fernandinite-like mineral:

A fernandinite-like mineral was found on one specimen of the sediment from Menzies Bay. It occurs in trace quantities as water-soluble, vitreous, creamy to greenish yellow flakes at the margins of brochantite incrustations on a weathered surface of the laminated rock.

Although the physical properties differ, the chemical properties and the x-ray powder pattern (appendix) are similar to those of fernandinite ($CaO \cdot V_2O_4 \cdot 5\ V_2O_5 \cdot 14H_2O$). The mineral is thus conveniently classified as "fernandinite-like".

PLATE XI

(A) specimen of the Menzies Bay laminated sediment, with malachite and brochantite coating weathered surfaces. Volborthite (yellow) is chiefly along the laminae parting planes. Coin is twenty-five cents.

(B) Light green translucent volborthite scales on the surface of the vanadiferous sediment. Maximum width of needle approximately 0.35 mm.

(C) Light brown volborthite as a powdery coating on the Menzies Bay massive "non-laminated" sediment.
Coin is twenty five cents.

PLATE XII

(A) Dark green hexagonal cores of volborthite surrounded by yellow volborthite with flaky, crustified outer zone. Diameter of uppermost core approximately 0.4 mm.

(B) Zoned volborthite. The succession, from the centre, a yellowish green teat which is not always present, (B) dark brown, (C) a narrow yellow zone, (D) golden brown, (E) a well-defined, narrow, yellowish-green zone, and a large (F) golden brown outer zone. This type of zoning is common in the Menzies Bay volborthite. Scale: top to bottom of photo 0.6 mm.

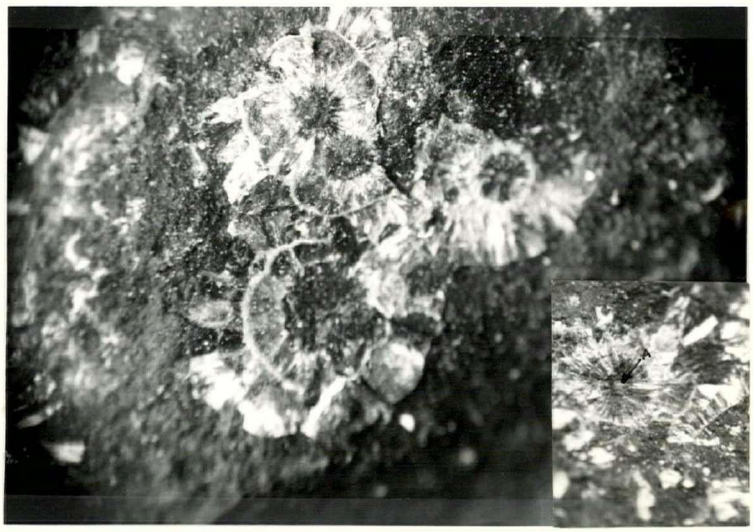
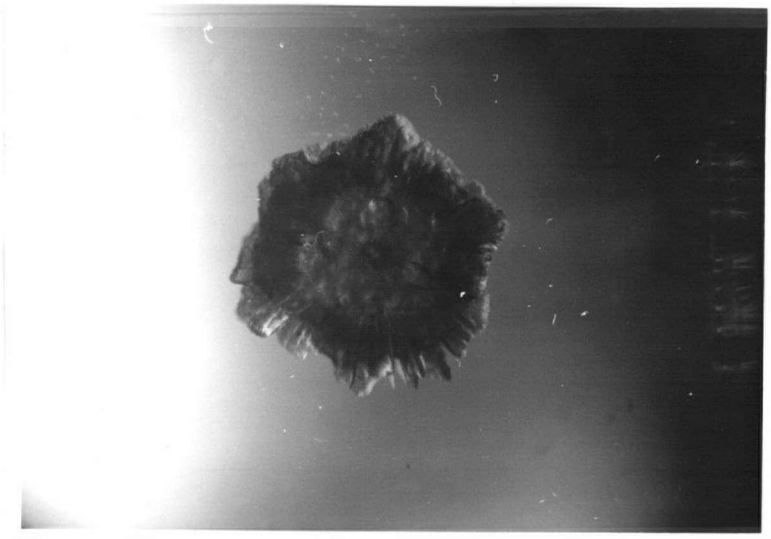


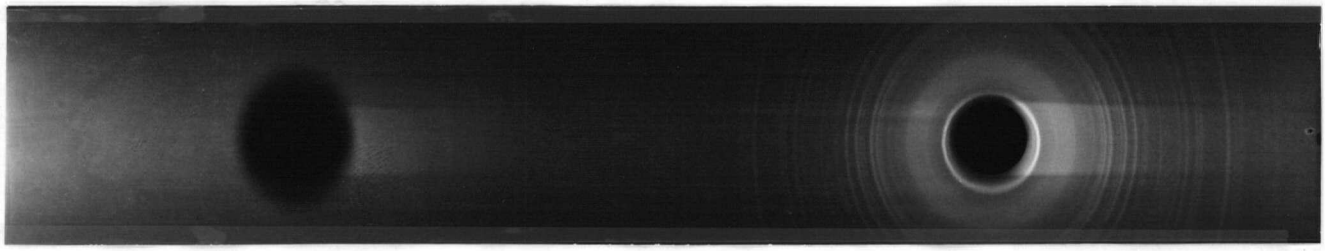
PLATE XIII

(A) Yellow volborthite spheres with crusts and fibrous, spherulitic malachite. Maximum width of needle approximately 0.4 mm.
This particular specimen of Menzies Bay laminated sediment was the only rock in which the writer encountered megascopic golden tan carbonaceous matter.

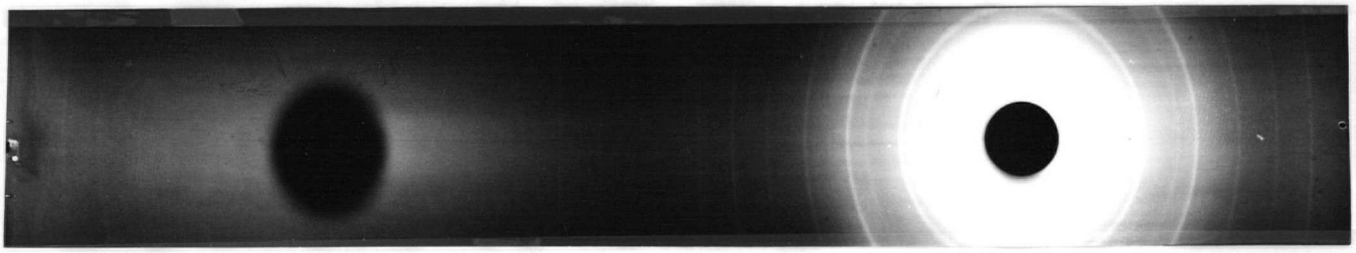
(B) Rosette-like volborthite on the Menzies Bay sediment. Scale is the same as above.



(A) Immersion oil view of the "hexagonal core" volborthite from Menzies Bay (see plate XII). A dark green core is surrounded by a brownish zone and an outer, light yellow zone. Scale: top to bottom of photo 1.47 mm.



(B) X-ray powder diffraction pattern of "hexagonal core" volborthite from Menzies Bay. Copper radiation, nickel oxide filter.



(C) X-ray powder diffraction pattern of "golden tan" carbonaceous substance, copper radiation, nickel oxide filter.

SILICATES

Heulandite: $(Na,Ca)_3Al_5(Al,Si)Si_{14}O_{40} \cdot 10H_2O$

In addition to its typical occurrence in vugs, heulandite was found on several specimens of the vanadiferous sediment as salmon-pink coatings which are incrusted on both top and bottom by malachite.

OTHER MINERALS

Mineral A

This mineral, which is opaque even in powdered form, was found on a Menzies Bay specimen as thin (0.01 mm) black coatings capping the volborthite hexagonal cores. The quantity is thus very small.

X-ray powder photographs gave the following results:

Intensity		d	
10	(S)	3.10	Powder ball; copper radiation, nickel oxide filter. Intensity values average of two films. Cutoff 9.41 A°.
3	(M)b	2.814	
½	(F)	2.475	
½	(F)	2.113	
½	(VW)	1.985	
9	(S)	1.918	
1	(W)d	1.814	
½	(VW)	1.734	
1	(M)	1.637	
1	(W)	1.593	
½	(F)	2 lines?	
½	(VW)	1.245	
½	(VW)	1.106	

The powder pattern bears similarities to the corvusite-like minerals discussed in the appendix. However, the black or blue-black supergene vanadium minerals generally

consist of the low-valent vanadium oxides which represent an intermediated stage of oxidation; volborthite is characteristic of fully oxidized vanadium ores. From the nature of the occurrence and the intimate association with volborthite, one would suspect that "mineral A" is unlikely to be a vanadium oxide.

Michrochemical tests, on the residue obtained from dissolving the powder ball in alcohol, gave positive results for copper but not for vanadium.

Mineral B

Near the contact of the lava and the sediment, a large vug was observed to contain small quartz prisms and trapezohedrons of analcite. The zeolite alone was covered with a light blue "skin" of mineral B.

X-ray powder photographs give a pattern somewhat similar to those of the halotrichite group, but with a larger unit cell. Mineral B is thus probably an aluminous sulphate formed by alteration of analcite.

Mineral C

Mineral C is a soft, grayish-green, clay-like substance which was found on the parting surface of one specimen of the laminated sediment. The x-ray pattern is similar to that of mineral B.

Mineral D

Mineral D occurs on the weathered surface of one specimen of the sediment as a "stain" resembling limonite. It is most abundant on brochantite, but is also associated with volborthite, the unidentified blue copper sulphate, and the fernandinite-like mineral.

The colour of the "stain" is light reddish brown to almost black. The substance dissolves readily in dilute HCl, turning the solution yellowish green, and leaving a silica residue containing many impurities. Although the mineral appears to turn reddish-brown when dissolved (a feature characteristic of vanadates), a vanadium microchemical hydrogen peroxide test was not positive. This test for vanadium was found to be unreliable.

The x-ray powder diffraction patterns obtained from the material are of poor quality and have much variation in line intensities. Microscopic examination had previously shown that the substance was indeed a mixture. It has not been possible to identify the principal component.

It should be stressed that minerals A, B, C and D are present in extremely minute quantites and are consequently of little importance in the vanadium problem. The minerals were given a cursory examination, but no systematic investigation was undertaken to identify them. Likewise, in an effort to determine whether additional vanadium minerals might be present in the sediment in substantial quantities, several x-ray patterns were taken of material

which was scraped off the laminae parting surfaces of hand specimens. Most of these substances were found to possess a white or grayish streak, a feature which is present in very few vanadium minerals. It was consequently possible to demonstrate, largely on the basis of the x-ray powder patterns, that these thin and sporadically distributed coatings are not comprised of vanadium minerals, but rather are, in essence, the non-metallic fraction which was added to the sediment during hypogene mineralization.

Conclusion

The metallic hypogene mineralization in the sediment was found to consist exclusively of chalcocite and traces of native copper, chalcopyrite, and bornite. Of the supergene minerals, only malachite, brochantite, and volborthite are widely distributed in relatively large quantities.

CARBONACEOUS MATTER

The "golden tan" substance is the carbonaceous matter which is dispersed throughout the laminated rock and constitutes as much as 40 to 50 per cent of some samples of the Quadra Island sediment. It is rarely recognizable in hand specimens.

Physical properties: Fracture conchoidal. Brittle. Hardness about 4. Specific gravity - very buoyant in liquid of gravity 1.75, but sinks in water. Colour and streak black. Lustre vitreous. Opaque.[3] In polished section: golden tan to pinkish tan; isotropic; takes good polish; $HgCl_2$, KOH, KCN, HCl, HNO_3, aqua regia - negative.

Composition

X-ray diffractograms and semiquantitative spectrographic analyses of the Menzies Bay material indicate that the golden tan "mineral" consists chiefly of carbon, with traces of copper. From the reactions obtained by heating in the closed tube, it is estimated that at least 90 per cent of the constituents are volatile.

The results of the spectrographic analyses and diffractograms are tabulated below (Table III).

A grain of the golden tan substance (Menzies Bay number 3, table III), very gently heated in a closed tube, yielded a colorless fluid and a clinker-like residue.

A small portion of the Menzies Bay number 2 sample was inserted in a minute silica tube and heated at the open end with a micro-flame. The contents were seen by Dr. R. Delavault to glow and then ignite. There was no solid

---

3 When finely disseminated in the sediment, the golden tan substance may be translucent and brownish or greenish at the grain edges. The x-ray patterns in all cases are identical.

TABLE II

Analyses of carbonaceous matter

Sample Number	Sample Location	Control	Method	Results
1.	Menzies Bay tunnel site	From polished section; quantity very small; possible copper sulphide impurities	Diffractogram	Tr. to minor copper
			Semi-quant. spectograph	Major carbon, Tr. Cu, Fe
2.	Menzies Bay tunnel site	As above. Quantity small	Diffractogram	Tr. Cu, Ni(?)
3.	Menzies Bay tunnel site	Binoc. mic. Moderate quantity of material	Semi-quant. spectrograph	Major:C Minor: Cu Tr.:Fe, Mn,Mg, Ca,Na, Si,V
4.	Patronite ore, Minasragra, Peru M 22213	Binoc. mic. Moderate quantity of material	Semi-quant. spectrograph	Major:C Minor to trace Mn Tr.: Fe Mg,Ca, Na,Si, Cu,V

residue visible, but a small half-ring of colorless fluid was deposited at the middle of the tube. Within 48 hours the vapour had disappeared, leaving only a trace of milky white residue.

X-ray powder diffraction photographs of the golden tan substance yield a relatively simple pattern (Plate XIV), which is identical to that obtained from material of similar

appearance found in a corvusite specimen from Naturita, Colorado. With the exception of a few weak lines, the same pattern was obtained from material labelled "patronite ore" from Minasragra, Peru (ROM 22213).

Genesis

The golden tan substance occurs in a variety of forms, some of which are poignant illustrations of a syngenetic origin. Paradoxically, there are certain textural features apparent, particularly in the Menzies Bay sediment, which are more consistent with a hydrothermal origin. Since the carbonaceous matter appears to have accumulated in part as a primary, integral constituent of some of the sediment, it will be advantageous to briefly describe the laminated rocks and their contained carbonaceous substance before proffering any hypothesis of origin.

CHAPTER V

THE LAMINATED VANADIFEROUS SEDIMENT

It has been mentioned previously that there are differences from place to place in the character of the vanadiferous sediment. However, one feature common to the rock in all the localities is the presence of the fine laminations.

The Menzies Bay sediment

In thin section, the Menzies Bay sediment is greenish, yellowish-brown, or sepia-coloured. The thickness of the laminae, which average about 0.02 mm, ranges from less than 0.01 mm to as much as 0.9 mm. Many of the laminae have darker margins which deepen in colour and become opaque, thus forming thin black interlayers usually no thicker than 0.005 mm.

Unlike the Quadra Island sediment, the Menzies Bay rock contains pyroclastic fragments which, though small in quantity, are widely dispersed. Most of the smaller particles are somewhat elongate, and parallel the bedding. The impact of the larger (up to 1 mm) particles has depressed the underlying laminae.

Concentrated in the thicker layers, but otherwise scattered indiscriminately throughout the rock, are numerous elongate or ellipsoidal bodies which are presumably fossil outlines (Plate XVI).

Composition of the Sediment

The laminae

The translucent laminae of the sedimentary rock are composed of cryptocrystalline material which is birefringent and may be slightly pleochroic. It is known from the chemical analysis reported by Ellsworth and Gunning (1932), that most of the Quadra Island sediment is made up of quartz. X-ray diffraction patterns indicate that the Menzies Bay sediment likewise consists principally of quartz.

In an effort to determine whether the colour of the sediment might be attributed to disseminated cryptocrystalline vanadium minerals, an x-ray investigation was conducted by preparing, under the microscope, several minute powder balls of sediment which lacked visible interlayered opaque material. The patterns consistently indicated that only quartz and the golden tan substance were present.

The opaque constituents of the sediment

Throughout the sediment are large quantities of opaque materials which may constitute as much as 50 per cent of a section. It is possible to see, in polished thin sections, that the opaque fraction of the rock is made up of chalcocite (or covellite), and the golden tan carbonaceous matter.

Hydrothermal non-opaque minerals

The appearance and composition of the sediment has

been somewhat modified by the introduction of the minerals which are characteristically amygdule fillings. Of these, only quartz and pumpellyite are relatively abundant and widespread.

The impregnation of the sediment by copious quantities of quartz has resulted in local, but rather severe, distortion of the originally gently undulating laminae. The quartz, which is present chiefly as large masses, has forced the laminae aside and fractured the pre-existing quartz veinlets (Plate XVI). Invariably associated with the quartz and projecting inward from the grain peripheries, are tiny crustification bands of the seemingly pervasive pumpellyite.

The Carbonaceous Matter in the Menzies Bay Sediment

Studies of polished thin sections of the Menzies Bay sediment revealed that much of the golden tan substance is present as veinlets which are commonly associated with quartz. However, an equal, or perhaps even greater quantity of the carbonaceous matter is disseminated throughout the laminated rock as blebs, slightly elongate grains, irregular blobs, and in many cases, as material filling the microfossil outlines.

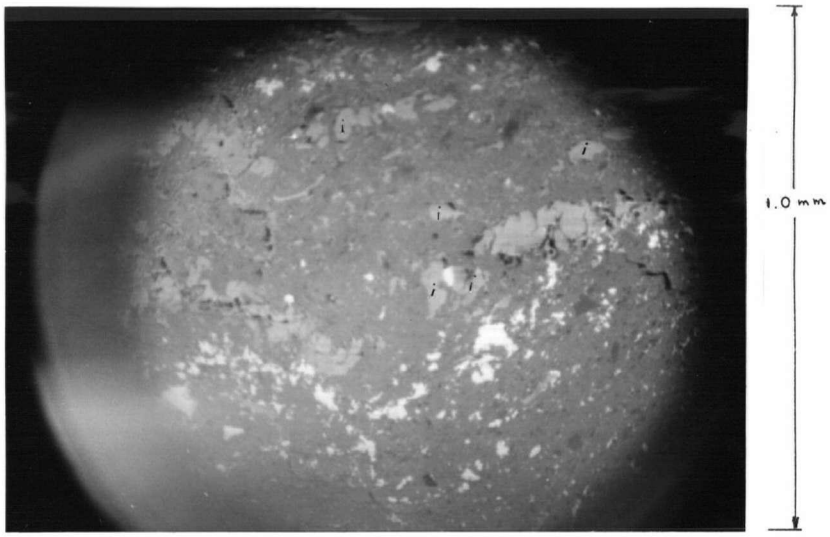
Since the textural features of the carbonaceous substance offer the main clues regarding the method by which it became part of the sediment, these occurrences

shall be described in more detail.

In the Menzies Bay sediment, the carbonaceous matter is present as:

(1) irregular blobs, such as is shown in plate XV. Many of these grains, which are disseminated throughout the sediment, definitely transect and replace the laminated rock. These replacements are accompanied by a small amount of bulging of the enclosing laminae. It is unlikely that the irregular blobs are of syngenetic origin.

PLATE XV



The golden tan carbonaceous substance occurring within the Menzies Bay sediment as irregular, disseminated grains, the larger ones of which are labelled (i). Most of the very large grains are associated with quartz and are allocated to another division (page 78). White metallic is chalcocite.

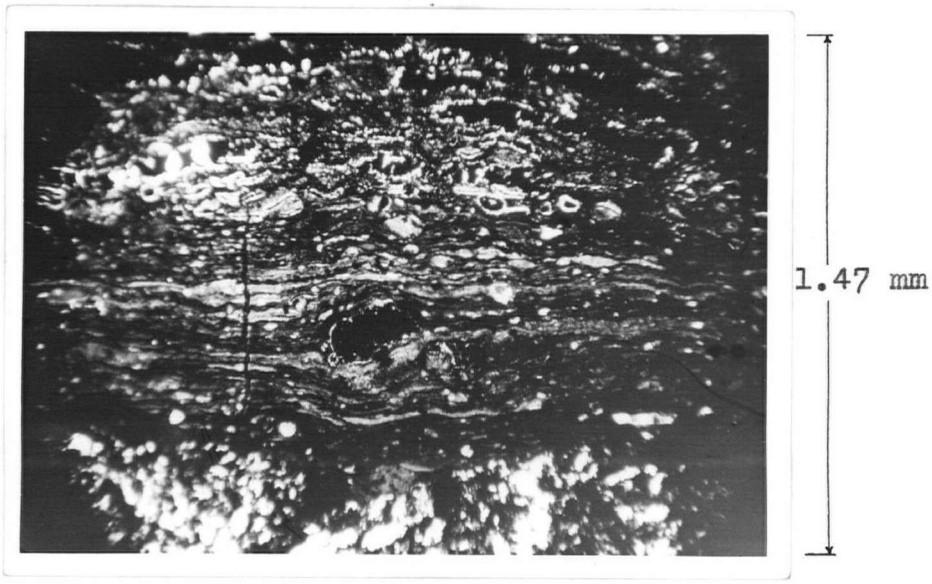
(2) blebs: these offer no data regarding their origin.

(3) elongate grains: these parallel the bedding and consequently may be syngenetic or epigenetic. The grains may have been deposited with the sediment or, on the other hand, may reflect the control of the bedding on hypogene deposition.

(4) cores of fossil material: there is little doubt that the elongate rod-shaped, gently curved or ellipsoidal bodies shown in Plate XVI are related to fossil material in the sediment. In Plate XVIB, it can be seen that the opaque matter making up the inner portion, or "core", of the fossils is the golden tan substance. Nearly all the cores are largely or completely enveloped by a non-opaque sheath which invariably consists of pumpellyite. A limited number of the opaque bodies are only partly surrounded by the silicate; a few are completely surrounded by the sediment.

The association of carbonaceous matter with organic remains is well known. Since the golden tan substance differs from most organic decomposition products, the staunch hydrothermal advocate might suggest a replacement origin for the above occurrence. To avoid becoming embroiled in a discussion in which the reader may feel there is no room for controversy, it perhaps is convenient at this point to pass on to the next mode of occurrence.

PLATE XVI



(A) Photograph of a polished thin section showing fossils in the Menzies Bay laminated sediment. The opaque material in the fossils is the golden tan substance. Transmitted light.

(B) The golden tan substance in the elongate fossil remnants of the Menzies Bay sediment. Polished thin section, reflected light.

(5) veinlet form, associated with quartz:

PLATE XVII

1.47 mm.

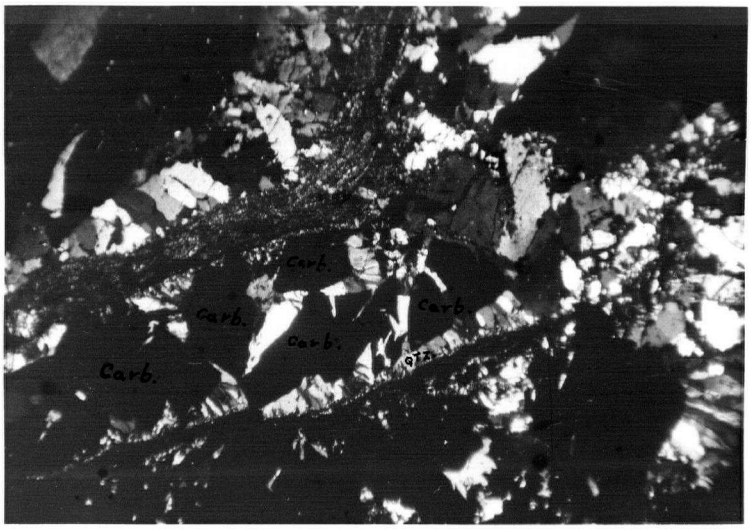
Quartz, in veinlet form, containing the golden tan carbonaceous substance (black). A younger, "amygdaloidal" quartz mass has distorted the sediment, fractured, and offset the veinlet. Note the matching walls of the fragments of the opaque carbonaceous matter within the older quartz. B and C are the continuation of veinlet A.

It can be seen in the above plate that the undistorted portion of the quartz veinlet containing the carbonaceous matter clearly does not parallel the laminae. It may thus be inferred that the veinlet is not a primary sedimentary feature.

The quartz in the above, and similar veinlets, differs from the "amygdaloidal" quartz in one aspect. In the vicinity of some of the golden tan fragments, the quartz grains are narrow and elongate. Some of these elongate grains radiate outward from the carbonaceous fragments, but

generally do not circumscribe the whole fragment. The sub-fibrous texture is best developed at the veinlet margins (Plate XVIII).

PLATE XVIII



1.47 mm.

Sub-fibrous quartz at margins of quartz veinlet and less well-developed at the peripheries of the carbonaceous fragments. Crossed nicols.

The carbonaceous matter within the quartz veinlets is for the most part separated from contact with the sediment by narrow intervening margins of quartz or pumpellyite. A rather peculiar feature of the brecciated golden tan substance is apparent in the photograph above, and is further emphasized in the plate below. It can be seen that although the substance has been brecciated, there has been no movement which would cause the fragments to be crushed or moved very far. Each breccia particle has

matching walls with its neighbour. Further mention of this unusual feature will be made in the discussion of the Quadra sediment.

PLATE XIX

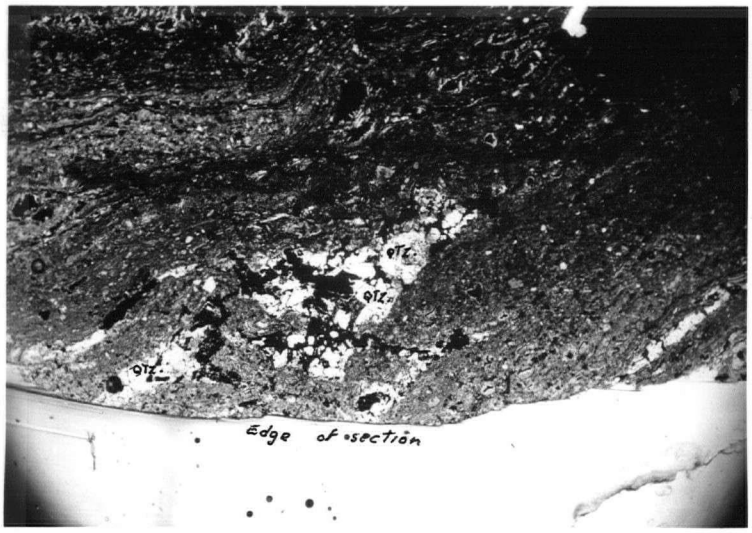
Fragmented golden tan carbonaceous matter (light grey) in quartz (q). Note the matching walls of all the fragments. The golden tan is veined by chalcocite (white). Polished thin section, reflected light.

(6) veinlet form, without quartz; these veinlets parallel the bedding, follow undulations and minor contortions, and have not been noted, per se, to transect the bedding. In minute detail, however, it has been noted that the veinlets appear to cut across the laminae at very low angles. The occurrences are not lucid examples of the carbonaceous matter cutting across the sedimentary structure.

(7) associated with non-veinlet form quartz:

This category refers to the association of the carbonaceous substance with large, irregular quartz masses which transect the laminae.

PLATE XX



Polished thin sections of the Menzies Bay sediment; transmitted light. Intergranular and interstitial golden tan carbonaceous material (black) in quartz (a few grains labeled). In left photo, quartz clearly transects the laminae. Scale: from top to bottom of photo, left 3.4 mm; right 0.9 mm.

The interstitial and intergranular carbonaceous matter is presumably later than the quartz.

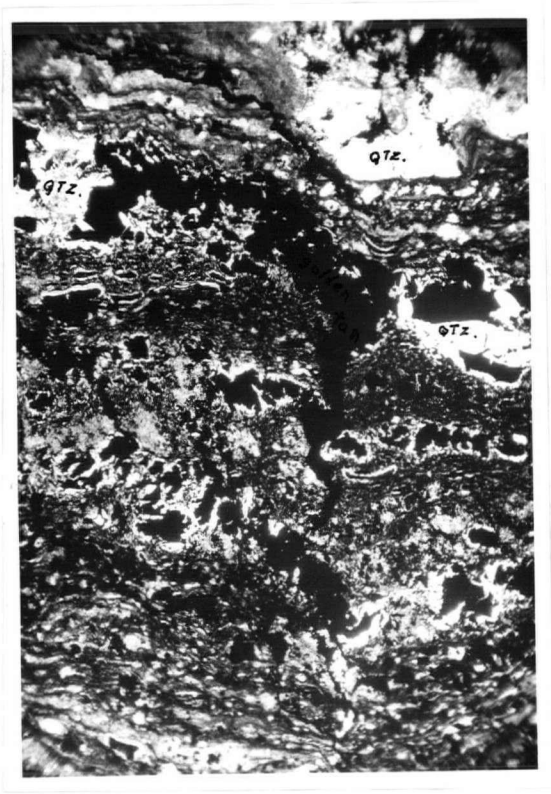
Also included within this category are veinlets of the carbonaceous matter which are apparently offshoots of quartz-golden tan veinlets. These outward projections from the main body have been noted to cut, at obtuse angles, up

to 0.7 mm thicknesses of the sediment. A carbonaceous veinlet transecting the sediment is shown in Plate XXI.

Origin of the carbonaceous matter

The forms in which the carbonaceous substance is present have been described and illustrated in some detail. In the paragenetic sequence, the golden tan material is older than the chalcocite mineralization. Carbonaceous

PLATE XXI



Veinlet of golden tan carbonaceous substance (black) transecting the laminae of the Menzies Bay sediment. Polished thin section, transmitted light. Quartz is white. Note the elongate, opaque, rod-like fossil remnants paralleling the laminae. The opaque portion of the fossils is the carbonaceous substance and the narrow white outer zone is pumpellyite. Scale: top to bottom of photo approximately 1 mm.

matter associated with the sub-fibrous quartz veinlets is healed by the quartz and thus, although they may have been essentially contemporaneous, the carbonaceous matter is relatively older. In the large, irregular quartz masses, the golden tan substance is intergranular and thus presumably younger.

Evidence suggests that the carbonaceous substance, as described above, was introduced from an extraneous source some time after the sediment had been deposited. Volcanic activity is the most likely source.

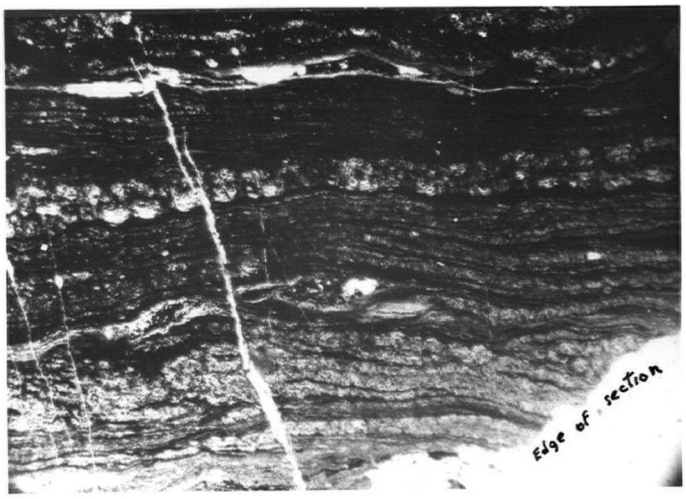
The above statements do not apply to the carbonaceous material interlayered with the sedimentary laminae, for there can be little doubt that this material accumulated with the sediment.

The Quadra Island type of sediment

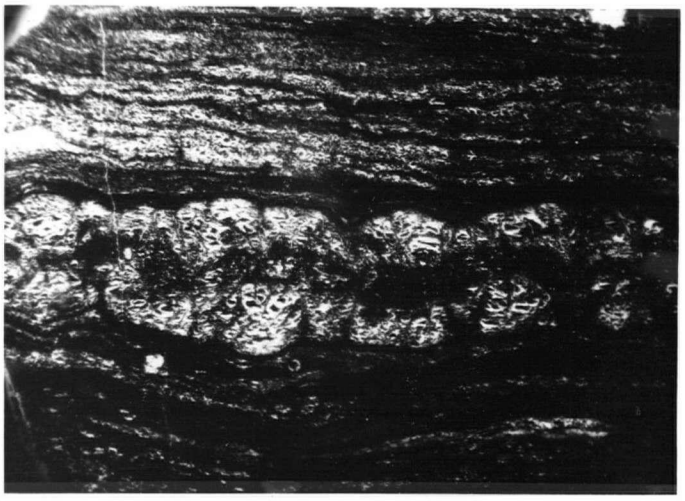
In thin sections, the Quadra Island type of laminated sedimentary rock differs quite markedly from the microscopically greenish and brownish-colored Menzies Bay rock. Unlike the latter, which has been generously impregnated with hypogene mineralization and made further heterogeneous by pyroclastic and fossil debris, the Quadra Island sedimentary rock is astonishingly uniform in appearance and composition. Furthermore, in remarkable contrast to the disturbed appearance common in hand specimens, the laminae of the Quadra rock in thin sections are relatively undisturbed. Most of the deformational stresses have apparently been relieved by fracturing rather than by folding.

The scale of the bedding and the character of the sediment can be seen in plate XXII. The colloform texture of the lighter layers is conspicuous.

PLATE XXII



(A) Microphotograph of the Quadra Island laminated vanadiferous sediment. The black laminae consist of carbonaceous matter and very fine quartz which is not visible. The white laminae are quartz with disseminated particles of the carbonaceous substance. The thin, cross-cutting veinlets are quartz. Transmitted light. Scale: from top to bottom of photo 3.4 mm.



(B) Microphotograph of the Quadra Island laminated vanadiferous sediment showing the pronounced colloform texture of some of the layers. Transmitted light. Scale: from top to bottom of photo, 1.47 mm.

The laminae

In broad aspect, the Quadra Island sediment consists of alternating dark and light laminae which consist of essentially two ingredients, quartz and carbonaceous matter. The light-colored laminae thus contain a preponderance of the microcrystalline to cryptocrystalline quartz, and conversely, the dark layers contain predominantly carbonaceous matter. Where the carbonaceous content is very high, the layers are opaque.

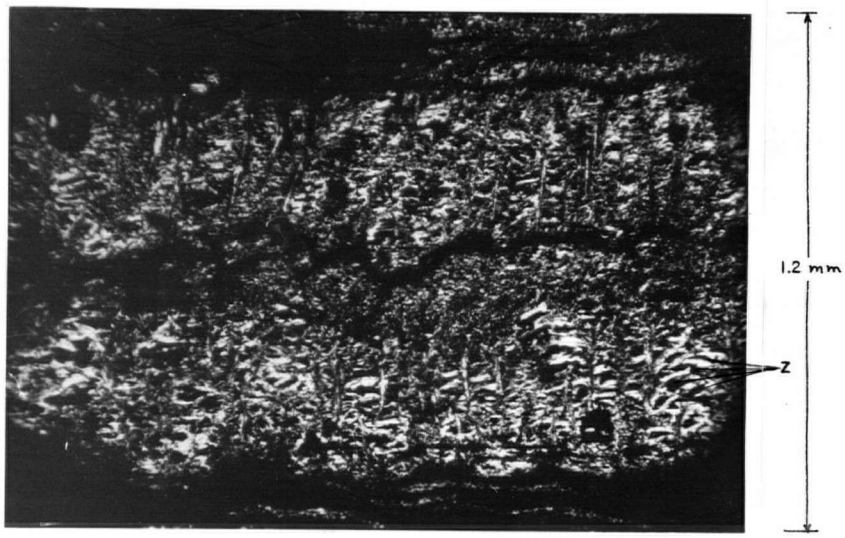
When the sedimentary rock is examined in detail, it may be seen that the light and dark laminae do not have sharp contacts, but blend into each other. In addition to these "black and white" laminae, dark reddish-brown interlayers are moderately common.

The carbonaceous matter

Within the light-colored laminae, the bulk of the carbonaceous matter is present as disseminated angular particles, many of which are elongated parallel to the bedding. Each opaque particle is separated from its neighbour by quartz which, in numerous cases, is sub-fibrous and radiates outward from a carbonaceous particle.

Plate XXIII shows another texture which is also conspicuous. The larger opaque bodies, for example those labelled "Z" are commonly crescentic in outline and may have matching walls. The elongate grains, and intervening

PLATE XXIII



Photograph of thin section of the Quadra Island sediment. The opaque, irregular grains, some of which are labelled "Z", are the carbonaceous matter. The opaque grains are surrounded by quartz. The alternations of quartz and opaque grains have produced a crude columnar texture which is emphasized by narrow vertical quartz "veinlets."

quartz, are crudely stacked one upon the other so that within each microscopic unit, a semblance of layering is attained. Since each of the units would be hemispherical in a three-dimensional view, a specimen of the sediment broken parallel with the bedding should expose a botryoidal surface. This is, in fact, precisely what is found.

When ground very thin, the opaque laminae of the rock are revealed to be a mixture of carbonaceous matter and subordinate quartz. This was confirmed by x-ray diffraction patterns obtained from micro- powder ball quantities of the material.

The dark reddish-brown colour present in some laminae is undoubtedly derived from admixed carbonaceous matter. X-ray powder patterns from these layers indicated that the golden tan substance was the minor constituent occurring with the quartz.

Relative ages of the quartz and carbonaceous matter

In addition to the above mentioned occurrences, the golden tan substance is present as opaque veinlets which are up to 0.2 mm in width. These veinlets transect the laminae of the sediment.

The quantity of carbonaceous material in the above form is quite small. With this exception, the remaining carbonaceous substance is present as the main constituent of the opaque laminae, and as the minor component of the quartzose layers. It is inconceivable that the quartz and golden tan material in these delicate laminae are not syngenetic.

In view of the common presence of matching walls in the opaque carbonaceous particles within the light-coloured quartzose laminae, it is suggested that this texture was formed by contraction of the carbonaceous substance within colloidal silica.

Origin of the sediments

It is obvious that the laminated, vanadiferous rocks are not normal clastic sediments. Carlisle (1944) discusses in considerable detail the possible origin of the

laminated rocks and concludes that they formed by "rhythmic precipitation of the silica and dark material in a colloidal medium followed by crystallization". The present writer is in agreement with this hypothesis.

CHAPTER VI

SOURCE OF THE VANADIUM

Vanadium analyses of the sediment

The quantity of vanadium within the sediment has a direct bearing on the possible forms in which it might be present. The maximum V_2O_5 values have been given (Chapter IV); more important however, is an estimation of the average vanadium content of the sediment. Therefore, it is necessary to consider all the assay data available.

Menzies Bay

The following assays and their location in the Menzies Bay workings were obtained from a sketch map generously donated by Mr. G.A. Dirom, formerly of Premier Gold Mining Company, Limited. The pertinent comments are abstracts from Mr. Dirom's report on the property.

(1) the southernmost large open cut:

% V_2O_5	% Cu		
0.36	14-16	0.2'	thickness of interflow sediments consisting of 0.1' heavily impregnated with CuS; remainder f.g. silicified, fossiliferous, slightly mineralized with CuS. Well-defined secondary canary yellow "carnotite" as thin coating.
0.124			Dark greyish f.g. sediment in curving crevices.[1] Trace CuS only.

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1 This assay was made on the sediment from the west side of the open cut.

% V_2O_5	% Cu	
0.26	4.0	0.4' flat sed. seam in flows. Impregnated with f.g. CuS. Distinct "carnotite" staining.

(2) in the prospect pits between the southernmost open cut and the tunnel site. These pits contain thin (less than one inch) seams of the laminated sediment.

% V_2O_5	% Cu	
0.75		0.1' of laminated fossil sed. heavily impregnated with CuS and showing well-defined "carnotite" coating.
1.14	23.5	values taken from map, no comments available.

(3) in the tunnel site sediment

% V_2O_5	% Cu	
0.40		grey black cherty sed. impregnated lightly with f.g. CuS and native Cu. also cpprite. Trace of carnotite weathering.

Quadra Island

In addition to the values reported by Ellsworth and Gunning, the following analyses were made by the British Columbia Department of Mines in 1943.

		V_2O_5
(1)	Chip sample of 12 inches of black sediment	1.96%
(2)	Mixed sediment and amygdaloid, south end of cut	0.28%
(3)	Same from 20 feet west of north end of cut	0.34%
(4)	Chip sample of middle flow between the laminated sedimentary layers in the cut	0.21%

	V_2O_5
(5) Dense black amygdaloid quarter of a mile north of cut	0.18%

The above analyses indicate that the average vanadium content of the Menzies Bay sediment, with volborthite, is probably less than 0.5 per cent. The Quadra Island sediment, presumably also with volborthite, possibly contains as much as 2 per cent V_2O_5.

Extraneous source of volborthite

If the volborthite was derived by weathering of the sediment, the problem becomes one of determining the primary form in which the vanadium is present in the sediment. The possibility exists that the vanadium was transported by ground waters and precipitated in the laminated seams. The surrounding lavas apparently contain significant quantities of vanadium and would thus provide the source.

The following objections can be raised:

(1) the volborthite should be more abundant along fractures and channelways, and concentrated along relatively impermeable laminae. This is not the case; the volborthite is evenly distributed along laminae and coats exposed, weathered surfaces. It is present in fractures, but is not particularly concentrated at these locations.

(2) in the old prospect pits, rubble from the sedimentary layers may be coated with fresh volborthite. As these fragments are not exposed to the percolating waters running off the lavas, the volborthite likely formed by

weathering of vanadium contained within the sediment.

(3) spectrographic analyses indicate that more than a trace of vanadium is present in sediment which does not contain microscopic volborthite or volborthite detectable on x-ray powder diffraction patterns.

(4) volborthite is restricted to the laminated sediment. This would imply that the carbonaceous matter was the precipitating influence. No such chemical reaction is known. If copper sulphide was the precipitating agent, volborthite would be found with chalcocite in amygdules or along shears.

(5) the lavas very close to the sediment are neither enriched nor depleted of vanadium.

(6) There are no obvious channelways through which the vanadium would reach the laminated layers.

It is concluded that the volborthite was formed by the alteration of vanadium contained in the laminated seams.

Sediment composition versus vanadium content

The lowest vanadium values at Menzies Bay are those from the southernmost large open cut. Aside from the physical character, the sediment is known to differ from the tunnel site rock in only one aspect, namely, the content of chalcocite and carbonaceous matter.

Although the golden tan carbonaceous substance was not observed in polished sections of the open cut sediment,

this is attributed to the inability of obtaining excellent polished surfaces on the sections. This lack of polishing is regarded as being the main factor contributing to the habitually low estimation of the carbonaceous content of polished sections. It was repeatedly demonstrated with polished thin sections that non-chalcocite opaque matter was the golden tan carbonaceous substance. The difficulty lies in the necessity of attaining a superpolished surface before significant quantities of the finer-grained carbonaceous material become visible.

Vanadium, chalcocite, and the golden tan carbonaceous substance are most abundant at Menzies Bay in the sediments north of the large open cut and at the tunnel site. Bearing in mind the compositional similarity of the tunnel and southern open cut sediments, one might deduce that the vanadium content of the laminated rocks is related to the chalcocite and/or carbonaceous matter.

The best V_2O_5 values were obtained from the Quadra Island sediments. In comparison to the copper sulphide content of the Menzies Bay rocks, the Quadra sediments are sparsely mineralized. The vanadium is therefore not related to the chalcocite.

The Quadra laminated rock was stated as consisting essentially of quartz and carbonaceous matter. The quantities of vanadium present are unlikely to be in the quartz.

Unknown factors

In the Menzies Bay sediment, it has not been proven that the dark margins of the laminae are the golden tan carbonaceous substance. Most of the discernable golden tan material was apparently introduced after deposition of the sediment.

Without chemical analyses, it is not known whether sufficient vanadium is present in the carbonaceous matter to account for the V_2O_5 values obtained by assays. The assay values could probably be lowered since presumably all samples were coated with volborthite.

Similar problems are encountered in the Quadra Island sediment. It has not been possible, for example, to prove that all the opaque material is the golden tan substance. However, the evidence is rather strong that such is the case. The relative V_2O_5 values of the epigenetic Menzies Bay and syngenetic Quadra Island carbonaceous substances are not known.

Primary form of the vanadium in the sediments

In lieu of the carbonaceous matter as a source, the following alternatives might be suggested:

(1) presence of a primary vanadium mineral within the sediment or within the carbonaceous matter: no such mineral has been detected.

(2) Presence of a primary vanadium mineral, now completely altered to volborthite: there is no evidence to suggest this. The sediment has not been oxidized to the extent that the copper mineralization is considerably altered.

A polished thin section of the Quadra sediment containing about 40 per cent opaque matter was noted to consist of three sets of laminae:

(1) opaque layers
(2) quartzose layers containing disseminated, angular, opaque fragments
(3) reddish brown layers

The section was superpolished by Mr. J.A.Donnan, revealing that

(1) some of the material making up the opaque laminae is the golden tan carbonaceous substance.

(2) some of the angular, opaque fragments in the quartzose laminae are the golden tan substance.

X-ray diffraction patterns from powder balls prepared under the petrographic microscope indicated

(1) the opaque laminae consist of the golden tan substance and quartz.

(2) the light-coloured laminae consist of quartz and the carbonaceous substance.

(3) the reddish-brown laminae consist of quartz and small amounts of carbonaceous matter.

(4) the absence of other minerals.

A semi-quantitative spectrographic analysis of a portion of the section indicated that more than a trace of vanadium was present.

It is concluded that the carbonaceous matter is probably the primary "mineral" source of vanadium in the Campbell River area laminated, siliceous sediments. Since the carbonaceous matter is believed to be inorganic and possibly volcanic in ultimate origin, the rather large vanadium content[1] of the Texada rocks in the area is compatible with this hypothesis.

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1 Carlisle, (1944): by spectrographic analyses, found that "All samples of the lava, except one, contain vanadium .. even though some of them were far away from the deposits." Three chemical assays of the lavas gave an average V_2O_5 content of 0.23 per cent. Clark and Washington (1924) give the average vanadium content of igneous rocks as .026 per cent V_2O_3.

Clark, F.W., and Washington, H.S. (1924) The Composition of the Earth's Crust; U.S. Geol. Surv., Prof. Paper 127, pp. 20-40.

BIBLIOGRAPHY

Ankinovich, E.A. (1959): The New Vanadium Minerals Satpaevite and Al'vanite; Zapiski Vses. Mineralog. Obshch. vol. 88, pp. 157-164. (abs. Am. Mineralogist, vol. 44, 1325).

-------(1954): Izv. Akad. Nauk Kazakhstan SSR, no. 134, Ser. geol. No. 19; p. 116; from an abstract by E.N. Bohnshtedt-Kupletskaya in Zapiski Vses. Mineralog. Obshch., vol. 84, 343-344 (1955). (abs. Am. Mineralogist (1957), vol. 42, p. 583).

Bancroft, J.A. (1913): Geology of the Coast and Islands Between the Strait of Georgia and Queen Charlotte Sound, B.C.; Geol. Surv., Canada, Memoir 23.

Barnes, W.H., (1955): "Hewettite" and "Metahewettite"; Am. Mineralogist, vol. 40, pp. 689-692.

Berry, L.G., and Graham, A.R. (1948): X-ray Measurements on Brackebuschite and Hematolite; Am. Mineralogist, vol. 33, pp. 489-485.

Breger, I.A., and Deul, Maurice, (1959): Association of Uranium with Carbonaceous Materials, with Special Reference to the Temple Mountain Region; Geochemistry and Mineralogy of the Colorado Plateau Uranium Ores, U.S. Geol. Surv., Prof. Paper 320, pp. 139-150.

Brown, A.S. (1958): in Airborne Magnetometer Surveys, 1956-57; B.C. Dept. Mines, pp. 16-19.

Carlisle, Donald (1944): Vanadium in an Interlava Sediment, Quadra Island, British Columbia; MASc. Thesis, The University of British Columbia, Vancouver.

Carpenter, Sir. H.C.H., and Fisher, M.S. (1930): A Study of the Crystal Structures of Native Copper; Trans. Inst. Mining Met., vol. 39, pp. 238-284.

Clothier, A., (1932): Annual Rept., B.C. Dept. Mines, p.208.

Coombs, D.S. (1953): The Pumpellyite Mineral Series; Min. Mag., vol. 30, pp. 113-135.

Dawson, G.M. (1887): Report on a Geological Examination of the Northern Part of Vancouver Island and Adjacent Coasts; Geol. Surv., Canada, Ann. Rept., New Ser., vol. 2, pp. 1B-107B.

Denson, N.M., and Gill, J.R. (1956): Uranium-bearing Lignite and Its Relation to Volcanic Tuffs in Eastern Montana and North and South Dakota; Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva 1955, U.S.Geol. Surv., Prof. Paper 300, pp. 413-418.

deVilliers, J.E. (1943): Gamagarite, a New Vanadium Mineral from the Postmasburg Manganese Deposits; Am. Mineralogist, vol. 28, pp. 329-338.

Edwards, A.B. (1954): Textures of the Ore Minerals; Austral. Inst. Mining Met., Melbourne.

Ellsworth, H.V. (1932): Rare-element Minerals of Canada; Geol. Surv., Canada, Economic Geol. Ser. 11, p. 139.

Ellsworth, H.V., and Gunning, H.C. (1933): An Occurrence of Vanadium-Bearing Rock on Quadra Island, B.C.; Geol. Surv., Canada, Summary Rept. 1932, Pt. AII, pp. 51-56.

Evans, H.T. Jr., and Mrose, M.E. (1955): The Crystal Structures of Three New Vanadium Oxide Minerals; Acta Cryst., vol. 11, pp. 56-57.

Evans, H.T. Jr., Mrose, M.E., and Marvin R. (1954): The Constitution of the Natural and Artificial Decavanadates; Bull. Geol. Soc. Amer. vol. 65, p. 1249 (abs).

-------(1955): A Crystal Chemical Study of Montroseite and Paramontroseite; Am. Mineralogist, vol. 40, pp. 861-875.

Fischer, R.P., (1942): Vanadium Deposits of Colorado and Utah; U.S. Geol. Surv., Bull. 936-p, pp. 363-394.

Fleischer, M., (1959): New Mineral Names; Am. Mineralogist, vol. 44, p. 1325.

------- (1958): New Mineral Names; Am. Mineralogist, vol. 43, p. 623.

------- (1957): New Mineral Names; Am. Mineralogist, vol. 42, pp. 117-118; p. 583.

------- (1955): New Mineral Names; Am. Mineralogist, vol. 40, p. 942.

Gabelman, J.W., (1956): Uranium Deposits in Paludal Black Shales, Dakota Sandstone, San Juan Basin, New Mexico; Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva 1955, U.S. Geol. Surv., Prof. Paper 300, pp. 303-320.

Guillemin, Claude, (1955): Une Nouvelle Espece Minerale; la Vesigniete $Cu_3Ba(VO_4)_2(OH)_2$; Compt. Rend., vol. 240, pp. 2331-2333. (abs. Am. Mineralogist, vol. 40, 942).

Gunning, H.C. (1931): Preliminary Report on the Nimpkish Lake Quadrangle, Vancouver Island, B.C.; Geol. Surv. Canada, Summary Rept., Pt. A, pp. 22-35.

------- (1930): Buttle Lake Map-Area, Vancouver Island, B.C., Geol. Surv. Canada, Summary Rept., Pt. A, pp. 56-78.

Gunning, H.C., and Carlisle, D., (1944): Vanadium on West Coast of B.C.; Can. Inst. Mining Met. Bull., no. 391, pp. 415-423.

Heinrich, E.W., (1958): Mineralogy and Geology of Radioactive Raw Materials, New York, McGraw Hill.

Heinrich, E.W. and Levinson, A.A. (1955): Studies in the Mica Group; X-ray Data on Roscoelite and Barium-Muscovite; Am. J. Sci., vol. 253, pp. 39-43.

Hess, F.L., (1925): New and Known Minerals from the Utah-Colorado Carnotite Region; U.S. Geol. Surv., Bull. 750, pp. 63-78.

Hess, F.L., and Henderson, E.P. (1931): Fervanite, a Hydrous Ferric Vanadate; Am. Mineralogist, vol. 16, pp. 273-277.

Hillebrand, W.F., Merwin, H.E., and Wright, F.E., (1914): Hewettite, Metahewettite, and Pascoite, Hydrous Calcium Vanadates; Am. Philos. Soc. Proc. vol. 53, pp. 31-54.

Jones, H.N. (1958): Selected Annotated Bibliography of the Geology of Uraniferous and Radioactive Native Bituminous Substances, Exclusive of Coals in the United States, U.S. Geol. Surv., Bull. 1059-D.

Larsen, E.S. and Berman, Harry, (1934): The Microscopic Determination of the Nonopaque Minerals; U.S. Dept. Inter., Bull. 848.

LeRoy, O.E. (1908): Preliminary Report on a Portion of the Main Coast of British Columbia and Adjacent Islands Included in New Westminster and Nanaimo Districts; Geol. Surv., Canada, Rept. No. 996.

Marvin, Richard, and Magin, G.B.Jr., (1959): Synthesis of Calcium Vanadate Minerals and Related Compounds; Geochemistry and Mineralogy of the Colorado Plateau Uranium Ores, U.S. Geol. Surv., Prof. Paper 320, pp. 103-112.

Mathews, W.H., and McCammon, J.W., (1957): Calcareous Deposits of Southwestern British Columbia; B.C. Dept. Mines, Bull. No. 40.

Mathews, W.H. (1947): Calcareous Deposits of the Georgia Strait Area; B.C. Dept. Mines, Bull. 23

McConnell, R.G. (1914): Texada Island, B.C. ; Geol. Surv. Canada, Mem. 58.

Murdoch, Joseph (1953): X-ray Investigation of Colusite, Germanite, and Renierite; Am. Mineralogist, vol. 38, pp. 794-801.

Neumann, Henrich, Sverdrup, Thor, and SÆBØ (1957): X-ray Powder Patterns for Mineral Identification; Oslo, I Kommisjon Hos H. Aschehoug and Co. (W. Nygaard).

Palache, Charles, Berman, Harry, and Frondel, Clifford (1944): Dana's System of Mineralogy, vol. 1-2, New York, John Wiley and Sons, Inc.

Ramdohr, Paul (1955): Die Erzmineralien Und Thre Verwachsungen; Berlin, Akademie-Verlag.

Robinson, S.C., Evans, H.T., Jr. Scaller, W.T., and Fahey, J.J. (1957): Nolanite, a New Iron-Vanadium Mineral From Beaverlodge, Saskatchewan; Am. Mineralogist, vol. 42, pp. 619-28.

Ross, Malcolm (1959): Mineralogical Applications of Electron Diffraction. II. Studies of Some Vanadium Minerals of the Colorado Plateau; Am. Mineralogist, vol. 44, pp. 322-341.

Shoemaker, E.M. (1956): Occurrence of Uranium in Diatremes on the Navajo and Hopi Reservations, Arizona, New Mexico, and Utah; Internat. Conf. on Peaceful Uses of Atomit Energy, Geneva 1955, U.S. Geol. Surv., Prof. Paper 300, pp. 179-186.

Short, M.N., (1940): Microscopic Determination of the Ore Minerals; U.S. Dept. Inter., Bull. 941.

Stern, T.W., Stieff, L.R., Evans, H.T. Jr., and Sherwood, A.M. (1957): Doloresite, a New Vanadium Oxide Mineral from the Colorado Plateau; Am. Mineralogist, vol. 42, pp. 587-593.

Ming-Shan Sun and R.H. Weber (1958): Santafeite, a New Hydrated Vanadate from New Mexico; Am. Mineralogist, vol. 43, pp. 677-687. (abs. Am. Mineralogist, vol. 43, p. 623.)

Thompson, M.E., (1958): Sherwoodite, a Mixed Vanadium (IV) - vanadium (V) Mineral from the Colorado Plateau; Am. Mineralogist, vol. 43, pp. 749-755.

Thompson, M.E., Roach, C.H., and Meyrowitz, Robt. (1958): Simplotite, a New Quadrivalent Vanadium Mineral from the Colorado Plateau; Am. Mineralogist, vol. 43, pp. 16-24. (abs. Am. Mineralogist, vol. 42, pp. 117-118).

-------(1957): Duttonite, a New Quadrivalent Vanadium Oxide from the Peanut Mine, Montrose County, Colorado; Am., Mineralogist, vol. 42, pp. 455-460.

Thompson, M.E., and Sherwood, A.M. (1959): Delrioite, a New Calcium Strontium Vanadate from Colorado; Am. Mineralogist, vol. 44, pp. 261-264.

Weeks, A.D. (1956): Mineralogy and Oxidation of the Colorado Plateau Uranium Ores; Internat. Conf. on Peaceful Uses of Atomic Energy, Geneva 1955, U.S. Geol. Surv., Prof. Paper 300, pp. 187-194.

Weeks, A.D., Cisney, E.A., and Sherwood, A.M. (1953): Montroseite, a New Vanadium Oxide from the Colorado Plateaus; Am. Mineralogist, vol. 38, pp. 1235-1241.

Weeks, A.D., Coleman, R.G., and Thompson, M.E. (1959): Summary of the Ore Mineralogy; Geochemistry and Mineralogy of the Colorado Plateau Uranium Ores, U.S. Geol. Surv., Prof. Paper 320, pp. 65-78.

Weeks, A.D., and Thompson, M.E. (1954): Identification and Occurrence of Uranium and Vanadium Minerals from the Colorado Plateau; U.S. Geol. Surv., Bull. 1009-B.

Weeks, A.D., Thompson, M.E., and Sherwood, A.M. (1955): Navajoite, a New Vanadium Oxide from Arizona; Amer. Mineralogist, vol. 40, pp. 207-212.

Winchell, A.N., and Winchell, Horace (1956): Elements of Optical Mineralogy, New York, John Wiley and Sons, Inc., 4th edit.

APPENDIX

The discovery in recent years of many new vanadium minerals, particularly from the Colorado Plateaus, has limited the usefulness of standard mineralogy text-books in this field. In conjunction with the study of the vanadium deposits of the Campbell River area, a compilation was made of the known non-uraniferous vanadium minerals.

The compilation is intended for use only as a reference table. A generalized list of important properties are given for each mineral along with the strongest x-ray powder lines where this information was available in the literature or determined by investigation. Mineralogical information on several new species from the Colorado region (Ross, 1959; Weeks, Coleman, and Thompson, 1959) has not as yet been published. However, as far as is known, the present mineral list is complete to date.

Alaite
Alvanite
Ardennite
Barnesite
Brackebuschite
Calciovolborthite
Colusite
Corvusite
Corvusite-like mineral
Delrioite
Descloisite-mottramite
Doloresite
Duttonite
Fernandinite
Fervanite
Gamagarite
Haggite
Hewettite
Metahewettite
Hugelite
Hummerite
Kolovratite
Kurumsakite
Melanovanadite
Minasragrite
Montroseite
Paramontroseite
Navajoite
Nolanite
Pascoite
Patronite
Pintadoite
Pucherite
Pyrobelonite
Roscoelite and
Vanadium hydromica
Rossite
Metarossite
Santafeite
Satpaevite
Sherwoodite
Simplotite
Sincosite
Steigerite
Sulvanite
Tangeite
Turanite
Vanadinite
Vanoxite
Vesignieite
Volborthite

Alaite (alaite, aloite)
- Dana System I, 602
- Dana Textbook, 510

An ill-defined substance, supposedly a hydrated vanadium oxide, $V_2O_5 . H_2O$, found as soft dark blood-red or bluish red mosslike masses in Turkestan. The artificial compound is known.

-no chemical data given, description incomplete. Generally regarded with much skepticism; see navajoite.

Alvanite
- Amer. Mineral. 44, 1325 (1950) abs.

- $3Al_2O_3 . V_2O_5 . 11H_2O$

-Light bluish-green to bluish-black, streak white, lustre vit., hardness 3-3½. Biaxial neg., 2V 80-85°, both positive and neg. elongation observed. Occurs in mica-like hexagonal platelets, cleavage (010) perfect, may be polysynthetically twinned with twin plane parallel to cleavage plane. X: cleavage = 14°

- Russian. In oxidation zone of vanadiferous clay-anthraxolite beds.

- Strongest lines of x-ray powder diffraction pattern: 4.477 (10), 1.484 (9), 1.982 (8), 1.911 (6), 4.80 (5), 1.686 (5).

Ardennite
-Winchell & Winchell, 529

-$(Mn,Ca)_5Al_5(As,V)O_4(OH)_2Si_5O_2O . 2H_2O$?

-Hardness 6, colour yellow to brown; pleochroic yellow to dark brown. Found in veins and pegmatites.

-for graphic illustration of x-ray powder diffraction pattern, see Neumann, Sverdrup, and Saebø, "X-ray powder patterns for mineral identification", vol. III (Silicates), plate XXV. Oslo, (1957).

Barnesite
-Amer. Mineral. 44, 322 (1959)
-U.S.G.S. Bull. 1009-B

-$Na_2V_6O_{16} . 3H_2O$ or $(Na,K)_2O . 2\frac{1}{2}V_2O_5 . 3H_2O$

-Described by Weeks and Thompson (Bull. 1009-B) as "sodium analogue of hewettite".

-Monoclinic, bladed or acicular, botryoidal. Colour deep red, brownish red on exposure. Lustre adamantine, dulls on exposure. Biaxial neg., 2V medium, pleochroic yellow to orange-red. Coating fractures, with steigerite.

-strongest lines of x-ray powder pattern: 7.97(VS), 3.13(S), 2.27(S).

Brackebuschite
-Winchell & Winchell, 189
-Dana System II, 1052
-Am. Mineral., 33, 489 (1948)

-$Pb_4(Mn,Fe)(VO_4)_4 \cdot 2H_2O$

-dark brown to black, yellow streak, translucent to nearly opaque. Found with descloizite and vanadinite, Argentina.

-strongest lines of x-ray powder pattern: A.S.T.M. 6-0284 3.25(100), 4.95(80), 2.76(80), 2.98(60), 1.72(60).

Calciovolborthite
-Bull. 1009-B
-Dana System II, 817
-Winchell & Winchell, 191

-$(Cu,Ca)_2(VO_4)(OH)$

-The mineral from the carnotite deposits of the Colorado-Utah region commonly identified as calciovolborthite is tentatively described by Dana (II,816) as being volborthite. Tangeite ($2CaO \cdot 2CuO \cdot V_2O_5 \cdot H_2O$) is discredited since it appears to be identical with calciovolborthite (see tangeite). It has also been suggested that calciovolborthite is only a calcian variety of volborthite; and that volborthite is isostructural with descloizite-mottramite.

-habit varied, commonly as scaly aggregates; also fibrous to dense. Biaxial neg. 2V large. nX 2.00, nY 2.01, nZ 2.02 and pleochroism grown, brown, green respectively. Soluble in acids.

-x-ray powder pattern: see volborthite.

Colusite
-Dana I, 386
-Am. Mineral., 38, 1235 (1953)

Essentially a complex sulfide of copper and arsenic, with V, Sn, and Te substituting for the As.

In polished section coppery cream in color and isotropic.

-x-ray powder diffraction pattern: A.S.T.M. 9-10. Strongest lines 3.07(100), 1.88(60), 1.60(40), 1.22(30), 1.085(30).

or

-3.075(10), 1.88(8), 1.60(6), 2.66(4), 1.084(3) - Am. Mineral.

Corvusite
-Dana System I, 602
-Bull. 1009-B

-a hydrous oxide of vanadium, with major H_2O, V, minor Fe, low Si, Al. ($V_2O_4 \cdot 6V_2O_5 \cdot nH_2O$?)

-The type specimen of corvusite was found by Weeks and Thompson to give a similar pattern to that of fernandinite. Further study showed a variation in properties and x-ray powder pattern among specimens of both species, and, as of 1954, the investigation was still in progress.

-the following properties are suggested by Weeks and Thompson for corvusite: habit, massive; very finely crystalline; slickensided surfaces appear fibrous; finely columnar coatings on pebbles and sand grains. Colour blue-black to greenish black. Lustre variable. Hardness $2\frac{1}{2}$-3. Opaque except on thin edges; green when finely ground. May alter to navajoite. On grinding, forms green waxy smear.

-x-ray powder pattern resembles that of fernandinite. Strongest lines 12.1(VS), 3.47(M), 1.83(W), 1.95(VW).

Comments:
-A specimen labelled corvusite from Naturita, Colorado, did not give an x-ray powder pattern approximating the above data on five attempts. Some of the material was corvusite-like in physical properties. A specimen of corvusite from Lewis Mines, Utah (ROM 20850) gave a pattern identical to one of several different patterns obtained from a specimen of fernandinite from Minasragra, Peru (ROM 12342). See fernandinite.

"Corvusite", Naturita, Colorado		"corvusite" ROM 20850		"corvusite" ROM 20850	
d	I	d	I	d	I
4.53	10	4.48	dark, diffuse	4.33	dark,diffuse
3.35	7	3.39	" MS	--	W
				2.83	MS
2.59	7	2.60	M	2.60	F
2.42	3	2.42	Wb	2.49	F
2.28	½				
2.00	1	2.01	M-W	1.99	W
1.83	½	1.81	VWb		
	½				
1.64	½	--		1.62	Mb
1.52	4	1.52	M	1.48	M
1.31	1	1.31	Fb		

Corvusite-like mineral

-No data is available on this mineral. It is listed by Weeks, Coleman, and Thompson (1959) as one of the vanadium minerals found on the Colorado Plateau. The formula is $V_2O_4 \cdot 6H_2O \cdot 12H_2O$

Delrioite
-Amer. Mineral. 44, 261 (1959)

-$CaO \cdot SrO \cdot V_2O_5 \cdot 3H_2O$

-From Colorado. Occurs as radial aggregates of pale yellow-green fibrous acicular crystals. Biaxial neg., 2V medium to large, nX = 1.783, nY = 1.834, nZ = 1.866, pleochroic colorless to light yellow. Hardness about 2. Fibers exhibit parallel extinction. Readily soluble in water, giving a yellow-green solution.

-strongest lines of x-ray powder pattern: 6.5(S), 4.95(MS), 3.45(MS), 4.40(M), 3.55(M), 3.04(M), 2.69(M), 1.80(M), 2.80(MW), 2.18(MW).

Descloizite Series
-descloizite $(Zn,Cu)Pb(VO_4)(OH)$ -- $(Cu,Zn)Ph(VO_4)(OH)$ mottramite.
-Dana System II, 811
-Winchell & Winchell, 217
-x-ray powder data available from A.S.T.M.

descloizite: 1.65(100), 3.20(80), 3.52(60), 2.28(60), 2.09 (60b), 1.79(60), 1.77(60) - A.S.T.M. 2-1364

mottramite: 1.64(100), 3.21(80), 2.84(80), 2.57(80)
A.S.T.M. 2-1368, 2-1369.

-color usually brownish red to blackish brown, also green. Transparent to nearly opaque, crystals often zoned; no cleavage, hardness about $3\frac{1}{2}$ S.G. about 6. Orthorhombic, biaxial negative, sometimes positive; fibres have negative elongation. Weakly to strongly pleochroic: canary-yellow to greenish yellow to brownish yellow. All indices over 2.17, 2V medium to large.

Doloresite
-Amer. Mineral., 42, 587 (1957)

-$H_8V_6O_{16}$ or $3V_2O_4 \cdot 4H_2O$

-Colorado Plateaus. Nearly black, submetallic lustre and greenish black streak. Normally shows a dark bronzy tarnish. Reddish yellow in very thin flakes. Slowly soluble in 1:1 HCl, yielding a green solution.

-Gray in polished section, variable in colour along the elongation of the crystals and shows selective absorption. Strongly anisotropic; lamellar twinning almost universal. HCl-slowly soluble; HNO_3-gives a blue solution; NH_4OH-no reaction; KOH-slightly soluble; KCN, $FeCl_3$ neg.

-Powder diffraction pattern: 4.70(100), 3.83(50), 2.45(50), 3.16(42), 1.933(25) are strongest lines.

-first published as "New Vanadium Oxide" in U.S.G.S. Bull. 1009-B, but with some differences in the properties given for doloresite.

Duttonite
-Amer. Mineral., 42, 455 (1957)

-$VO(OH)_2$

-Colorado. Occurs as crusts and coatings of pale-brown transparent platy crystals, as one of the first oxidation products of montroseite ore. Monoclinic, strongly pseudo-orthorhombic, biaxial positive, 2V about 60°, X=a, pale pinkish brown; Y=c, pale yellow-brown; Z=b, pale brown

-strongest lines of powder pattern: 4.40(100), 3.61(85), 1.838(21), 2.480(15), 2.454(15), 1.974(14), 2.64(13).

Fernandinite
-Dana System II, 1062
-Winchell and Winchell, 100

-$CaO \cdot V_2O_4 \cdot 5V_2O_5 \cdot 14H_2O$

-Massive, cryptocrystalline to fibrous, rarely in rectangular plates. Colour dull green. Opt.: light green to dark olive-green to brownish green and nearly opaque. Biref. strong. Mean index refraction about 2.05. Not pleochroic.

-Tests: easily soluble in acids to a green solution; sufficiently soluble in cold water to give a yellow solution.

Comment:
-Weeks and Thompson state that the chief difference between fernandinite and corvusite seems to be the presence of several percent of calcium in fernandinite and little or none in corvusite (see Dana System analyses: reported maximum CaO is 1.98% for corvusite versus average of almost 4% CaO for fernandinite). Electron diffraction studies by Ross (1959) indicated that fernandinite and corvusite are structurally similar.

A massive specimen of blackish-green fernandinite from Minasragra, Peru (ROM 12342) yields two different patterns. The pattern from slightly lighter-colored surface material of the specimen is identical to one of several types obtained from corvusite from Lewis Mines, Utah (ROM 20850). The bulk of the specimen gives powder data close to that listed by Weeks (Bull. 1009-B) for corvusite.

Fernandinite surface
ROM 12342

d	I
2.89	S
2.51	Wb
2.20	VF
2.07	VF
2.00	M
1.63	Mvb
1.48	MS
1.32	Wb
1.27	W
1.17	VW

Centre portion of film dark; possible line about 4.3 A°.

Massive fernandinite; two attempts.

d	I	d	I
3.51	10	3.52	10
3.36	½		
3.22	½		
2.82	2	2.82	4
2.68	1		½
2.54	½		
2.13	1		
		2.00	½
1.95	2	1.95	½
1.83	4	1.83	2
1.70	½		
1.63	1		
1.51	3	1.51	1
	½		
1.38	½		
1.33	1	1.33	½

The Menzies Bay fernandinite-like mineral is almost identical to the ROM fernandinite surface material.

Fervanite
-Bull. 1009-B
-Dana System II, 1049
-Am. Mineral., 16, 273 (1931)

-$Fe_4V_4O_{16} \cdot 5H_2O$

Colorado Plateau and Peru. Brilliant golden brown parallel fibrous aggregates. Probably monoclinic, slightly inclined extinction. Biaxial negative, 2V very small; nX 2.186, nY 2.222, nZ 2.224. As coatings and fracture fillings. Apparently insoluble in water.

-strongest lines of x-ray powder pattern: 6.46(S), 8.83(M), 2.94(M)

From Am.Mineral., graphic illustration, approximately 6.7(10), 4.40(8), 3.05(7), 3.50(6), 2.9(5), 8.0(5)

Gamagarite
-Winchell and Winchell, 189
-Amer. Mineral. 28, 329 (1943).

-$Ba_4(Fe,Mn)_2(VO_4)_4(.H_2O?)$

-In manganese ore, South Africa. Monoclinic, xls elongated along b; poor 001 and 100 cleavages. Hardness about 5, S.G. 4.62. Biaxial positive, 2V about 55°. Colour dark brown. Pleochroic red-brown to light salmon-buff.

Haggite
-Bull. 1009-B
-Acta. Cryst., 11, 56 (1958)

-Colorado Plateau. Closely related to doloresite and first mentioned in Bull. 1009-B as "Another new V mineral". Crystal structure given in Acta Cryst., but no properties. Orthorhombic. Formula is $V_2O_3 \cdot V_2O_4 \cdot H_2O$

Hewettite and Metahewettite - discussion

Confusion exists about the names hewettite and metahewettite, originally described (Hillebrand, Merwin, and Wright, 1914) as having different optical properties and dehydration properties but the same chemical formula, $CaO \cdot 3V_2O_5 \cdot 9H_2O$. The type specimens in the U.S.National

Museum have now dehydrated to $CaO \cdot 3V_2O_5 \cdot 3H_2O$ and give the same X-ray powder pattern. Investigation of vanadium ores from the Colorado Plateaus indicates at least two hydrates of calcium vanadate in nature, one with $9H_2O$ and one with $3H_2O$, but Weeks and Thompson (1009-B) have not found material with the optical properties given for metahewettite (Hillebrand et. al, loc. cit.). The natural vanadate with $9H_2O$ can be dehydrated readily in the laboratory with loss of $6H_2O$. During rehydration from the $3H_2O$ form to the $9H_2O$, an intermediate stage is observed (probably $6H_2O$). Although each of the hydrates has a distinct X-ray powder pattern, only the $3H_2O$ hydrate is abundantly found.

Barnes (1955), in a study of hewettite and metahewettite, found that X-ray powder patterns obtained from the dehydrated forms of these minerals are identical. On addition of water to the samples, the powder pattern changes but the final "constant" pattern frequently is not precisely the same (especially in the region of small 2θ values) for samples from different specimens, and even for the same sample after repetition of the dehydration-hydration cycle. No regularities, however, have been observed to suggest any basis for distinction between the behaviour of "hewettite" and "metahewettite"; the evidence indicates that they are structurally identical. Therefore, it was suggested by Barnes that the name "metahewettite" is unnecessary unless it be used to designate one of the hydrate phases.

A.D.Weeks (in Ross, 1959) suggests that the name metahewettite be used to designate the common $3H_2O$ hydrate phase. Therefore, in Weeks and Thompson Bulletin 1009-B (1954), the powder pattern listed for dehydrated ($3H_2O$) hewettite is now allocated to metahewettite. Since the optical properties given by Hillebrand, Merwin, and Wright (1914) have never been duplicated and no longer apply to their original metahewettite, it is suggested by the writer that the optical properties listed by Weeks and Thompson (1009-B) for hewettite now be applied to metahewettite.

In summary, the name metahewettite is applied, in accordance with Weeks (1959) suggestion, to the $3H_2O$ phase of the calcium vanadate. The optical properties given for the original metahewettite by Hillebrand, Merwin, and Wright, (1914) have not been duplicated and are consequently not retained. The optical properties listed by Weeks and Thompson in Bulletin 1009-B (1954) for hewettite, probably can be generally applied to the presently designated hewettite ($9H_2O$), and metahewettite ($3H_3O$). X-ray powder patterns should be used to distinguish between the two.

<u>Hewettite and Metahewettite</u> - properties

-Hillebrand, W.F., Merwin, H.E., and Wright, F.E., 1914, <u>Hewettite, metahewettite, and pascoite, hydous calcium vanadates</u>: Am. Phil. Soc. Proc., v. 53, pp. 31-54.

-Weeks, A.D., and Thompson, M.E., <u>Identification and Occurrence of Uranium and Vanadium Minerals From the Colorado Plateaus</u>, U.S. Geol. Surv. Bull, 1009-B, (1954).

-Barnes, W.H., 1959, "Hewettite" and "metahewettite", Am. Mineral., v. 40, nos. 7-8, pp. 689-693.

-Ross, M., Mineralogical applications of electron diffraction. II. Studies of some vanadium minerals of the Colorado Plateau, Am. Mineral., v. 44, nos. 3-4, pp. 322-341 (1959).

- $CaV_6O_{16} \cdot nH_2O$

-Monoclinic. Occurs as nodular aggregates and coatings of fibers. Colour deep red, less vivid on exposure in dry atmosphere. Biaxial negative; indices probably vary with water content; pleochroic light orange-yellow to dark red.

- strongest lines of x-ray powder pattern:

Metahewettite ($3H_2O$) : 8.2(VS), 3.06(M), 2.29(M), 2.20(M),

alternate : 8.1(S), 3.01(M), 1.80(W)

hewettite ($9H_2O$) : 11.12(VS), 5.59(M), 3.11(M), 3.69(M).

Comment:

Metahewettite from Jackpile Mine, New Mexico, gave strongest lines of 8.1, 3.09, 1.83.

Hugelite (huegelite)
-Winchell and Winchell, 191
-Dana System, II, 815

-vanadate of lead and zinc. Formula uncertain.

-crystals prismatic, laths. Color orange-yellow to yellowish-brown. Streak pale yellow. Biaxial positive, 2V small (for red); pleochroic red to blue. From Baden, Germany.

-needs verification.

Hummerite
-Bull. 1009-B

-$K_2Mg_2V_{10}O_{28} \cdot 16H_2O$

-Colorado Plateau. Bright orange with yellow streak. May develop greenish tint on exposure to sunlight. Lustre subadamantine, dulling on exposure. Water soluble. Finely crystalline aggregates or massive. Triclinic; biaxial negative, 2V large, Z c = 32°.

-strongest lines of x-ray powder pattern: 8.3(VS), 9.7(M), 2.76(M), 7.5(W).

Kolovratite
-Dana System II, 1048
-Min. Mag., 20, 290 (1925)

-a vanadate of nickel of uncertain composition

-Russian Turkestan. Occurs as yellow to greenish yellow incrustations and botryoidal crusts. Reported to be widely distributed in quartz schists and carbonaceous slates.

Kurumsakite
-Am. Mineral. 42, 583, (1957).

-$8(Zn,Ni,Cu) \cdot 4Al_2O_3 \cdot V_2O_5 \cdot 5SiO_2 \cdot 27H_2O$

-Greenish yellow to bright yellow vitreous to silky, finely felted fibers on the walls and in cavities in bituminous schists of Kara-Tau. Positive 2V about 35°, parallel extinction, positive elongation.

-strongest x-ray lines are: 1.53, 3.91, 2.61, 1.28 (A°, kX?)

Melanovanadite
-Bull. 1009-B
-Dana System II, 1058

-$2CaO \cdot 2V_2O_4 \cdot 3V_2O_5$

-Velvety, elongated, divergent bunches of crystals with prism faces usually rounded or striated. Colour black, streak reddish-brown. Perfect (010) cleavage. Hardness 2½. Biaxial negative with medium 2V; pleochroic from light to dark reddish brown.

-strongest lines of x-ray powder pattern: 8.5(VS), 4.21(S), 2.99(M).

-a specimen from Minasragra, Peru, gave strongest lines at 8.59(VS), 4.17(S), 2.97(MS), 2.73(M), 1.80(W), 2.62(W).

Minasragrite
-Winchell and Winchell, 92
-Dana System II, 437

-$(VO)_2H_2(SO_4)_3 \cdot 15H_2O$

-As a delicate efflorescence composed of minute crystals; also in granular aggregates, small mamillary masses or in spherulites. Color blue. Biaxial negative with medium large 2V; pleochroic colorless to deep blue. Easily soluble in cold water.

-Strongest lines of x-ray pattern: because of technical

difficulties, only a very poor pattern was obtained. The strongest lines are 5.28, 4.46, 3.93, 1.98 (all strong). From ROM 22213, Minasragra, Peru.

Montroseite
-Bull. 1009-B
-Am. Mineral., 38, 1235 (1953)

-Colorado Plateau. Microscopic bladed and prismatic orthorhombic crystals; also in compact crystalline aggregates. Submetallic lustre, color and streak black; opaque. Soft. Occurs in unoxidized ore; in oxidized zone alters to corvusite and metahewettite.

-strongest lines of x-ray powder pattern: 4.30(S), 2.65(S to M), 3.38 (M), 2.495(M), 2.216(M), 1.512(M).

Paramontroseite
-Am. Mineral, 40, 861.

-VO_2

-Montroseite is altered in the solid state to paramontroseite by oxidation. The process takes place readily as is shown by the transformation of montroseite to paramontroseite in specimens kept in the laboratory for a few months. Paramontroseite is itself unstable and is subsequently destroyed by weathering action and replaced by the corvusite type of minerals.

The structure of montroseite and paramontroseite is the same, but the former phase gives rise to a sharp diffraction pattern, whereas the paramontroseite diffraction pattern is diffuse. Because of the invariable partial oxidation, x-ray powder patterns generally contain both phases and are consequently multiple patterns.

Navajoite
-Amer. Mineral. 40, 207 (1955)
-Bull. 1009-B

-$V_2O_5 \cdot 3H_2O$

-Fibrous, silky, dark brown color, brown streak, soft. Biaxial neg., pleochroic yellowish brown to dark brown, parallel extinction.

-strongest x-ray powder pattern lines: 12.11(VS), 10.61(M), 2.90(M), 2.12(M), 5.79(Wb), 4.35(W), 3.53(W), 3.47(W), 3.10(Wb), 2.49(W), 1.99(W).

Nolanite
-Amer. Mineral. 42, 619 (1957)

-composition near $3FeO.V_2O_3 \cdot 3V_2O_4$

-From Beaverlodge area, Saskatchewan. Occurs as small, black, opaque, hexagonal plates with a submetallic lustre, usually intimately associated with another unidentified iron vanadium oxide mineral. Powdered nolanite is brownish black.

-hardness about 5. In polished section, pleochroic from dark brown to deep blue.

-strongest lines of x-ray powder pattern: 3.44(100), 2.66 (90), 2.49(90), 1.495(60), 4.66(55)

or

2.47(10), 3.43(6), 2.44(6), 1.503(6), 2.64(5), 1.962(4), 1.634(4).

Pascoite
-Bull. 1009-B
-Dana System II, 1055
-G.S.A. Bull., 65, 1249 (1954)

-$Ca_3V_{10}O_{28} \cdot 11H_2O$ (G.S.A.Bull).

-Peru and Colardo Plateau. Dark red-orange to yellow-orange granular crusts, rarely showing minute lathlike crystals with oblique terminations. Biaxial negative; pleochroism light cadmium yellow to orange. Soluble in water.

-strongest lines of powder pattern: 8.7(VS), 7.4(M), 9.4(W) 4.69(W).

Patronite
-Dana System I, 347

-a mixture

Pintadoite
-Dana System II, 1053
-Bull. 1009-B

-supposedly a light to dark green hydrated calcium vanadate.

-The description of pintadoite is so incomplete that apparently no more of the mineral can be recognized. Weeks and Thompson (Bull. 1009-B) could not obtain an x-ray pattern

from the National Museum sample of pintadoite which appears as a faint green stain on sandstone.

Comment:

Similar difficulty was encountered in an attempt to obtain x-ray diffraction powder patterns from "pintadoite" from Uranium Bell Mine, San Miguel Co., California (ROM 14317). The best material from this specimen gave a pattern containing many lines attributable to quartz.

Pucherite
-Dana System II, 1050

-$BiVO_4$

-Numerous localities. Massive, ocherous, or as coatings of minute crystals. Color dark brownish-red to reddish brown and yellowish brown. Streak yellow. Opaque to transparent. Both primary and supergene.

Pyrobelonite
-Dana System II, 815

-$MnPb(VO_4)(OH)$

-Longbar, Sweden. Color fire-red, resembling proustite. Lustre adamantine; streak orange-yellow or reddish; transparent. Habit acicular. Isostructural with descloizite-mottramite.

Roscoelite and Vanadium Hydromica
-Bull. 1009-B
-Am. Jour. Sci., 253, No. 1, 39 (1955)

-$(Al,V)_2(AlSi_3)(K,Na)O_{10}(OH,F)_2$ -hydromica contains less potassium and is more hydrated than roscoelite.

-Monoclinic. Habit massive. Colour green, gray, tan, brown. Basal cleavage present. Transparent if finely divided; birefringent. Impregnates sandstone and replaces clay pellets and stringers; in oxidized zone.

-strongest lines of x-ray powder pattern: 10.0(S), 3.34(S), 4.50(M), 2.59(M).

or

10.0(VS), 4.55(MS to S), 4.39(MW to VW), 3.66(S to M), 3.34(VS to S), 3.11(S to M), 2.69 (M to W), 2.60(MS to S), 2.42(M), 1.52(MS).

Rossite
-Bull. 1009-B
-Dana System II, 1053

-$CaV_2O_6 \cdot 4H_2O$

-Colorado Plateau. Glassy lumps surrounded by flaky alteration rims of metarossite; thin seams in sandstone or shale. Color yellow, lustre vitreous to pearly. Cleavage 010 good. Brittle. Hardness 2-3. Biaxial negative? 2V large; nX 1.71, nY 1.77, nZ 1.84. Soluble in hot water. Dehydrates readily to metarossite.

-strongest lines of powder pattern: 7.3(S), 6.66(S), 3.87(S).

Metarossite
-Bull. 1009-B
-Dana System II, 1054

-$CaV_2O_6 \cdot 2H_2O$

-A dehydration product of rossite. Soft and friable, platy to flaky masses in veinlets. Very light yellow to greenish yellow. Biaxial positive, 2V large; indices 1.840 and above. Soluble in hot water.

-strongest lines of powder pattern: 5.9(S), 5.1(S), 3.05(M).

Santafeite
-Amer. Mineral., 43, 623 (1958) abs.
-Amer. Mineral., 43, 677 (1958)

-$Na_2O \cdot 6(Mn,Ca,Sr)O \cdot 3MnO_2 \cdot 3(V,As)_2O_5 \cdot 8H_2O$

-Colorado Plateau. Occurs as an encrustation of small rosettes of acicular crystals on a limestone joint surface. Orthorhombic, with perf. (010) and distinct (110) cl., very brittle, S.G. 3.38, black with brown streak, subadamantine lustre, translucent only in very small fragments, pleochroic.

-x-ray powder pattern: strongest lines 14.88(10), 7.47(5), 2.702(5), 2.788(4), 1.667(4), 3.66(3), 3.39(3), 2.908(3), 2.607(3).

Satpaevite
-Amer. Mineral. 44, 1325 (1959) abs.

-$6Al_2O_3 \cdot V_2O_4 \cdot 3V_2O_5 \cdot 30H_2O$

-Russian. Occurs in the oxidation zone of vanadiferous clay-anthraxolite beds.

-Canary to saffron-yellow, occurring in floury aggregates of fine grains, but occasionally foliated and showing a perfect pinacoidal cleavage. Luster pearly on the cleavage, dull for fine-grained. Biaxial positive, 2V near 70°. Weakly pleochroic. Dissolves readily in dil. acids. Extinction parallel, orthorhombic.

-Occurs as veinlets and crusts in a decomposed tremolite-carbonaceous shale; associated with gypsum, steigerite, hewettite, and delvauxite.

-Strongest lines of powder pattern: 1.918-1.926(10), 2.330-2.336(9), 1.471-1.469(8), 3.905(7), 5.86(6).

Sherwoodite
-Am. Mineral., 43, 749 (1958)

-$Ca_3V_8O_{22} \cdot 15H_2O$

-Occurs as dark blue-black holohedral tetragonal crystals in many mines of the Colorado Plateau. Uniaxial neg., n_o= 1.765, n_e=1.735, dichroism strong, O green, E blue.

-strongest lines of x-ray diffraction pattern: 12.3(S), 10.00(S), 9.3(MS), 2.61(M), 2.10(Mb), 4.65(MW).

Simplotite
-Amer. Mineral. 42, 117, (1957), abs.
-Amer. Mineral. 43, 16, (1958)

-$CaV_4O_9 \cdot 5H_2O$

-Colorado Plateau. Occurs as dark-green micaceous plates and as hemispherical aggregates of plates, coating fracture surfaces in sandstone impregnated by relatively unoxidized vanadium and uranium minerals. Monoclinic, pseudotetragonal, biaxial neg., 2V about 25°, X= b yellow, Y green, Z c about 58° green.

-strongest lines of x-ray powder pattern: 8.51(100), 2.62 (25), 3.14(18), 4.26(9), 2.84(9), 3.42(6), 2.52(5).

Sincosite
-Winchell and Winchell, 204
-Dana System II, 1057

-$CaV_2O_2(PO_4)_2 \cdot 5H_2O$

-Peru, Colorado. Striated rectangular scales of thin plates usually aggregated; also as crudely radial aggregates and

small nodules. Color various greens. Cleavage present. Brittle. Hardness low. Streak green. Various greens in transmitted light; uniaxial negative, in part biaxial negative; both strongly pleochroic. Insoluble in water; readily soluble in dilute acids to a blue solution.

Steigerite
-Bull. 1009-B
-Dana System II, 1049

-$Al_2(VO_4)_2 \cdot 6\frac{1}{2}H_2O$

-Colorado Plateau. As canary-yellow pulverent coatings that are variously composed of cryptocrystalline fibrous material resembling chalcedony, gumlike masses, and occasionally flat plates. Lustre waxy in compact aggregates. Mean index 1.71. Insoluble in water; easily soluble in dilute acids to a deep cherry-red solution.

-x-ray data lacking. Even the artificial material gives few and faint diffractions.

Sulvanite
-Dana System I, 384

-Cu_3VS_4

-Color bronze-gold, streak black. Lustre metallic, tarnishing dull. Opaque. Hardness $3\frac{1}{2}$. Cleavage 001 perfect. In polished section cream-gold in color and isotropic, sometimes weakly anisotropic. Numerous localities.

-x-ray powder data available in A.S.T.M:
A.S.T.M. 3-0545: 3.12(100), 1.90(100), 2.41(80)
A.S.T.M. 3-0909: 2.40(100), 5.20(90), 3.11(90)
A.S.T.M. 2-1308: 1.91(100), 5.39(80), 3.11(80).

Tangeite
-Dana System II, 816
-U.S.G.S. Prof. Paper 320 (1959)

-Was shown to be identical with calciovolborthite by Strunz (in Dana, 1944). Tangeite is apparently being used instead of calciovolborthite (Prof. Paper 320: "...tangeite, formerly known as calciovolborthite...").

Turanite
-Dana System II, 818

-$Cu_5(VO_4)_2(OH)_2$

-Reniform crusts and spherical concretions with a radial fibrous structure. Color olive green. Hardness 5. Biaxial negative, 2V medium. nX 2.00 (brown), nY 2.01 (brown), nZ 2.02 (green). In cavities in limestone, Ferghana, Turkestan, U.S.S.R., Appears to be related to Mottramite.

Comment:

Turanite from Fergana Radium District, Russian Turkestan (ROM 14452) gives strongest x-ray lines of 2.88(100), 2.59(100), 5.83(85), 3.13(80), 4.11(70), 1.61(70), 1.73(65).

Unnamed Mineral
-Dana System II, 818

-The green unnamed Colorado mineral of Hillebrand (1924) is suggested by Guillemin (1955) to be vesignieite.

Unnamed Mineral
-Dana System II, 818

-Rosettes and patches of minute reticulated scales associated with volborthite. Birefringent with mean index of refraction about 1.92. A hydrated arsenate-vanadate of copper and calcium probably related to calciovolborthite. Utah.

Vanadinite
- Dana System II, 895
- Winchell and Winchell, 202

-A.S.T.M. 2-0708; 2.95(100), 3.00(80), 1.55(80).

Vanoxite
-Hess, U.S.G.S. Bull. 750d, 63 (1925)
-Dana Textbook 510
-Dana System, I, 601
-Bull. 1009-B, pp. 46-47.

-Weeks and Thompson (1009-B) report that the name vanoxite has been used for a variety of vanadium minerals. The composition of vanoxite had been calculated from a rock analysis of sandstone ore from the Jo Dandy mine, Colorado, after deducting quartz, gypsum, tyuyamunite, and limonite. The type specimen in the U.S. National Museum came from Wild Steer mine, Colorado, and was not analysed. X-ray powder

patterns of this type specimen are similar to those of corvusite and fernandinite.

It is suggested by Weeks and Thompson that the black crystals observed in thin sections (Hess, 1925, p.65) may have been montroseite.

Comment:

-A single x-ray powder diffraction pattern on material from a vanoxite specimen (Jo Dandy Mining Lode, Paradox Valley, Colorado; ROM 14669) gave a corvusite-like pattern.

Vesignieite
-Amer. Mineral., 40, 942 (1955) abs.

-$Cu_3Ba(VO_4)_2(OH)_2$

-Lamellar aggregates and polysynthetic twins with pseudohexagonal outline up to more than 0.5 mm. in diameter. Color yellow-green to dark olive-green, lustre vitreous. Cl. parallel to base. Biaxial negative, 2V about 60°. Hardness 3 to 4.

-strongest lines of x-ray powder pattern: 3.20, 2.71, 2.29.

-ROM 23096 specimen of volborthite from Paradox Valley, Colorado, does not give an x-ray pattern attributable to volborthite. The specimen deserves further investigation. The strongest lines are 3.209(10), 2.714(9), 2.557(8), 1.814(7), 1.484(6).

Volborthite
-Dana System II, 881
-Bull. 1009-B
-Amer. Mineral., 42, 444(1957)

-$Cu_3(VO_4)_2 \cdot 3H_2O$

-Uzbekite and vesbine have been discredited, being identical to volborthite. The mineral from the carnotite deposits of the Colorado-Utah region commonly identified as calcio-volborthite is tentatively described by Dana (1944) as volborthite. The distinction between volborthite and calcio-volborthite is not well established.

-No additional properties available other than those listed by Dana, and this paper.

Comment:

-Volborthite from Hartzel, Park County, Colorado, calcio-

volborthite from Paradox Valley, Montrose County, Colorado, (ROM 13414), volborthite from Menzies Bay, and volborthite or calciovolborthite from Ruwe, Katanga all yield identical x-ray powder patterns. The five strongest lines listed by Weeks and Thompson (Bull. 1009-B) are identical for both minerals.

-The Menzies Bay volborthite has an unusually low index of refraction. nY was determined as being approximately 1.837 and was independently verified by J.H. Montgomery and W.D. Tedlie. The mineral is biaxial negative, with r less than v. Although this data is not in general agreement with Dana (1944), there is much variation in properties in the literature. Larsen and Berman (1934) also show the mineral as having variable indices. Recent chemical analyses are lacking; those reported are from impure material.

The following ROM minerals were studied:

Calciovolborthite, Paradox Valley, Montrose Co. Colo.	M 13414
Chalcoalumite, Bisbee, Arizona	M 14464
Corvusite, with carnotite, Lewis Mines, Utah	M 20850
Devillite, Herrungrund, Hungary	M 21777
Fernandinite, Minasragra, Peru	M 12342
Glockerite, Kupferberg, Silesia	E 3040
Kroehnkite, Chuquicamata, Chile	M 11190
Langite, Cornwall England	M 18730
Leightonite, Chuquicamata, Chile	M 19356
Minasragrite, on patronite ore, Minasragra, Peru	M 22213
Pintadoite, Uranium Bell Mine, San Miguel Co. Calif.	M 14317
Turanite, with volborthite, Fergana Radium Dist. Russian Turkestan	M 14452
Vanoxite, Joe Dandy Mining Lode, Paradox Valley,Col.	M 14669
Volborthite, Paradox Valley, Colorado	M 23096
Woodwardite, Cornwall, England	M 12857

Calciovolborthite was found to be identical to the Menzies Bay volborthite. The Colorado volborthite is an unidentified mineral (see vesignieite). The specimen labelled devillite gave patterns for brochantite and malachite (herringrundite).