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**The Geology Of The Burnt Hill Area
and Ore Controls of the
Burnt Hill Tungsten Deposit**

by

Ralph Richard Potter

**A thesis submitted to the Faculty of Graduate Studies
in partial fulfilment of the requirements of the
degree of Doctor of Philosophy**

The undersigned hereby recommend to the Faculty of
of Graduate Studies acceptance of this thesis, submitted by
Ralph Richard Potter, B.Sc., M.Sc., in partial fulfilment of
the requirements for the degree of Doctor of Philosophy.

.....
Chairman, Department of Geology

.....
Supervisor

.....
External Examiner

ABSTRACT

Burnt Hill is situated in central New Brunswick near the middle of a northwest striking belt of Ordovician geosynclinal sedimentary and volcanic rocks. Two sequences of strata have been recognized: (1) - an Early to Middle Ordovician conglomerate-sandstone-chert sequence; which is conformably overlain by (2) - a Middle Ordovician or younger greywacke-quartzite-argillite sequence. The argillites and quartzites are host rocks for quartz veins with wolframite, molybdenite, cassiterite and other minerals.

All strata strike northeast, are overturned and dip 70 - 80 degrees to the northwest. A large strike fault, the Tom McKiel fault, has been interpreted to cross the middle of the area and separates an overturned anticline to the west from an overturned syncline to the east. The folded rocks were intruded by coarse grained, porphyritic quartz monzonites of Early Devonian age. The argillaceous rocks were metamorphosed and porphyroblasts of biotite, andalusite and cordierite were developed near the contact with these quartz monzonites. A younger equigranular quartz monzonite was intersected about 600 feet below the Burnt Hill tungsten deposit and is believed to have produced a semi-circular zone of retrograde chlorite about 6000 feet in diameter. Nearly all the mineralized veins are located within this zone.

The complex system of faults and joints containing mineralized veins were formed after the retrograde metamorphism. Fractures striking 100 - 120 degrees were filled with quartz-muscovite veins with minor wolframite, molybdenite, fluorite, beryl and cassiterite (375 - 370 m.y.). Faults developed later in the 140

degree direction and re-opened many of the earlier fractures and formed new ones striking 120 - 140 degrees. These were filled with quartz-topaz veins with wolframite, Mo, Fe, Cu, As, Zn and Pb sulphides, beryl, fluorite, cassiterite and native bismuth. Composite veins are common. The 140 degree faults and later unmineralized faults and joints may have been produced by slight wrench movement on the Tom McKiel fault.

A study of similar deposits elsewhere in the Canadian Appalachian region indicates that all are associated with Early Palaeozoic pelitic sedimentary rocks and/or Devonian granitic batholiths. A direct relationship to either one could not be confirmed at Burnt Hill. It is postulated that most of the W, Mo and Sn were derived from the Ordovician strata which were incorporated by the Devonian quartz monzonites. These elements were concentrated in a marginal or near-roof phase that was assimilated by the younger equigranular quartz monzonite. They were concentrated within this intrusive until the area was fractured and wolframite, molybdenite, cassiterite and other minerals were emplaced as the last phase of a single Devonian magmatic event.

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chapter 1

INTRODUCTION

The Burnt Hill area is situated in central New Brunswick. It is underlain by deformed Ordovician sedimentary rocks that have been intruded by Devonian granitic batholiths and stocks. Quartz veins with W, Mo and Sn minerals occur in the region.

The geology was first described by Robb (1870) and Bailey (1885). Young (1918) examined the region around Burnt Hill and studied the tungsten deposit. Poole (1963a) mapped the Hayesville area for the Geological Survey of Canada on a scale of one inch to one mile, and was the first to outline in detail the lithology and structure of the lower Palaeozoic rocks of this area. The geology of the immediate mine area was described by Wright (1940) and by Tupper (1955). The mineralogy of the Burnt Hill Tungsten deposit has been investigated more recently by Victor (1957).

PURPOSE AND SCOPE OF INVESTIGATION

The objective of this project is to determine the factors controlling the localization, mode of emplacement and possible genesis of the veins in the Burnt Hill area. This will be accomplished by:

- (1) - Describing the geology of the Burnt Hill Tungsten deposit and vicinity in detail by:
 - (a) - studying the stratigraphy and petrology of Ordovician strata

- (b) - examining and describing the igneous rocks and working out their emplacement history
 - (c) - relating metamorphism to intrusion.
- (2) - Studying the structural development of the area
- (a) - folds, their geometry and significance
 - (b) - faults, their direction, age, movement and relation to regional structure
 - (c) - joints, direction, age, relation to faults and to strata in which they occur, significance with respect to mineralized veins.
- (3) - Studying the mineralized veins
- (a) - their mineralogy
 - (b) - reasons for variations in size, orientation and relative ages
 - (c) - mineralogical variations within veins with respect to structures and/or host rocks.
- (4) - Geochemical studies on host rocks and granites to provide data on possible source of vein minerals.
- (5) - A metallogenic analysis to determine the geological factors common to all W, Mo and Sn deposits in the Canadian Appalachian region.

This dissertation summarizes the results of field work conducted in 1960, 1967 and 1968 and laboratory investigations in 1963 and 1964. Most of the field time was spent mapping an area of approximately 25 square miles in the central part of the Hayesville (21-J/10) map-area (Poole, 1963a) on a scale of one inch to 500 feet.

The accessible underground workings of the Burnt Hill Tungsten mine were mapped on a scale of one inch to 50 feet.

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The field work was supported by the Geological Survey of Canada, and the writer is indebted to this organization for help with many aspects of the work.

Most of the thin sections were prepared by the Geological Survey of Canada. Special thanks are due to W. Yzerdraat of Carleton University who prepared polished sections and thin sections of vein minerals. The help of R. Levick, who prepared the synthetic wolframite standards is gratefully acknowledged. Chemical analysis of rocks were carried out by the Geological Survey. Trace W, Mo and Sn determinations were made by Bondar-Clegg and Co. Ltd.

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This thesis was prepared under the direction of W. M. Tupper and F. K. North, of Carleton University, and W. H. Poole of the Geological Survey of Canada.

LOCATION AND ACCESSIBILITY

The Burnt Hill area is situated in central New Brunswick, near the junction of Burnthill Brook and the Main Southwest Miramichi River. It may be reached by gravel road from Maple Grove on the Canadian National Railway line between Chipman and Juniper. Access to the area from the north side of the Main Southwest Miramichi River is gained by another gravel road from Holtville, a small settlement northwest of Boiestown, New Brunswick (Figure 1, in pocket).

A road has recently been constructed from Napadogan station to join the road from Maple Grove two miles south of the map-area.

TOPOGRAPHY AND GLACIATION

The Burnt Hill area is situated within the Central (or

Miramichi) Highlands of New Brunswick (Weeks, 1957). This highland area is gently undulating, the average elevation being between 1,000 and 2,000 feet. The Main Southwest Miramichi River flows through the middle of the map-area in an easterly direction. This river and its tributaries form valleys between 500 and 950 feet deep. The larger tributaries, including Burnthill, Clearwater, and Sisters Brooks, flow southeasterly.

Most of the area is covered by several feet of glacial drift. Erratics are common, and many large boulders have been derived from the granitic terrain to the west. Fluvial sand was noted on a small terrace near the mouth of Burnthill Brook, but no similar deposits were observed elsewhere.

The area is forest covered. Deciduous trees are abundant in areas burned by a forest fire more than 50 years ago. Large outcrops are abundant in the burned-over areas, but elsewhere good exposures occur only along the Miramichi River and the lower parts of its tributaries. Outcrops are also common near the crests of larger hills.

chapter II

REGIONAL GEOLOGY

The Burnt Hill area is underlain by steeply dipping quartzose and argillaceous sedimentary rocks of Ordovician age (Figure 1 in pocket). All strata were folded during the Acadian orogeny (Neale and others, 1961), and the region was intruded by granitic batholiths of Devonian age.

Ordovician sedimentary rocks of this area were deposited during the geosynclinal stage of development of the Appalachian folded belt (McCartney and Potter, 1962). Strata of similar age, but with more abundant volcanic rocks occur to the northeast (Figure 2), and include the Tetagouche Group (Skinner, 1956). Silurian and Devonian sedimentary and volcanic rocks occur to the west and northwest (Anderson, 1962; Potter, 1965). Silurian greywackes have been mapped to the southeast, and are unconformably overlain by conglomerates and sandstones of Carboniferous age (Anderson and Poole, 1959).

The Ordovician formations (Table I) will be described with particular emphasis on their petrology, provenance, and environment of deposition. The stratigraphic succession presented here differs from that proposed by Poole (1963a). Both interpretations are discussed at the end of this chapter.

SEDIMENTARY ROCKS (Ordovician)

Ordovician strata comprise a sequence of argillites, cherts, sandstones and conglomerates overlain by carbonaceous grey-

TABLE 1: TABLE OF FORMATIONS				
PERIOD OR EPOCH	ROCK UNITS (THICKNESS IN FEET)	MAP UNIT	LITHOLOGY	
CENOZOIC	PLEISTOCENE	UNCONSOLIDATED DEPOSITS (0-100)		TILL, SAND, GRAVEL
PALAEZOIC	EARLY TO MIDDLE DEVONIAN OR YOUNGER	VEINS	7c	QUARTZ, TOURMALINE, WOLFRAMITE, PYRITE, PYRRHOTITE, CHALCOPHYRITE, ARSENOPYRITE, SANGERITE, MOLYBDENITE, FLUORITE, BERN, AMYNTALE, ENNITE, CASITERITE.
			7b	QUARTZ, MOSCOVITE, BERN, MOLYBDENITE, WOLFRAMITE, FLUORITE, PYRITE, SANGERITE, ORSOLITE.
			7a	QUARTZ, PYRITE, PYRRHOTITE (MAY BE OLDER)
	EARLY DEVONIAN	MINE QUARTZ MONZONITE	6c	MEDIUM GRAINED EQUIGRANULAR ENTIRE QUARTZ MONZONITE
		BURNTHILL QUARTZ MONZONITE	6b	POPHYRITIC, BIOTITE QUARTZ MONZONITE
		CLEARWATER QUARTZ MONZONITE	6a	COURSE GRAINED BIOTITE QUARTZ MONZONITE
	ORDOVICIAN OR YOUNGER		5	DIVERSE
		MARATHON FORMATION (6500+)	4	INTERBEDDED ARGILLITE AND QUARTZITE
	MIDDLE AND LATE ORDOVICIAN	PULP AND BE-DAMMED FORMATION (5000+)	3	CARBACEOUS CRYSTALLINE ARGILLITE, QUARTZ WACK
		HYDEN LAKE FORMATION (1300)	2	DARK GRAY, MAROON AND GREEN CHERT AND ARGILLITE, MINDOR GRAY ARGILLITE
	MIDDLE ORDOVICIAN AND OLDER	BUTTERMILK BECK FORMATION (800+)	1	GRAY-GREEN SLTSTONE ARGILLITE, SANDSTONE AND CONGLOMERATE

wackes, quartzites and argillites. They may be subdivided into four major stratigraphic units (Table I), to which the informal names Buttermilk Brook, Hayden Lake, Push-and-be-Damned, and Miramichi Formations have been applied. Age relationships and correlations are based on lithology, structure, and on fossil localities in similar strata outside the map-area.

BUTTERMILK BROOK FORMATION (map-unit 1)

The name of this formation is derived from Upper Buttermilk Brook which is located approximately 2000 feet west of the ridge on which this unit is exposed. The thickness of this formation is not known, but is interpreted to be approximately 800 feet.

Grey-green conglomerate with clasts of quartz sandstone, quartz siltstone, and laminated quartz siltstone is common in the lowermost exposed parts of the unit.

The coarse clastic beds are composed of closely packed subangular to subrounded rock fragments (locally > 4 cm) in a matrix of fine sand and silt (Plate 1 a, b). Fragments of quartz sandstone are most abundant, and constitute as much as 35 per cent of the rock. They are composed of small (approximately 0.1 mm) grains of quartz in a matrix of pale green chlorite and quartz. Sodic plagioclase, chert and opaque minerals constitute less than one per cent of these fragments. Clasts of quartz siltstone form nearly 30 per cent of these conglomerates. Fragments of finely laminated quartz siltstone are not abundant, and probably constitute less than 5 per cent of the total detrital grains.

Sandstones and siltstones in the upper part of this unit have a distinctive grey-green colour and are poorly sorted.

Plate 1a - Hand specimen of conglomerate, Buttermilk Brook Formation (1). Note pebbles of quartz sandstone.

Plate 1b - Thin section of conglomerate, Buttermilk Brook Formation (1). Note well rounded quartz sandstone clasts in matrix of quartz grains and quartz-rich sedimentary rocks.

Subrounded clasts up to 1.0 cm may be observed within outcrops of massive siltstone.

Strata of this map-unit strike northeast, dip 70-80 degrees to the northwest and are overturned. The lowermost beds are bounded by a large strike fault that has been mapped across the area (the Tom McKiel fault). The formation is conformably overlain by cherts and argillites of the Hayden Lake Formation (2). There is no field evidence to suggest large scale folding or faulting within the Buttermilk Brook Formation.

This map-unit is correlated with the argillites and quartzites which underly cherts to the east at Lower Birch Island (Poole, 1963a). Brachiopods from this locality and from similar strata to the southeast (Anderson and Poole, 1959) have been correlated with fauna of the Shin Brook Formation in Maine (Neuman, 1964 and personal communication, 1968; L. M. Cumming, personal communication, 1965) to which an Arenig-Whiterock* age has been assigned.

HAYDEN LAKE FORMATION (map-unit 2)

This Formation is best exposed on the ridge approximately 4500 feet west of Hayden Lake. The presence of angular fragments of maroon chert in the soil 2500 feet south of Hayden Lake suggests another belt of this unit occurs to the east. The thickness of this formation is estimated to be about 1300 feet.

Maroon and green cherts and argillites constitute about 25 per cent of this map-unit, and are restricted to the lowermost

* Stages below Whiterock have not been named in North America.

600 feet. Their distinctive colour, hardness, and manganese stained bedding surfaces make them an excellent marker bed.

Carbonaceous cherts and argillites are restricted to the upper part of this formation. They are dense, hard, and locally cut by numerous quartz veinlets. The surface is silvery grey, due to the development of sericite. Highly sheared equivalents, such as those north of Tom McKiel Brook are soft and fissile, and minute flakes of graphite occur along cleavage planes. Primary structures such as fine laminations are common and individual beds of white chert (up to 4 inches thick) have been observed in several areas.

Thin beds of grey and green-grey argillite occur throughout the Hayden Lake Formation, but are most abundant in the uppermost 500 feet. They resemble the argillaceous rocks of the underlying Buttermilk Brook Formation (1).

Strata of the Hayden Lake Formation (2) conformably underlie carbonaceous greywackes and argillites of the Push-and-be-Damned Formation (3). They strike northeast and appear to be overturned to the southeast. This map-unit is correlated with similar strata to the east (map-unit 2f; Poole, 1963a) where graptolites have been found and a middle and (?) late Ordovician age has been assigned by L. M. Cumming.*

PUSH-AND-BE-DAMNED FORMATION (map-unit 3)

The name of this map-unit is derived from the salmon

* Unpublished report of the Palaeontology Section, Geological Survey of Canada.

fishing pool on Southwest Miramichi River, three miles above Burnt Hill Brook. Many large outcrops occur near this pool, and for several thousand feet downstream. Rocks of this formation form two northeasterly striking belts flanking the map-area (Figure 1). A minimum thickness of 5000 feet has been estimated.

WESTERN BELT

Strata are overturned and dip 70-80 degrees to the northwest. The belt appears to form the eastern limb of a northeasterly trending overturned anticline whose axis is about one mile to the west of the thesis area. The base of the unit was not observed in the western belt, but a conformable contact with the overlying argillites and quartzites of the Miramichi Formation (4) was noted on the north side of a small hill, 1500 feet north-northeast of the mouth of 2½ Mile Pond Brook.

Rocks of the western belt are carbonaceous and dark grey to black in colour. Conglomerates and greywackes* are most abundant near the base but more than 80 per cent of the unit consists of sandstones, siltstones and argillites. The conglomerate-greywacke beds vary in thickness from a few inches to several feet. Graded bedding and poor sorting are typical, and the size of the detrital fragments varies from more than 10 mm at the base to less than 1 mm at the top. The bottom is generally well defined and the contact with the underlying fine material is smooth and sharp. In places, coarse clastic material scoured several centimetres into the underlying argillaceous strata.

* Greywacke (and quartz wacke, P.14) used in this report are field terms based on classification of: Turner, Williams and Gilbert (Petrography, Freeman & Co.) 1954. Modal analyses indicates the former are subfeldspathic lithic wackes.

In thin section, the coarse conglomeratic beds consist mainly of subangular to subrounded fragments of quartz, quartzite, quartz sandstone, chert, argillite, feldspar, diabase and felsic igneous rocks in a carbonaceous and argillaceous matrix (Plate 2a, b). Modal analyses of several typical rocks from this unit are shown on Figure 3.

EASTERN BELT

Dark grey carbonaceous greywackes, conglomerates, sandstones and siltstones which occur at the base of the eastern belt (just below Tom McKiel Brook) closely resemble the rocks of the western belt. Thin sections show they contain fewer fragments of igneous rocks, argillite, and feldspar (Figure 3). They are in general finer grained (Plate 3a, b).

Grey quartz wackes and siltstones predominate in the upper part of this unit. These quartzose rocks generally contain less carbonaceous material (Plate 4a, b) than the underlying strata and are lighter coloured. Graded bedding is difficult to observe but in general primary structures are similar to those in the underlying rocks within this map-unit. Although included with the Push-and-be-Damned Formation, these quartz wackes and siltstones resemble, and may, with more detailed work, be correlated with argillites and quartzites of the Miramichi Formation (4).

The contact between the Push-and-be-Damned Formation (3) and the underlying cherts and argillites of the Hayden Lake Formation (2) is both gradational and conformable. The base of the Push-and-be-Damned

Plate 2a - Thin section, typical carbonaceous greywacke of Push-and-be-Damned Formation (3)(western belt). Note varied lithology of clasts and streaks of graphite.

Plate 2b - Thin section, interbedded sandstone and siltstone Push-and-be-Damned Formation (3)(western belt).

WESTERN BELT

EASTERN BELT

NOTE: GREYWACKS ARE SUCCEDANEOUS LITHIC WACKS (SEE FOOTNOTES, PAGE 13)

FIGURE 3: MINERAL ANALYSES OF SEDIMENTARY ROCKS FROM PUGH AND DE-
GRAINED FRACTIONS, EASTERN AND WESTERN BELTS

Plate 3a - Thin section, sheared siltstone of Push-and-be-Dammed Formation (3)(eastern belt). Note ovoid knots, streaked graphite and lithic fragments.

Plate 3b- Thin section, carbonaceous greywacke, Push-and-be-Dammed Formation (3)(eastern belt). Note large number of quartz clasts

Plate 4a - Quartz wacke and siltstone of Push-and-be-Damned Formation (3)(eastern belt). Note scouring by fine siltstone.

Plate 4b - Thin section, quartz wacke of Push-and-be-Damned Formation(3)(eastern belt). Note large number of angular quartz clasts, poor sorting and high percentage of matrix.

Formation (3) is fixed arbitrarily within the grey-green argillites near the top of the Hayden Lake Formation (2) that contain interbeds of dark grey, pyritic, carbonaceous cherts and argillites.

No fossils have been found within the Push-and-be-Damned Formation, but graptolites have been collected in similar strata to the northeast on Clearwater Brook (Poole, 1963a). According to L. M. Cumming* a Llandeilo-Bala age is indicated. This is similar to the age assigned to the Hayden Lake Formation (2) equivalents, and is compatible with stratigraphic interpretations presented here.

THE MIRAMICHI FORMATION (map-unit 4)

Argillites and quartzites of this formation form a wide ($\frac{1}{2}$ mile) belt which strikes northeast across the central part of the map-area (Figure 1). The best exposures were found on Miramichi River, from which the name of this unit was derived. Excellent outcrops were also mapped on many small brooks, on the western flank of Burnt Hill and north of the Burnt Hill fishing club. These rocks form the host for most of the mineralized quartz veins in the area.

The Miramichi Formation (4) consists of interbedded argillaceous and quartzose strata (Plate 5a) and is estimated to be 6500 feet thick. Primary structures such as graded bedding, fine laminations and minute cross beds can be seen in most outcrops. Quartzites and argillites are intergradational, and intermediate lithologies are common.

Argillaceous strata constitute approximately 90 per

* Unpublished report of the Palaeontology Section, Geological Survey of Canada.

cent of this formation. They are grey-blue to grey-green, fine grained, and very soft. Light coloured laminae of sand and silt size particles commonly occur, and are easily observed in outcrop.

In thin section, these rocks consist of cloudy argillaceous material, converted by metamorphism to a mass of sericite laths 0.03 to 0.05 mm (Plate 5a). Irregular and subhedral graphite, pyrite and magnetite constitute as much as 5 per cent of some rocks.

Quartzite beds several feet thick are most abundant near the base of this unit. They are in almost all cases separated by variable thicknesses of argillite and/or argillaceous quartzite (Plate 5a). The quartzites decrease in abundance and thickness towards the top of the unit, and rarely occur within the uppermost 1500 feet.

Beds of quartzite are lenticular, and have not been traced for more than a few feet along strike. They are grey to grey-green and contain innumerable anastomosing veinlets of quartz (Plate 6a). In thin section, the quartzite consists of an interlocking mosaic of irregular sand and silt size quartz fragments in an argillaceous-quartzose matrix (Plate 6b). They are quartz arenites (Turner, Williams and Gilbert, P. 13). Boundaries of the grains are highly sutured, and inclusions of sericite are common.

Like other Ordovician rocks of the area, this map-unit strikes northeast, and is steeply overturned to the southeast. The contact between the Miramichi Formation (4) and the underlying Push-and-be-Damned Formation (3) is sharp and conformable. The uppermost beds are in fault contact with strata of the Buttermilk Brook Formation (1). A few minor folds have been observed, but the absence of distinctive marker beds precludes any precise interpretation of the

Plate 5a - Interbedded quartzite, argillite and argillaceous quartzite of Miramichi Formation (4).

Plate 5b - Thin section of argillite, Miramichi Formation (4).
Note fine sericite oblique to bedding. Dark coloured areas are limonite stain.

Plate 6a - Thick quartzite bed typical of Miramichi Formation (4).
Note anastomosing quartz veinlets.

Plate 6b - Thin section, quartzite, Miramichi Formation (4).
Note poor sorting of quartz clasts.

internal structure of this unit. A contorted zone with minor folds were observed on Southwest Miramichi River, approximately 3000 feet east of 2½ Mile Brook, but is probably related to cross-faults with apparent right-lateral displacement.

No fossils were found in strata of this map-unit. As a conformable contact was observed with the underlying Push-and-be-Dammed Formation, a Late Ordovician or younger age has been assigned.

IGNEOUS ROCKS

DIABASE (Map - unit 5)

Eight lenticular masses of diabase have been mapped within a narrow northeasterly trending zone across the central part of the map-area (Figure 1). Diabasic rocks also occur to the northwest near the road to 2½ Mile Pond.

The largest mass in the central part of the area has been traced for more than 8,000 feet, and has a maximum thickness of 1,320 feet.

Rocks of this map-unit are commonly grey-green, fine to medium grained, and very tough. Many outcrops are cut by numerous irregular pink-brown veinlets of epidote and contain small ovoid masses of epidote, quartz and calcite.

Plagioclase constitutes about 22 per cent of these rocks. Randomly oriented laths of this mineral (0.5 mm to 20 mm) occur in all thin sections, and are partly enclosed by amphibole (Plate 7a, b). Extinction angles indicate a composition in the An₁₀ to An₂₀ range.

Amphibole (up to 60 per cent) is green and strongly pleochroic. It is optically negative with a high 2V (more than 60 degrees) (anthophyllite?). In places, this mineral appears to be an alteration of pyroxene (hypersthene?).

Other minerals present in minor amounts include: quartz, epidote, chlorite, and opaque.

Rocks of this map-unit are distributed in a narrow zone within and parallel to the Tom McKiel fault. They are interpreted to be mainly sills or dykes for the following reasons:-

- (1) close spatial relationship to the Tom McKiel fault, suggesting extrusion or intrusion along this zone of structural weakness;
- (2) no conclusive primary structures within the map-area indicative of a volcanic origin;
- (3) texturally these rocks are fine to medium grained and diabasic. Coarse grained varieties are also present. Parallel and sub-parallel zones of different textures suggest multiple intrusion and or differentiation. Garnets have been recognized in the contact aureole of these rocks suggesting therefore a slightly higher grade of metamorphism.
- (4) rocks of this unit are not restricted to one stratigraphic horizon, and in this narrow zone have been emplaced within all map-units.
- (5) there is little stratigraphic evidence for volcanic activity near the diabasic rocks in the Burnt Hill area, even though Poole (personal communication, 1964) believes pillowed extrusive rocks occur four miles to the northeast. It is possible that the

Plate 7a - Thin section, diabase, (5). Note highly altered laths of plagioclase in groundmass of amphibole and chlorite.

Plate 7b - Thin section, diabase, (5) (northwestern part of map-area). Note large subhedral laths of plagioclase.

basic rocks at Burnt Hill are younger and unrelated to these flows.

The age of the diabasic rocks is not known. The metamorphic grade attained within them is comparable to that of the enclosing sedimentary rocks of the region and they were probably metamorphosed contemporaneously. They are Late Ordovician or younger and pre-date the Early Devonian granitoid rocks (6).

Similar rocks which have been mapped in the northwestern part of the area appear to be less metamorphosed even though they are close to the granitoid batholiths. They may be younger but have been included with this map-unit until more definite age relationships are established.

BATHOLITHIC GRANITOID ROCKS (map-units 6 a, b, c)

Much of the geanticlinal area of central New Brunswick (Figure 2) has been intruded by large granitic batholiths, mostly of Devonian age (Neale and others, 1961). Recent absolute age determinations (Poole, Kelley and Neale, 1964) have shown that older intrusive events have affected the area, but the exact distribution of these older rocks has not been determined. The Burnt Hill area includes an apophysis of a large batholith on the west, and the western extremity of the Trout Lake stock to the east (Figure 1).

Three types of granitic rocks occur in the vicinity of the Burnt Hill tungsten deposit. A coarse to medium-grained porphyritic biotite quartz monzonite (6a) occurs in the extreme northwestern part of the map-area. A porphyritic biotite quartz

monzonite (6b) crops out along Burnthill Brook, and a homogeneous, fine-grained equigranular biotite quartz monzonite (6c) was intersected in diamond drill-holes beneath the Burnt Hill tungsten deposit. These three types will be described separately. Dykes composed of muscovite and quartz which have been termed greisen by Wright (1940) were mapped within the area but will be described in chapter 4.

CLEARWATER BIOTITE QUARTZ MONZONITE (6a)

The only outcrops of this unit within the Burnt Hill map-area occur along the Miramichi Lumber Company road, between Burnthill Brook and 2½ Mile Pond Brook. The general distribution can be determined from the presence of angular fragments in the glacial drift. These rocks are similar to the coarse-grained biotite quartz monzonite mapped to the north by Poole (1963a, unit 8b).

Rocks of this map-unit are variable in texture: fine to coarse-grained, and both equigranular and porphyritic. The coarse-grained porphyritic varieties appear to predominate. They are pink to buff, and weather light grey to white. They are massive and contain no recognizable lineation or foliation. A near horizontal sheeting is common.

In thin section, this rock consists of mosaic of unoriented plagioclase laths, idiomorphic against, and in places completely enclosed in larger subhedral masses of alkali feldspar (Plate 8). The size of the major constituent minerals varies considerably, from 1-30 mm, but averages about 3 mm. The texture

Plate 8 - Thin section, Clearwater quartz monzonite (6a). Note sericitized feldspar phenocrysts.

is typically hypidiomorphic granular.

On the basis of modal analyses of three representative specimens, alkali feldspar constitutes 32 per cent of this rock. This mineral forms large masses (phenocrysts?) up to 30 mm, or irregular anhedral grains enclosing, and interstitial to, plagioclase laths. Several varieties of alkali feldspar are present: (1) large untwinned masses with patchy extinction ($2V=30-40$), (2) microcline with well developed grid twinning, and (3) perthitic intergrowths with plagioclase. Most grains are clear, but small selvages of biotite and muscovite are common.

Plagioclase averages 35 per cent of the rock. Well formed euhedra are common and average a few millimetres in length, with some up to 9 mm occurring rarely. Albite, Carlsbad and Pericline twins were noted, and extinction angles indicate an albite-oligoclase composition. Many of the cores are sericitized, and twin lamellae are locally bent. Both normal and reverse zoning were noted.

Quartz constitutes approximately 27 per cent of this rock, and forms irregular anhedra up to 5.0 mm in diameter. It encloses all other minerals, and forms embayments in feldspar. Granophyric intergrowths were noted. Most grains show undulose extinction and contain fine dusty inclusions.

Biotite forms plates up to 2 mm in diameter. Most are red brown in colour and strongly pleochroic. Others are dark brown, and only slightly pleochroic. Irregular masses of opaque material are common, and dark pleochroic haloes occur around zircon euhedra. Small prisms of apatite were also noted, and appear to be confined entirely to the biotite.

Muscovite is not abundant, and rarely forms individual grains. It forms parallel intergrowths with biotite, and in a few places, plumose masses interstitial to other minerals.

Chlorite occurs along the ragged edges of biotite flakes, and appears to be an alteration product. Some chlorite possesses anomalous blue interference colours.

The relationship between map-unit 6a and the Ordovician strata was not observed in the northwestern part of the map-area, but was noted in rocks identical to 6a 2250 feet east of Deadman Brook. There, the contact is sharp and well defined.

An age of 339 ± 25 m.y. (Mississippian) has been obtained on a quartz monzonite (similar to 6a) from Clearwater Brook approximately 4 miles northeast of the Burnt Hill area (Poole 1963b). This, and absolute age determinations from other rocks in the area are discussed at the end of this chapter.

TROUT LAKE QUARTZ MONZONITE

The western part of the Trout Lake granite (Poole, 1963) underlies the eastern part of the map-area. It is exposed on the north bank of Southwest Miramichi River below Deadman Brook. Some angular fragments and one outcrop was noted on the hills east of Deadman Lake.

In general, these rocks are similar in mineralogy and texture to those of map-unit 6a, but certain parts resemble the Burnthill quartz-monzonite (6b).

BURNTHILL BIOTITE QUARTZ MONZONITE (6b)

This map-unit consists of a fine to medium-grained equigranular to porphyritic biotite quartz monzonite. Good exposures occur along Burnthill Brook, and large angular blocks have been noted on nearby hills. A small outcrop area also occurs on the Southwest Miramichi River, approximately 1600 feet above the mouth of Burnthill Brook. The configuration and outcrop pattern indicate that the roof of this pluton dips gently south at approximately 20 degrees.

These rocks are buff to light grey on the weathered surface, massive, and both equigranular and porphyritic. Foliation and lineation of constituent minerals are uncommon, but schlieren were noted in one outcrop. No inclusions of country rock were observed. All outcrops are well jointed, and dykes and veins of greisen and quartz were observed in a few places, particularly near the contact with Ordovician strata.

In thin section, rocks of this map-unit are finer grained than those of map-unit 6a, but mineral relationships are similar. The texture is hypidiomorphic granular, with grains 0.5 mm to 3.0 mm most abundant (Plate 9). Phenocrysts up to 1.5 cm were noted in some sections.

On the basis of nine modal analyses, plagioclase averages 30 per cent of the rock. Grains are subhedral to anhedral, and vary in size from 0.5 mm to 1.5 mm. They resemble those of unit 6a in composition and twinning. Alkali feldspar averages

Plate 9 - Thin section, Burnthill quartz monzonite (6b). Note sharp grain boundaries and less altered feldspar (in comparison to 6a).

30 per cent of the rock. Grains are irregular, and in places completely enclose plagioclase laths. Well developed grid twinning predominates, and perthitic intergrowths with plagioclase have been noted. Quartz constitutes approximately 33 per cent of the rock and occurs as irregular anhedral. Micrographic intergrowths with orthoclase are more abundant than in the previous map-unit. Most quartz is strained, but it is relatively free of inclusions. Biotite is fairly common, and makes up more than half of the total mica content. It occurs as irregular plates, approximately 2 mm in diameter. Muscovite occurs in parallel intergrowth with biotite, as an alteration product of plagioclase, and as large individual plates where it appears to fill interstices between other minerals. Chlorite, zircon and apatite occur within biotite.

The contact between the Burnthill quartz-monzonite (6b) and the enclosing Ordovician sedimentary rocks was observed at two localities, on the Southwest Miramichi River, and on Burnthill Brook. At both places, it is sharp, somewhat irregular, and clearly discordant. There is no increase in the degree of deformation, or marked change in the general attitude of the enclosing strata. It appears that the Ordovician argillites and quartzites of the Miramichi Formation (4) were folded prior to the emplacement of these rocks. The upper surface of the Burnthill quartz monzonite is exposed on Southwest Miramichi River, and the contact is quite smooth. No inclusions of country rock were observed.

An age determination from a greisenized margin of a quartz vein cutting quartz monzonite on Burnthill Brook yielded 392 ± 15 m.y. (Poole, 1963c). Age relationships with 6a could not be obtained in the Burnt Hill area. It is interpreted to be either a separate (younger) intrusion or a marginal phase of 6a. Rocks similar to the Burnthill quartz monzonite occur as individual stocks elsewhere in New Brunswick.

MINE BIOTITE QUARTZ MONZONITE (6c)

This unit is not exposed at the surface, but was intersected in drill holes 8s and 9s, at 625 feet and 553 feet respectively (Figure 1).

Rocks of this unit appear to be uniform in mineralogy and texture. They are light grey, fine to medium grained, and equigranular (Plate 10) with quartz, alkali and plagioclase feldspar present in nearly equal amounts. Biotite is distributed evenly throughout the rock. Muscovite is slightly more abundant, and constitutes approximately 3 per cent.

In thin section, interlocking subhedral and anhedral grains of leucocratic minerals possess a typical hypidiomorphic texture (Plate 10). The grain size is in general finer than in the previously described map-units, and averages from 0.5 mm to 1.0 mm. Phenocrysts of quartz and biotite up to 3.0 mm have been observed, but are not abundant. Greisen dykes are common within this unit.

On the basis of four modal analyses, plagioclase constitutes approximately 29 per cent of the rock. Grains for the most part possess idiomorphic outlines, and average approximately 0.3 mm in length. The central parts are sericitized, but much

Plate 10a - Drill core, Mine quartz monzonite (6c)

Plate 10b - Thin section, Mine quartz monzonite (6c). Note equigranular texture.

less so than those in the Burnt Hill quartz monzonite (6b). Albite-Carlsbad twins are common, and extinction angles suggest an albite-oligoclase composition.

Alkali feldspar constitutes approximately 27 per cent of the rock. It occurs as irregular anhedral, approximately 0.5 mm in diameter. Microcline with well developed grid twinning is most common. Sericite flakes occur within the grains, but may be an alteration product of included plagioclase.

Quartz occurs as irregular anhedral, approximately 0.5 mm in diameter. It constitutes approximately 40 per cent, and is considerably more abundant than the average of the previous map-unit.

Dark red-brown to green-brown biotite forms grains approximately 1.0 mm in maximum dimension. Highly irregular sinuous masses are also present, and some are completely altered to chlorite (in part, with anomalous blue interference colours). Pleochroic haloes are common, and a few irregular masses of ilmenite (?) were noted. Individual plates of muscovite up to 0.7 mm are common throughout the rock, particularly as an alteration product of plagioclase. Muscovite also occurs as parallel intergrowths with biotite.

Accessory minerals are not abundant, but small zircons occur within the biotite plates. Small amounts of fluorite, approximately 0.1 mm in diameter, have been observed.

The contact between the mine quartz monzonite and strata of the Miramichi Formation (4) is sharp and well defined.

Dykes and veins of greisen and quartz are common 100 feet or more on either side of the contact. Relationships between this quartz monzonite and 6a, b were not observed, but the former is interpreted to be a separate and younger intrusion. Reasons to support this interpretation are presented at the end of this chapter.

METAMORPHISM

Strata of the map-area have undergone low grade regional metamorphism, with the development of sericite and chlorite. Porphyroblasts of biotite, andalusite and cordierite are developed by contact metamorphism near the granitoid rocks. Argillaceous strata of the Miramichi Formation (4) appear to be most "sensitive" to the effects of metamorphism and they are spotted for more than a mile away from the contact. The unmetamorphosed or slightly metamorphosed rocks are grey-green to grey, whereas those within the contact aureole are purple-brown due to the formation of biotite. Mineral isograds are delineated on Figure 1.

In areas outside the zone of contact metamorphism, sericite, and chlorite occur as ragged and irregular masses (0.01 to 1.0 mm) which are parallel or sub-parallel to the bedding (Plate 5b).

Biotite, like some sericite, locally develops at an angle of 20 - 30 to bedding. It is pale brown in colour and forms stubby laths (0.01 to 0.05 mm). Larger laths up to 1.0 mm were recognized closer to the contact of the quartz monzonites. It replaces sericite and fills voids between laths of this mineral. It is commonly replaced by chlorite. Andalusite forms irregular xenoblastic aggregates (1.0 mm)

and is restricted to rocks within a few hundred feet from the contact with the granitoid rocks. Subhedral porphyroblasts of colourless cordierite (approximately 2.0 mm) were noted in the metamorphosed argillites west of the granite mass that crops out on Miramichi River a few hundred feet above Burnthill Brook (Plate 11a).

Ovoid knots or "spots" of unidentifiable material occur within rocks of units 3 and 4. They vary in size from 1.0 mm to 3.0 mm. The central core consists of fine sericite with chlorite, biotite and quartz. Opaque minerals are common. Primary sedimentary features such as fine laminations and streaks of opaque minerals pass through the knots. The outer rims locally contain chlorite and biotite (Plate 3a).

The assemblage of quartz, sericite, biotite, chlorite, andalusite and cordierite is characteristic of the hornblende-hornfels facies (Turner, 1967). As biotite, andalusite and cordierite have only been developed near the granitic rocks these minerals are attributed to contact metamorphism.

RETROGRADE METAMORPHISM

Porphyroblasts of biotite, andalusite and cordierite in the argillaceous strata of the Miramichi Formation (4) are locally mantled by thick (up to 0.5 mm) rims of chlorite with anomalous blue interference colours (Penninite?). This chlorite is developed within a semi-circular zone about 6000 feet in diameter centering on an area underlain by the mine quartz monzonite (6c). This mineral transects sericite, replaces muscovite and biotite and forms rims around

Plate 11a - Thin section, spotted argillite, Miramichi Formation(4).
Note cordierite porphyroblast.

Plate 11b - Thin section, spotted argillite, Miramichi Formation (4).
Note irregular patches and thick rims of chlorite around andalusite.

andalusite and cordierite (Plate 11b). The isograd delineating this zone truncates the isograds of progressive metamorphism nearly at right-angles and it is believed that this chlorite is the product of retrograde metamorphism.

Modal analysis indicates the altered rock contains about 17 per cent chlorite (average of 12 thin sections). About 2 per cent water would have to be introduced to form this chlorite. This water might have been derived from strata of the Miramichi Formation (4) but it is more probable that the source was the Mine quartz monzonite (6c) 600 feet beneath the surface. It contains nearly twice as much water, is texturally different from the other quartz monzonites (6a, b), (Table 5) and is probably a younger intrusion.

SYNTHESIS OF STRATIGRAPHY AND IGNEOUS INTRUSION

ORDOVICIAN STRATIGRAPHY

Ordovician sedimentary rocks of the Burnt Hill area comprise approximately 13,600 feet of argillaceous and quartzose strata. Two main sequences are interpreted: (1) - Conglomerate-sandstone-argillite-chert (including the Buttermilk and Hayden Lake Formations (1 & 2); and (2) - Greywacke-quartzite-argillite (including the Push-and-be-Damned and Miramichi Formations (3 & 4). Although the two sequences are conformable, their lithologies are believed to reflect different provenances and environments of deposition.

Sequence (1) - 2100 feet. Quartzite pebble conglomerate is most abundant near the lower part of this unit, and grades upward to fine cherty and argillaceous strata. At the top of this sequence, fine grained rocks predominate and include cherts and argillites of the

Hayden Lake Formation (2), for which conditions were probably alternating between aerobic to anaerobic, as indicated by the presence of red to green, and dark grey to black carbonaceous rocks.

This is shown schematically in Figure 4. The presence of a conglomerate at the base of the Buttermilk Brook Formation with large well rounded pebbles of quartzite suggest a nearby source area in which quartzite was present. As the age of the Buttermilk Brook Formation is interpreted to be Early Ordovician, a Cambrian or Precambrian basement with quartz-rich cratonic cover rocks would be expected. Quartz clasts in these conglomerates are riddled with inclusions, suggesting derivation from a metamorphic terrain. This is compatible with the concept of the geanticline through Central New Brunswick (Schuchert 1930). Neuman (1966) has proposed a Penobscot orogeny in Maine, to explain an unconformity between the Grand Pitch (Cambrian) and Shin Brook (Early Ordovician) Formations. The quartzite which provided the detritus for the Buttermilk Brook Formation could be Cambrian and Neuman (personal communication) believes conglomerates of the Buttermilk Brook Formation closely resemble conglomerates he has mapped in the Shin Brook Formation. The base of the Buttermilk Brook Formation was not observed and relationships with older rocks could not be verified.

Sequence (2) - 11,500 feet. Highly carbonaceous greywackes of the Push-and-be-Damned Formation mark the beginning of sequence (2). Angular clasts of igneous and sedimentary rocks are abundant. They are entirely different from the clasts in strata of Sequence (1) but were possibly derived from the more deeply eroded parts of the same source area. (Figure 4). The presence of carbonaceous material may indicate a reducing environment of deposition.

Only more stable constituents survived in the overlying quartzites and argillites of the Miramichi Formation (4) are mineralogically more mature. These rocks are in general fine grained and better sorted than those of the underlying strata.

In figure (4) (deposition of 3), the source area is indicated to the west, and modal analyses show that strata in the western part of the area contain more labile (unstable) constituents than similar beds to the east (figure 3 and 5).

The quartz wackes and sandstones of the eastern belt may be equivalent to the quartzites and argillites of the Miramichi Formation (4).

THE TOM MCKIEL FAULT

Strata of the Push-and-be-Damned Formation (3) in the eastern and western parts of the map-area are separated by a wide belt of rocks of the Miramichi Formation (4). All strata are overturned to the southeast and a fault is required to explain the distribution and orientation of these units. There is much evidence to indicate this fault is located at the top of the Miramichi Formation (4):

- (1) Local intense shearing - Highly deformed siltstones and argillites of the Buttermilk Brook Formation (1) were noted at South Ridge. Farther to the south and outside the map-area, contorted strata of this unit are exposed on the mine road, immediately southeast of the bridge crossing Upper Hayden Brook.

FIGURE 5: MINERALOGICAL MATURITY OF SIX TYPICAL
GREYWATERS, PUSHING-SE-DRAINED FORMATION(3)

Deformed strata of the Push-and-be-Dammed Formation (3) are also noted on Tom McKiel Brook, about 800 feet south of southwest Miramichi River. Similar rocks were mapped on the north side of southwest Miramichi River.

A zone of contorted strata was mapped on the southeast side of southwest Miramichi River, near a diabase sill and immediately east of Tom McKiel Brook. Here, carbonaceous greywackes are highly sheared and brecciated. In thin section, graphite and opaque minerals are streaked, and clasts within the greywackes are stretched and broken (Plate 3a). Poole (1963a) interpreted these rocks to be a rhyolitic tuff (his unit 2c).

- (2) Occurrence of igneous rocks - Several elongate masses of diabase have been mapped along the fault zone. They have been emplaced within strata of all map-units.

The Tom McKiel fault and related parallel faults strike northeast, and are interpreted to dip northwest at the same attitude as the country rocks. As younger rocks west of this structure are faulted against older strata on the east, the Tom McKiel fault is primarily a normal fault. There is also some evidence for late wrench movement, which will be described in chapters 3 and 4.

STRATIGRAPHIC INTERPRETATION OF POOLE (1963a)

The basic difference between the stratigraphy interpreted by Poole (1963a) and that proposed by the writer is in the stratigraphic position of the argillites and quartzites of the Miramichi Formation (4). Poole interprets all argillites and quartzites in the Hayesville area to

underlie ferruginous, manganiferous and carbonaceous cherts similar to the Hayden Lake Formation (2). The writer, however, mapped coarse clastic sediments of the Buttermilk Brook Formation (1) beneath these cherts and considers them to be older than the argillites and quartzites of the Miramichi Formation (4) (which conformably overlie the Push-and-be-Damned Formation (3)). Poole's argillite and quartzite therefore includes two map-units (1 & 4) of different ages in the Burnt Hill area.

Although the regional distribution of mixed basic dykes, flows and sills would suggest his interpretation is correct, further detailed mapping would be required before these basic rocks may be used in interpreting the stratigraphy of the region. There is evidence to the northeast that some of these flows may be as young as Silurian (F.D. Anderson, personal communication), which is compatible with the Ordovician or younger age assigned to the Miramichi Formation by the writer.

Poole also interpreted the fault separating the two belts of carbonaceous greywackes of the Push-and-be-Damned Formation (3) to be at the top of the western belt. The writer could not find any evidence for a northeast striking fault in this area. In fact, a conformable contact was observed between the greywackes of map-unit (3), and argillites and quartzites of map-unit (4) (see page 13). If the upper part of the Miramichi Formation (4) is not faulted as Poole suggests, conglomerates and clastic sedimentary rocks would be expected in the nearly continuous section on the south side of Southwest Miramichi River, opposite Beatty Brook. Only fine argillites and siltstones were mapped here by the writer, and if strata of this map-unit were present, they were cut off by the Tom McKiel fault.

IMPORTANCE OF STRATIGRAPHY IN DETERMINING GENESIS OF
MINERALS IN VEINS OF BURNT HILL AREA

Both the Ordovician strata and granitoid rocks may be considered as possible sources for the W, Mo and Sn minerals in the veins of the Burnt Hill area. For this reason, it is important that some conclusions be drawn concerning the provenance and depositional environments of the sedimentary rocks. It is difficult to determine the form in which W, Mo and Sn would occur in strata of this area, but if present, W and Sn may have been transported as wolframite (or scheelite) and cassiterite. The common Mo minerals are not resistant and this element was probably transported in solution to the depositional area. W and Sn would be expected in the clastic sedimentary rocks and Mo would be concentrated in the reducing environment associated with argillaceous and cherty strata.

Sequence (1) - The Buttermilk Brook and Hayden Lake Formations (1 and 2) are predominantly quartzose, and coarse clastic horizons near the bottom of this sequence were probably derived from a quartz-rich source area. Detrital W and Sn could occur in these rocks. Mo is most likely to occur in the fine grained strata near the top of the sequence.

Sequence (2) - Carbonaceous greywackes and related rocks of the Push-and-be-Damned Formation reflect a reducing environment in which a great variety of clastic material was deposited. A pre-Early Ordovician (Cambrian-Precambrian) source area is interpreted. W and Sn would be expected in these rocks as clastic minerals and higher concentrations should occur in the western belt where a greater abundance of unstable constituents has been recognized. Mo may be concentrated in the silty and more argillaceous beds.

The overlying quartzites of the Miramichi Formation (4) may contain W and Sn but Mo should be concentrated in the fine grained rocks of this unit. Little carbonaceous material was noted in these rocks and a semi-stable environment is indicated.

In summary, W and Sn could be concentrated in the clastic rocks of the Buttermilk Brook (1) Push-and-be-Dammed (3) and Miramichi Formations. Concentrations of Mo could occur in the Top of the Buttermilk Brook Formation (1), the Hayden Lake Formation (2) and the argillaceous silty strata of the Push-and-be-Dammed and Miramichi Formations (3 and 4). Samples collected from these map-units were analysed for W, Mo and Sn and the results obtained are discussed in Chapter 5, pp. 95 - 100.

IGNEOUS ROCKS

Granitoid rocks of the Burnt Hill area may also be considered as a source for W, Mo and Sn minerals. Although a sequence of intrusion has been inferred at Burnt Hill, all show chemical and mineralogical similarities (Table 2 and 3). They are texturally distinctive and different units are easily mapped in the field.

The following mineralogical variations have been recognized

TABLE 2: AVERAGE MODAL ANALYSES AND MINERAL RATIOS, BATHOLITHIC ROCKS (6)
 (MINIMUM OF 1000 POINTS COUNTED PER THIN SECTION)

MFP-UNIT	NAME	NO. OF ANALYSES	% QUARTZ	% ALKALI FELSPAR	% PLAGIOCLASE	% Biotite	% Muscovite	ALKALI FELSPAR / PLAGIOCLASE	QUARTZ / TOTAL FELSPAR	MUSCOVITE / BIOTITE
6a	CLARKVILLE QUARTZ MONZONITE	3	27	32	35	33	25	0.9	0.41	0.73
6b	CLARKVILLE QUARTZ MONZONITE	9	33	30	30	26	27	1.0	0.50	1.1
6c	NINE QUARTZ MONZONITE	4	40	27	29	10	33	0.9	0.70	3.3

Map-Unit	6a	6b	6c
Sample.No.	5-51-3/PB	BH-478/PBP	BH-861/PBP
SiO ₂	73.78	74.84	75.55
Al ₂ O ₃	13.82	14.91	14.26
Fe ₂ O ₃	0.82	0.49	0.07
FeO	0.60	0.35	0.79
CaO	0.79	0.31	0.25
MgO	0.18	tr.	tr.
Na ₂ O	3.78	3.56	3.55
K ₂ O	4.99	4.49	4.51
H ₂ O ⁺	0.46	0.35	0.74
H ₂ O	0.06	0.09	0.04
TiO ₂	0.18	0.09	0.07
P ₂ O ₅	0.09	0.02	0.02
MnO	0.07	0.07	0.10
CO ₂	0.03	0.01	0.00
BaO	0.01		
Total	99.66	99.58	99.97

TABLE 3

Chemical Analyses, Granitic Rocks, Burnt Hill*

5-51-3/PB - Clearwater biotite quartz monzonite (6a)
 BH-478/PBP - Burnthill biotite quartz monzonite (6b)
 BH-861/PBP - Mine biotite quartz monzonite (6c)

* Analyses by the Geological Survey of Canada

* Analyses 5-51-3/PB and BH-861/PBP by wet chemical analyses,
 BH-498/PBP by wet chemical and X-ray Fluorescence analyses.

OLDEST	(1) Increase in quartz content.
	(2) Decrease in the total amount of feldspar,
(decrease in both plagioclase and alkali feldspar)
	(3) Decrease in the amount of total mica (decrease
in biotite, and increase in muscovite).
YOUNGEST	

The following may be derived from this data:

OLDEST	(1) Ratio: alkali/plagioclase feldspar similar
in all units.
	(2) Progressive increase in the ratio
(muscovite/biotite).
YOUNGEST	(3) Progressive increase in the ratio
(quartz/total feldspar).

Perhaps the only significant difference in the chemical composition of these rocks is the slight increase in silica from 6a to 6c. The H_2O content of the younger mine quartz monzonite (6c) is considerably higher than the older varieties. Its position on the flanks of these intrusives suggests it may be a marginal phase of the granitoid batholith. As its inferred location is similar to the outline of the retrograde-chlorite isograd and because this isograd cuts the andalusite and cordierite isograd nearly at right angles, it is interpreted to be a separate intrusion. The anomalously high water content of this rock is compatible with this interpretation.

ABSOLUTE AGE DETERMINATIONS ON GRANITOID ROCKS AND TYPES

Several absolute age determinations have been made on material from map-units 6 and 7 which are described below: veins and dykes will be discussed in detail in Chapter IV. The data are summarized in Table 4.

TABLE 4: ABSOLUTE AGE DATA ON GRANITOID ROCKS AND VEINS, BURNT HILL AREA

NO. UNIT	LITHOLOGY	LOCATION		SAMPLE NUMBER	MINERAL DATED	PERCENT K	PERCENT ANOMALOUS K	A^{40}/K^{40}	AGE (M. Y.)	ERROR	REFERENCE
		LATITUDE	LONGITUDE								
6a	QUARTZ MONZONITE (SUNSET MOUNTAIN WEST OF MAP AREA)	43°50' N	66°16' W	5533/AB	BIOTITE	7.78	99.0	0.0217	339		POOLE (1963b) G.S.C. NO. 61-182
6b	QUARTZ MONZONITE	46°35'05" N	66°49'25" W	5534/AB	MONZONITE	8.77	100.00	0.02551	392		POOLE (1963c) G.S.C. NO. 62-157
6c	ANNE QUARTZ MONZONITE		DATA	NOT	AVAILABLE						
7a	GABBRO DYKE				MONZONITE				375	±26	CARLETON UNIVERSITY M. SHAPIRO & L. L. (CARLETON COMMUNITY '963).
7b	QUARTZ MONZONITE VEIN	43°41'0" N	66°49'35" W	6444-1	MONZONITE	8.54	95.0	0.0239	370	±15	POOLE (1967) G.S.C. NO. 63-180

* FROM GRAB-SAMPLED QUARTZ MONZONITE NEAR MOUNTAIN OF QUARTZ VEIN

DECAY CONSTANTS
USED:

$$\lambda_e = 0.585 \times 10^{-10} \text{ yr}^{-1}$$

$$\lambda_{\text{total}} = 5.30 \times 10^{-10} \text{ yr}^{-1}$$

Map-Unit 6a (equivalent) (339 $\pm$ 25 m.y.)

This date was obtained on a biotite quartz monzonite about four miles northeast of the Burnt Hill area. It is lithologically similar to rocks of Map Unit 6a. A Mississippian age* is indicated which is much too young when compared to other geochronological data from New Brunswick (Tupper and Hart, 1961), Poole (1963b) interpreted this anomalously young date to be a result of metamorphism or subsequent intrusion.

Map-Unit 6b - Burnthill quartz monzonite (392 $\pm$ 25 m.y.)

Muscovite for this determination was obtained from a greisenized granite at the margin of a quartz vein cutting the Burnthill quartz monzonite. A minimum age for this map-unit (Early Devonian) is indicated and is in good agreement with other dates obtained in the Province.

Map-Unit 7b - Greisen dyke (375 $\pm$ 26 m.y.)

Greisen dykes in the Burnt Hill area cut both the mine quartz monzonite and strata of map-unit (4). This date indicates the greisen dykes are Early Devonian. The absolute age obtained correlates well with those obtained for the Burnthill quartz monzonite (6b) and the quartz-muscovite vein (7b) below.

* this and other age assignments based on the Phanerozoic time scales of the Geological Society of London (1964).

Map-Unit 7b - Quartz muscovite vein (370 ± 15 m.y.)

Veins of this type are interpreted to be younger than the greisen dykes (7). This date confirms this interpretation and an Early to Middle Devonian age is indicated.

All the quartz monzonites of the Burnt Hill area are spatially related and are probably associated with a single magmatic event. The slight mineralogical changes may be due to differentiation and are compatible with the mineralogy of the dykes and veins emplaced later. Geochronologic data indicate that the granitoid rocks were emplaced during the Early Devonian. The dykes and veins were intruded somewhat later during Early-Middle Devonian.

Chapter III

STRUCTURAL GEOLOGY

The Burnt Hill area is situated in the central part of a geanticlinal zone of Ordovician sedimentary rocks that strike northeasterly across northwestern New Brunswick. Unfortunately Ordovician - Silurian relationships in this part of the Province are not clear and it is not known if the zone was affected by Taconic (Ordovician) deformation. Acadian (Devonian) deformation affected both Ordovician and Silurian rocks and northeasterly striking folds at Burnt Hill are truncated by granitic batholiths and stocks. East-northeasterly and northwesterly striking faults have been mapped within the geanticlinal zone (Figure 6) and transcurrent movement has been recognized on some of these structures.

The structural geology of the Burnt Hill area was investigated to determine: (1) type of fold pattern developed, (2) the type of fault - joint and pattern developed, (3) the relationship between folds, faults, joints and granitoid batholiths, and (4) the factors controlling the location of joints and faults that contain mineralized veins.

The Burnt Hill area is located at the faulted boundary of an overturned anticline to the west and an overturned syncline to the east and has been divided into five structural areas which correspond to the major map-units (Figure 7).

FOLD ANALYSES

Bedding attitudes were easily obtained from sedimentary rocks of all map-units. The data from areas I, II and III were

plotted stereographically. In order to locate the π circle accurately the contoured bedding pole distribution was rotated so the maxima would be positioned at the bottom of the hemisphere.

Areas I and II in the western belt appear to be structurally homogeneous (Figure 8), and synoptic diagrams of this and the eastern part of the area are shown on Figure 9. Maxima occur in the southeast quadrant in both areas. Mapping has outlined regional folds whose axes may be traced for several miles. No large folds have been recognized within the map-units of the Burnt Hill area. The arcuate form of the bedding pole distribution (particularly in the western belt) suggests a bending of the strata about northwesterly trending axes. This was not recognized during field mapping but lineations (cleavage-bedding intersections and minor folds) confirm the existence of northwest striking folds. This was also supported by inscribing other possible π circles (Haman, 1961).

Fold patterns in areas I, II and IV (west and east of the Tom McKiel fault) are similar, but slight differences in the average strike and the strike spread in these two areas suggest strata of the western belt were warped about northwesterly axes after the main period of folding (about northeasterly axes). The exact reason for this warping is not known, but it is interpreted as resulting from wrench movement on the Tom McKiel fault, as right-hand displacement on numerous small northwest striking faults located in the vicinity of Burnt Hill. Right hand movement on major east-west fault about 16 miles north of the Burnt Hill area (Poole, 1963a, F.D. Anderson, personal communication) shown on Figure 6 would also produce broad regional northwest folds.

AREA I

PUSH-AND-BE-DRAWN FORMATION (3)

31 POLES, CONTOURS: 18, 42, 62, 82, 122

AREA II

HIRANYICHI FORMATION (4)

275 POLES, CONTOURS: 362, 12, 42, 62, 82, 122

FIGURE 8: β DIAGRAMS, ORDOVICIAN STRATA WEST OF TOM MCKEL FAULT

The northeasterly striking regional folds were formed by NW-SE compression. There is no evidence to indicate that the area was affected by more than one major period of deformation.

JOINT-FAULT ANALYSES

Joints and faults are abundant in the Burnt Hill area, and may be mapped in all outcrops. They strike northeast or southeast, are generally straight and are traceable for several tens of feet. The southeasterly striking joints are abundant and many are mineralized, particularly in the area between Burnt Hill and the Burnthill quartz monzonite (6b). Those with slickensided walls are classified as faults (undoubtedly many structures mapped as joints are actually faults). All joints, mineralized joints, faults and mineralized faults were plotted stereographically. They have the same general orientation and a common origin is indicated.

Synoptic diagrams of the joints and faults in the western and eastern parts of the area are plotted stereographically on Figure 10. The angular strike spread of the northeast and southeast joints and faults is essentially identical in both areas (74 - 75 degrees). There appears to be a small (6 - 7 degrees) clockwise rotation of these structures in the western belt, but the significance of this cannot be ascertained without more field data.

RELATIONSHIPS BETWEEN JOINTS, FAULTS AND GRANITOID BATHOLITHS

Joints and faults in the Burnt Hill area occur in all map-units, including the granitoid batholiths. Thin sections show

they were formed after the retrograde metamorphism as vein filled fractures truncate porphyroblasts rimmed with chlorite. This implies they are younger than the Mine quartz monzonite 6c, the Burnthill and Clearwater quartz monzonites (6b, c). It may be concluded that joints and faults of the Burnt Hill area are not directly related to batholithic activity.

FACTORS CONTROLLING THE LOCALIZATION OF JOINTS AND FAULTS

Joints and faults are developed throughout the region, but there are no quantitative data available concerning their distribution and abundance in any particular area. They are well developed (closely spaced) near Burnt Hill and it is possible that such a concentration of joints and faults reflects a reaction to late (tensional?) stresses applied to a comparatively competent or brittle rock. Competency here might be due to the presence of; (1) - quartzite beds, (2) - granitoid batholiths, and (3) - metamorphosed strata of the Miramichi Formation (4) - Fractures would be expected in this environment, and should be most abundant in the tensional zone about the Mine quartz monzonite (6c).

In summary, the earliest or major period of deformation folded Ordovician strata about northeast axes. The principle stress direction was probably NW-SE. Granitoid batholiths were then emplaced and aureoles of progressive and retrogressive metamorphism formed. Joints in the regional tensional direction developed, and were filled with vein material. The country rocks west of the Tom McKiel fault

were bent about northwest axes after the main period of folding but it is not known if this bending took place before, during or after the joints and faults developed. There is much evidence to indicate that many of the quartz-filled joints developed into faults and this will be described in the following chapter.

CHAPTER IV

BURNT HILL TUNGSTEN DEPOSITINTRODUCTION

The Burnt Hill deposit consists of a large number of quartz, quartz-topaz, and quartz-muscovite veins with local concentrations of wolframite, molybdenite, beryl, fluorite, cassiterite, and various sulphides that occur on the north slope of Burnt Hill in metamorphosed argillites and quartzites of the Miramichi Formation (4). These veins strike approximately southeast and dip vertically or at 70-90 degrees to the northeast or southwest. Granitic rocks occur about 600 feet beneath the veins, and are exposed on Miramichi River, approximately one mile to the northwest.

HISTORY

Quartz-molybdenite veins were first noted on the banks of Southwest Miramichi River by Charles Robb (1870) of the Geological Survey of Canada, but no extensive development work was carried out until the Acadia Tungsten Mining Company was formed in 1912. The property produced 2940 pounds of concentrate up to 1918 when operations were suspended. Accounts of this early period of development work have been given by Wright (1940). The Burnt Hill Tungsten Mining Company started development work on the

property in 1953. A road was constructed from Maple Grove and several buildings were erected. A mill was built and more than 5000 feet of drifts and cross-cuts were completed prior to 1957. Several thousand feet of exploratory diamond drilling was also undertaken at that time. Interest in the property was revived in 1963 and a diamond drilling program was initiated late in that year. Some surface stripping was done. A new shaft was started late in 1968.

Approximately 50,000 pounds of wolframite concentrate were shipped (1953-1957). At that time, the remaining reserves (probable) were estimated to be 260,000 tons averaging 1.5 per cent WO_3 .

GEOLOGY

The Burnt Hill Tungsten property has been described by Young (1917) and Wright (1940). Tupper (1955) was the first to describe the geology and mineralogy of the veins in the underground workings. Further studies of the mineralogy were made by Victor (1957).

HOST ROCKS

Veins at the Burnt Hill deposit occur in joints, faults and shear zones within steeply dipping argillites and quartzites of the Miramichi Formation (4) (Figure 1). At the mine, these strata strike approximately 040, are overturned to the southeast and dip 60-90 degrees northwest.

The lithology and structure of the Miramichi Formation (4) at the deposit do not differ from those of the Formation elsewhere in the map-area (with the possible exception of the contorted zone below 2½ Mile Pond).

The argillites at the mine are finely laminated, but a few massive beds up to two feet thick occur locally. Quartzites average more than one foot in thickness, and contain numerous anastomosing quartz veinlets. In general, the delineation of quartzite, argillaceous quartzite and argillite beds is most difficult, even with good underground exposures.

Argillaceous rocks near the mine are contact metamorphosed, with the development of small (1 mm) ovoid knots or porphyroblasts of biotite rimmed with chlorite. The known vein system is within the large aureole of retrograde metamorphism previously described.

MINERALOGY

Veins in the Burnt Hill area contain a variety of minerals, including: quartz, muscovite, topaz, plagioclase, wolframite, scheelite, molybdenite, cassiterite, beryl, chlorite, fluorite, anatase, arsenopyrite, pyrite, pyrrhotite, marcasite, chalcopryrite, sphalerite, galena, and native bismuth. Most contain minerals of economic interest, but they may not be present in sufficient quantities to be termed ore.

Field studies, both on the surface and underground, suggest different ages of veins, each with specific widths, textures and mineralogy. Thin sections helped to confirm the presence of composite veins, whereas the gross relationships were determined in the field.

VEINS (map-unit 7)

Three types of veins have been recognized in the Burnt Hill area (Table 1). Their distribution is shown on Figure 1 and Figure 11 (in pocket). The general characteristics of each are described below and details of their size, orientation, mineralogy, etc. are shown on Table 5 (in pocket).

7a VEINS - Quartz, with minor pyrite, pyrrhotite

Veins of this type are commonly small and have been observed only in shear zones parallel to the strike and dip of strata of the Miramichi Formation (4). They may be observed at several places on Southwest Miramichi River and in the main crosscut at the Burnt Hill tungsten deposit, between No. 1 and 2 drifts. Their age is uncertain but they post date the regional folding and are older than all southeasterly striking faults, joints and other veins.

7b VEINS - Quartz, muscovite, with minor beryl, molybdenite, wolframite, fluorite, pyrite, scheelite and cassiterite

Veins of this map-unit have been observed on the surface, underground and in drill core. They strike southeasterly and cut veins of map-unit 7a. In contrast to other veins, muscovite is a major constituents.

Greisen dykes are included with this map-unit. They occur in the area between Burnt Hill and the Burnthill quartz monzonite (6b) and were logged in drill core within the Mine quartz monzonite (6c). (Two were noted near the quartz monzonite east of Deadman Brook). Excellent exposures may be observed a few hundred feet above the Burnt Hill Fishing Club. Muscovite is the main constituent (up to 70 per cent) and quartz is the next most abundant (Plate 12a). Orthoclase, plagioclase, molybdenite and fluorite are present in minor amounts. The contact between these dykes and the strata of map-unit 4 is sharp and they are in turn cut by younger quartz veins. A K/A date of 375 ± 25 m.y. (Early Devonian) was obtained on muscovite from one of these dykes (see page 56).

Beryl-rich sections were noted within and near the margins of the greisens at the Burnt Hill Fishing Club. Here, large beryl prisms (up to 20 mm) occur in radiating aggregates within narrow (one inch or more) bands (Plate 12b). Molybdenite and muscovite are associated with the beryl, and fluorite and cassiterite have been recognized.

Veins with quartz and randomly distributed muscovite are abundant in the underground workings Figure 11 and may be observed in the main cross-cut, between the portal and No. 1 drifts. They are smaller than the greisens and contain more wolframite and fluorite. The exact relationship between the two types is uncertain, however there is some evidence to indicate the quartz-muscovite veins cut the greisens. A K/A age on muscovite from these quartz-muscovite

Plate 12a - Thin section, greisen(7b) showing abundant muscovite and disseminated molybdenite. Note clean plagioclase.

Plate 12b - Thin section, beryl-rich section of greisen dyke (7b). Note radiating strain shadows in quartz near beryl crystals.

veins gave an absolute age of 370 ± 15 m.y. (Potter, 1967), which is compatible with the date obtained on the greisen dykes.

Greisen dykes appear to be concentrated 100 feet or more above and below the contact between the Mine quartz-monzonite (6c) and metamorphosed strata of the Miramichi Formation (4). Quartz muscovite veins occur farther away from this contact.

Veins of this map-unit most commonly occur in joints striking 100-120 degrees. The greatest number are found in the 120 degree orientation. The walls of the veins are slickensided and cataclastized (Plate 13b).

7c VEINS - Quartz, topaz, with minor wolframite, pyrrhotite, chalcopyrite, pyrite, arsenopyrite, fluorite, sphalerite, molybdenite, beryl, bismuth, anatase, cassiterite

Veins of this map-unit can be distinguished from those of 7b by width (up to 4 feet), low muscovite content (< 5 per cent), large euhedral wolframites (up to 4 cm) and abundance of topaz.

Quartz veins with wolframite (with or without topaz) are abundant in the Burnt Hill area (Figure 1), and may be observed both underground and in the area of large outcrops north and northwest of Burnt Hill. Two main assemblages have been recognized:

(1) - Quartz-topaz-wolframite veins, and (2) - quartz-beryl-molybdenite veins.

Quartz-topaz-wolframite veins are best exposed in West No. 2 drift. Clusters of wolframite occur locally (Plate 14a) and well formed euhedra are typical. Powder diffraction and X-ray fluorescence studies indicate they are ferberite. Inclusions of bismuth and pyrrhotite were noted, (Plate 14b) however scheelite is not as

Plate 13a - Hand specimen, typical quartz-muscovite vein (7b)

Plate 13b - Hand specimen, slickensided wall of typical quartz-muscovite vein(7b).

Plate 14a - Hand specimen, quartz-topaz vein (7c) showing large euhedral blades of wolframite.

Plate 14b - Polished section, quartz-topaz vein (7c). Note bismuth encloses pyrrhotite and forms inclusions in wolframite.

abundant within the wolframites of this map-unit as it is within those of 7b.

Veins with beryl and molybdenite are not abundant, but were noted in West No. 2 drift, about 100 feet west of the main cross-cut. Native bismuth and galena are concentrated along cleavage planes in the molybdenite (Plate 15a). Cassiterite is restricted to the beryl-molybdenite rich sections of veins of this map-unit.

A few small veins ($\pm$ 1 inch) consisting almost entirely of topaz and sulphide minerals (pyrrhotite, arsenopyrite, pyrite, chalcopyrite, sphalerite and galena) with some wolframite and fluorite were noted in the waste dump of the tungsten deposit (Plate 15b). They could not be found in the underground workings but have been included with this unit on the basis of minerals present. They cut quartz-topaz veins and are therefore younger.

Quartz-wolframite veins of 7c resemble some of the quartz-muscovite veins of 7b and at a few localities the two types occur together as composite veins. They may be observed underground in West No. 2 and 3 drifts, and can easily be distinguished in this section (Plate 16).

Veins of map-unit 7c are restricted to joints and faults in the 120 - 140 degree range. Those in the 120 degree range are most abundant and composite veins occur in joints and faults with this orientation.

STRUCTURAL GEOLOGY

All veins with minerals of economic interest occur in fractures which are approximately normal to the regional structural

Plate 15a - Polished section, quartz-topaz vein (7c). Note bent plates of molybdenite with bismuth and galena along cleavage planes.

Plate 15b - Hand specimen, pyrrhotite-arsenopyrite-wolframite-rich section of quartz-topaz vein (7c).

Plate 16 - Thin section, composite vein. Note typical cataclastized wall of quartz-muscovite vein (7b), bottom of plate, and sharp contact with quartz-topaz vein (7c), top of plate.

trend 120-140 degrees (Figure 12). Their orientation and relative age with respect to contained vein material is described below. The detailed information obtained in the underground workings was used to prepare a synthesis of joint-fault-vein relationships (Figure 13).

Northeasterly striking quartz veins with minor pyrite and pyrrhotite (map-unit 7a) occur in shear zones which pre-date all other joints, faults and veins (Figure 13a). These shears are irregular, branching, and occur in zones several feet wide. A few joints were mapped with this orientation, but they are unmineralized and may be younger.

A large number of joints and faults were recognized in the 120 degree direction (Figures 12 and 13b). They are straight and planar, but in places are irregular and pinch out like tension joints. Many are filled with narrow quartz-muscovite veins (7b), and locally have small tension fractures branching off them filled with the same material. They are always at an angle less than 120 degrees and are most common in the 100-110 degree range. Most of the 120 degree quartz-muscovite veins are sheared. The quartz is broken along one or more central fractures and the margins have slickensided walls (Plates 13b, 17a,b). Later faulting has re-opened many of these vein filled fractures and veins of map-unit 7c were emplaced.

Faults in the 140 degree direction have been recognized at several places in the underground workings (Figure 11) and they are generally more abundant than joints with this orientation (Figure 12). Veins of map-unit 7c were emplaced (Figure 13c) both in the 140 degree faults and joints but it is difficult to determine the exact relationships between these structures. They occur together and locally the 140 degree vein filled joints change direction (particularly near older 120 degree faults and joints). Age relationships are complicated by

FIGURE 12: ORIENTATION, MINERALIZED AND MINERALIZED JOINTS AND FAULTS, BURNT HILL AREA

FIGURE 13

**SCHEMATIC DIAGRAM SHOWING DEVELOPMENT OF
FRACTURE PATTERN AND SEQUENCE OF VEIN EMPLACEMENT**

- **T_C VEINS - QUARTZ, TOPAZ-WOLFRAMITE, BERYL, HOLYDENITE, FLUORITE, SULPHIDE MINERALS**
- **T_B VEINS - QUARTZ, MUSCOVITE MINOR WOLFRAMITE, HOLYDENITE, FLUORITE, BERYL, CRATERITE**
- **T_A VEINS - QUARTZ, PYRITE, PYRRHOTITE**

Plate 17a - Slickensided wall of vein in 120 degree direction.
(West No.2 drift)

Plate 17b -Large quartz-muscovite vein (7b) in 120 degree direction.
(East No. 1 drift). Note slickensided wall. This vein
is displaced by 140 degree fault, beyond photo.

later movement on the 140 degree structures which displaced the 7c veins with left-lateral movement (Plate 18a). Older 7b veins are also displaced and breccias composed of fragments of 7b veins have been recognized, particularly 25-200 feet south of the portal. These 149 degree faults locally splay and follow older 120 degree faults previously filled with veins of map-unit 7b. This may be observed at the entrance to No. 1 east drift. Composite veins of units 7b and 7c are common in fractures in the 120 degree direction, but new joints in the 120 degree direction developed and were also filled with veins of unit 7c. They resemble tension joints and pinch out a few feet along strike (Plate 18b).

A few late joints and faults were observed cutting veins, faults and joints in the 120-140 degree direction (Figure 13d). They strike about 040 degrees and also between 160-180 degrees. Displacement on these structures is commonly less than a few inches.

CORRELATION, JOINTS, FAULTS, MINERALIZED VEINS AND REGIONAL STRUCTURE

Field data indicates that joints and faults in the Burnt Hill area developed after regional; folding, emplacement of granitoid batholiths (6a,b) contact metamorphism, retrogressive metamorphism and the intrusion of the Mine quartz monzonite (6c). The greatest number of joints and faults strike southeast but a few were mapped with a north-east orientation.

The earliest fractures occur in the 120 degree direction. and are commonly filled with veins of map-unit 7b. In places, veins with this orientation maintain a uniform strike and thickness for several hundred feet. These fractures are interpreted to be tension joints as they are normal to the regional trend of the Ordovician strata (Figure 13b).

Plate 18a - Quartz-topaz vein (7c) in 120 degree joint, closely related to and displaced by 140 degree fault. (West No. 2 drift, approximately 2000 feet from main cross cut).

Plate 18b - Quartz-topaz vein (7c) in 120 degree tension joint near 140 degree fault. Note these veins pinch out along strike, unlike the quartz-muscovite veins (7b) which maintain width for several hundred feet (Plate 17b)

Joints and faults striking 140 degrees are abundant in the underground workings (Figure 12). and are oriented in the theoretical shear direction (Figure 13b). They developed after the 120 degree tension joints were filled with vein material and faulted. Faults striking 140 degrees re-opened many of these older 120 degree structures and quartz-topaz veins of map-unit 7c were emplaced in both the 120 and 140 degree structures. Faulting predominated in the area after the 120 degree tension joints were developed and it is assumed this was due to regional rather than local stresses. All joints and faults were cut and locally displaced by younger joints and faults striking 040 and 160-180 degrees. None are mineralized.

The greatest number of veins appear to be concentrated about zones where the 140 degree faults are best developed (Figure 11). Here, veins of map-unit 7c are superimposed upon older 7b veins in the 120 degree fractures. Individual veins are larger (up to 4 feet) and can be traced in some places for several hundred feet. Slickensides in the 140 and 120 degree faults plunge steeply to the northwest at about 75 degrees. Well mineralized zones rake, possibly in this direction. As many of the 7b and 7c veins are displaced by left-lateral faults, an en echelon arrangement of these zones has resulted. Individual veins may be displaced by late left-lateral faults striking 040 and 160-180 degrees.

Few data are available on the nature and origin of joints. At Burnt Hill, joints in the tensional direction (120 degrees) developed throughout the area, and in places have associated fractures striking 100-110 degrees which is an orientation compatible with the theoretical planes of maximum shear. The problem of mineralized

veins occurring in the theoretical shear direction has been recognized by De Sitter (1956) and Wilson (1961). It is difficult to determine the reason for the repeated movement on the 120 degree faults as well as the younger 140 faults. Late wrench movement is interpreted on the Tom McKiel fault to explain possible dissimilarities in the orientation of folds and joints in the eastern and western parts of the map-area, and it is postulated that the 140 degree faults as well as younger faults and joints observed at the Burnt Hill deposit are also related to wrench movement. If so, the 140 degree faults might be equivalent to the second order left-lateral shears as in a model proposed by Moody and Hill (1956). If this interpretation is correct, the best developed veins may be concentrated in and near fault zones with this orientation.

CHAPTER V

METALLOGENIC ANALYSES

The principles of metallogenesis as developed by Soviet workers such as Bilibin (1955) and others provide a new approach to the study of ore deposits. This approach is most useful in the study of large areas in which the regional relationships of mineral deposits to sedimentation, intrusion, vulcanism and deformation may be determined. In this section, occurrences of W, Mo, Sn and related elements are correlated in an attempt to find the common factors controlling their distribution throughout the Canadian Appalachian folded belt. A possible origin for the Burnt Hill deposit is proposed and tested by using this regional data and the detailed geological and geochemical information obtained in this thesis.

OCCURRENCES OF WOLFRAMITE, MOLYBDENITE, CASSITERITE AND RELATED MINERALS IN THE CANADIAN APPALACHIAN FOLDED BELT

It has recently been shown by Neale and others (1961) and by McCartney and Potter (1962) that the Soviet concepts of metallogenesis are applicable to the Canadian Appalachian folded belt. This folded belt is a northeasterly trending zone of highly deformed Precambrian and Palaeozoic sedimentary and volcanic strata which have been intruded by igneous rocks of various ages. Although the structural history is extremely complex, three stages of structural development have been recognized. They are: the initial stage, (Cambrian-Ordovician)

representing the geosynclinal period in the history of the folded belt; the intermediate stage (Silurian to Devonian), representing the period of orogenic activity; and the terminal stage (Late Devonian-Triassic), representing the epeirogenic period of development. All occurrences of W, Mo and Sn minerals are related to the intermediate and terminal stages. Cu - Mo occurrences which may be related to older intrusives are excluded from this discussion.

Occurrences of W, Mo, and Sn minerals are known in the Eastern Townships of Quebec and Gaspé, New Brunswick, Nova Scotia and Newfoundland (Figure 14, in pocket). Not only are different types of occurrences present, but host rocks vary in age from Precambrian to Mississippian. Fluorite, beryl and bismuth minerals are intimately associated with these deposits. They are summarized in Appendix 1. From this information, four main types of deposit are recognized.

CAMBRIAN-ORDOVICIAN (Initial stage) - no deposits appear to be directly related to deformation or igneous activity of this stage. Many occurrences are known in sedimentary and volcanic rocks deposited during the initial stage, but they appear to be related to younger igneous events.

SILURIAN-DEVONIAN (Intermediate stage) - the greatest number of occurrences are related to the intermediate stage, and include:

- (1) - Group A: Contact metasomatic deposits of Cu - Fe with minor W and Mo minerals.
- (2) - Group B: Veins of quartz-native gold, with W minerals.

- (3) - Group C: Veins of quartz-pegmatite-greisen with minerals of W, Mo, Sn, Be, Bi and F.

UPPER DEVONIAN-TRIASSIC (Terminal stage) - only one major deposit with W, Mo, Sn minerals is known and is intimately related to Mississippian volcanic and tectonic activity.

- (4) - Group D: Disseminated Cu and Zn, As and Sn sulphides with fluorite, kaolin, cassiterite, molybdenite and wolframite in Mississippian volcanics.

GROUP A OCCURRENCES

Contact metasomatic deposits of chalcopyrite, magnetite, pyrite and minor scheelite and molybdenite are known near Nicholas Denys, Popelogan Lake, N.B. and St. Francois, Que. Mineralization is restricted to the metamorphic aureole of felsic or granitic dykes, sills or stocks of Silurian and/or Devonian age. These intrusive rocks are found only in the areas outside the main zone of intermediate stage batholithic intrusion, and may be related to Silurian and Devonian volcanic activity. The deposits are restricted to calcareous sedimentary rocks and the known occurrences are confined to the relatively undeformed basins of Silurian and/or Devonian strata where calcareous sedimentary rocks are abundant.

GROUP B OCCURRENCES

Quartz vein deposits with native gold, scheelite and minor sulphides have a restricted distribution, and are found mainly in Nova Scotia. A few small occurrences of scheelite without native

gold are known in Newfoundland and Quebec. Scheelite is not present in all of the gold deposits of Nova Scotia, but was found in large quantities at Moose River, Indian Path, and Lake Charlotte. The structural control for these deposits is remarkably uniform, and has been discussed by Douglas (1948). In general, quartz gold-scheelite veins are found parallel to the bedding, or in cross-joints and faults.

Known occurrences are found only within initial and intermediate stage sedimentary rocks which were deposited within large basins (generally non-calcareous). Scheelite is localized in quartz veins which may be concordant or discordant to the bedding. All deposits occur in strata deformed and intruded by granite batholiths of the intermediate stage; but a specific relationship to any particular phase of granitic intrusion has not been established. There is indeed some evidence in the Forest Hill and Country Harbour area of Nova Scotia to suggest the veins may pre-date the granitic rocks (Malcolm, 1929).

GROUP C OCCURRENCES

The greatest abundance of W, Mo and Sn minerals belong to this group. They are found in many areas within the Canadian Appalachian region and are mineralogically different from the preceding group as wolframite is the main tungsten mineral. Scheelite is present only in minor quantities. W, Mo and Sn minerals are disseminated in pegmatite and greisen veins, and disseminated molybdenite, beryl, and fluorite are found within the granites in a few places.

Deposits of this group include one past producer, the Burnt Hill tungsten deposit of central New Brunswick. Although the fluorite veins of the St. Lawrence area in Newfoundland may be the same age as other occurrences of this group, further work is necessary before they can be included. Other occurrences worthy of note are: the Rencontre East and Grey Rivers areas of Newfoundland, the Gabarus and New Ross areas of Nova Scotia, and the Pabineau and Square Lake areas of New Brunswick. Base metal and silver have been reported from similar occurrences in Quebec, and in this regard they are unlike most other deposits in the Appalachian region.

Most deposits of this group are spatially related to the aplitic, quartz monzonitic, alaskitic and pegmatitic phases of the main intermediate stage (Devonian) granite batholiths which occur either as separate intrusions, or as marginal phases of the larger batholiths. The data available indicates that the largest deposits are associated with the former. The age and lithology of the country rock appears to be of some significance as these deposits are found near the margins of intrusive rocks which have been emplaced mainly within the sedimentary and volcanic strata of the initial stage (Cambrian-Ordovician). In many cases mineral occurrences of this type are concentrated within granitic embayments into the country rock. Numerous other occurrences have been found several miles inside the batholiths.

Faults, shear zones, joints in the direction perpendicular to the regional strike appear to be the most favourable structural controls for these deposits.

GROUP D OCCURRENCES

There is only one known example of this type of deposit,

i.e. Mount Pleasant, New Brunswick. Here, cassiterite, stannite, and other sulphide minerals occur in highly altered rhyolitic volcanic rocks believed to be of Mississippian age (van de Poll, 1966). Molybdenite and fluorite are common. Wolframite is locally abundant (J. E. Riddell, Personal communication, 1969). Mineralization appears to be concentrated along fracture zones, shears, or within highly irregular breccia pipes and dykes. The mineralization may be derived from older deposits of type C (A. A. Ruitenberg, personal communication, 1969).

In summary, most occurrences of W, Mo and Sn minerals are associated with the Intermediate (batholithic) stage of folded belt development. Sn however may be most abundant in the Terminal stage.

Almost all of Type B and C deposits are found within Cambrian-Ordovician pelitic sedimentary rocks. Contact metasomatic deposits of Type A are found in calcareous strata which are as young as Devonian. Rarely do Type B and C deposits occur together and rarely to Type C deposits occur in non-sedimentary rocks. Occurrences similar to Burnt Hill are found within or just outside the margins of Devonian granitic batholiths. A large number are concentrated near small stocks which have been mapped on the flanks of these batholiths.

GENESIS OF THE BURNT HILL TUNGSTEN DEPOSIT

Mineral occurrences in the Canadian Appalachians which are similar to Burnt Hill appear to have a two-fold lithologic control:

- (1) Pelitic sedimentary rocks of Early Palaeozoic age (Cambrian-Ordovician mainly) are the most common host for the quartz

veins with W, Mo and Sn minerals. Exceptions are known, i.e.: the Grey River prospect in Newfoundland which occurs in metamorphosed sedimentary and volcanic rocks. Strata near W, Mo and Sn occurrences are folded and metamorphosed.

- (2) There is a close spatial relationship with Devonian granitic batholiths, and locally these igneous rocks form the host rock for quartz veins with W, Mo and Sn minerals.

Both the Ordovician strata and the Devonian granitic rocks occur at Burnt Hill and two genetic models may therefore be considered: Model I - W, Mo and Sn were derived from the argillites and quartzites of the Miramichi Formation (4) which contain the mineralized veins; and 2 - W, Mo and Sn were derived from and related to the granitoid batholiths (6).

Model I - Argillites and quartzites of Miramichi Formation (4)

Nearly all the mineralized veins in the Burnt Hill area occur within the argillites and quartzites of the Miramichi Formation (4), the only exception being a few that have been found within the Burnt Hill and Mine quartz monzonites (6b, c). The association here, as well as elsewhere in the Canadian Appalachians would indicate a genetic relationship to the sedimentary rocks.

Petrographic studies of the Ordovician strata in the Burnt Hill area suggests W and Sn may have been deposited with other clastic material in the Push-and-be-Damned Formation (3) and the Miramichi Formation (4) (Chapt. 2, pp 47-48). Mo should be most abundant in the fine silty and argillaceous beds.

If W, Mo and Sn occurs within these sedimentary rocks, lateral secretion is perhaps the most likely method by which they may be removed and deposited in fractures. This theory of origin has received considerable support in recent years and has been demonstrated in numerous papers by R. W. Boyle (Boyle, 1961, 1965).

W, Mo and Sn are chalcophile elements and Boyle (personal communication, 1969) believes they should be concentrated in the sulphide minerals within sedimentary rocks. The ionic potential also permits them to be precipitated with alumina and clay minerals. Regardless of the form in which they are transported or precipitated, Boyle envisages small amounts of these elements being extracted from the country rock and transferred to joints, faults shear zones or other areas of low chemical potential. The mobility of elements is dependant upon many factors, particularly the presence of volatile constituents (H_2O & F). The latter were undoubtedly present when the veins at Burnt Hill developed. Suitable structural sites for deposition were also available and it is possible that W, Mo and Sn were derived from the argillites and quartzites of the Miramichi Formation (4).

Model 2 - Granitoid batholiths (6)

Without exception, W, Mo and Sn deposits of the Canadian Appalachians are spatially related to Devonian granitic batholiths and the Burnt Hill area is a typical example of this association. Descriptions of deposits which are mineralogically similar are well documented in the literature, but the great variety of minerals present at Burnt Hill indicates it has the characteristics of pegmatitic, mesothermal and xenothermal deposits.

Most authors agree that quartz veins with wolframite, topaz, beryl, molybdenite and cassiterite represent the last stages of magmatic activity. Veins which are gradational between the batholiths, pegmatites and quartz veins are rare but have been recognized in a few places (Bateman, 1950). Mineralogical, textural and chemical variations have been noted at Burnt Hill between the batholithic rocks, greisens and quartz veins (Figure 15) and a genetic association is supported.

The minerals present at Burnt Hill belong to a complex group whose charge and ionic radius does not permit them to be incorporated within the lattices of the common rock forming minerals (Be^{+2} 0.35, W^{+6} 0.62, Mo^{+4} 0.70 and Sn^{+4} 0.71). The presence of volatiles has been recognized and the Mine quartz monzonite contains about twice as much water as the other granitoid rocks. It is possible that this is only part of the total water originally present as much was lost during the formation of the retrograde metamorphic aureole. These data are in agreement with the concepts of residual magmatic fluids and the mineralized veins at Burnt Hill may represent the last phase of a single magmatic event.

GEOCHEMISTRY OF SEDIMENTARY AND IGNEOUS ROCKS OF THE BURNT HILL
AREA WITH SPECIFIC REFERENCE TO W, MO, AND SN

Geological studies provided information on the stratigraphy, structure, metamorphism and igneous activity in the Burnt Hill area; but fundamental questions concerning the ultimate source of W, Mo and Sn and the origin of the mineralization still remain. In an attempt to resolve these problems all map-units were analysed for trace amounts of these elements. Their distribution and abundance in the Ordovician strata may test earlier predictions (Chapter II, pp 47, 8) and will aid in the evaluation of genetic model (I) based on an origin of W, Mo and Sn from within the sedimentary rocks. Their distribution within the quartz monzonites may provide data on the relationships of these rocks to the mineralized veins and thereby test model (2) based on an origin from within the granitoid batholiths. Information of the role of these elements during metamorphism will be discussed (p. 110). The source of these elements is considered and the geological and geochemical data are correlated in order to construct a genetic model for the mineralized veins at Burnt Hill.

The location of specimens collected for trace element analyses is shown on Figure 16. Sampling, preparation and analytical techniques are described in Appendix 2. The detection limits for these elements in parts per million are: W-3, Mo-1, Sn-2. Analytical precision varies with concentration and is approximately ± 25 per cent in the vicinity of 10 ppm. No data is available on the accuracy of the method employed but quantities obtained are in good agreement with the W, Mo and Sn content of rocks from other areas.

FIGURE 16

SKETCH MAP SHOWING LOCATION OF SPECIMENS COLLECTED FOR U, MO, SN ANALYSES

0 1
SCALE OF MILES

● - SAMPLE LOCATION AND NUMBER

x - SAMPLE FROM DRILL CORE

SEDIMENTARY ROCKS

The general distribution of W, Mo and Sn within the sedimentary rocks of the area is described below, and is followed by a brief account on the geochemistry of each element (Tables 6 & 7). The Ordovician sedimentary rocks are considered as a possible source for the W, Mo and Sn that occurs in the mineralized veins.

SEQUENCE (1)

Conglomerates and argillites in the lowermost part of this sequence were believed to contain resistant W and Sn minerals (Chapt. 2, pp 47, 8). Mo was anticipated in the argillaceous and fine grained beds near the top of map-unit (1) and in cherts and argillites of the overlying Hayden Lake Formation (2).

Buttermilk Brook Formation (1) - W, Mo and Sn were not detected in the single sample obtained from this unit which contained nearly equal amounts of clastic and argillaceous material.

Hayden Lake Formation (2) - W, Mo and Sn were not detected in the red-brown cherts of the Hayden Lake Formation (2), but W and Mo were detected in the black cherts (7 and 10 ppm respectively). These quantities are higher than concentrations found in carbonaceous rocks from other areas.

SEQUENCE (2)

Resistant W and Sn minerals were expected within the clastic rocks of the Push-and-be-Dammed Formation (3) and the quartzites of the Miramichi Formation (4) (Chapt. 2, pp 47, 8). Concentrations of Mo were anticipated in the argillaceous and silty beds.

Table 6: W, Mo and Sn content of sedimentary rocks, Burnt Hill area.
(expressed in parts per million)

<u>Sample No.</u>	<u>Map-unit</u>	<u>Lithology</u>	<u>W</u>	<u>Mo</u>	<u>Sn</u>
1	1	cong.	<3	<1	<2
2	2	red chert	<3	<1	<2
3	2	blk. chert	7	10	2
4	3	carb. arg.	5	48	<2
5	3	carb. arg.	<3	4	8
6	3	carb. arg.	<3	<1	15
8	3	carb. arg.	10	1	5
7	3	carb. arg.	3	<1	2
9	4	arg.	3	1	5
10	4	qtzite.	<3	<1	<2
11	4	qtzite.	<3	<1	5
12	4	arg.	20	2	2
13	4	arg.	<3	<1	<2
14	4	arg.	<3	<1	<2
15	4	arg.	<3	<1	<2
16	4	arg.	<3	<1	<2
17	4	arg.	<3	<1	5
18	4	arg.	<3	<1	<2
19	4	arg.	<3	<1	<2
20	4	arg.	5	<1	<2
21	4	arg.	7	1	<2
22	4	arg.	10	<1	<2
23	4	arg.	3	<1	10
24	4	arg.	<3	3	5
25	4	arg.	3	1	5
26	4	arg.	3	<1	10

Table 7: Average W, Mo and Sn content of stratigraphic units, Burnt Hill area* (expressed in parts per million)

Sequence	Map-unit	Formation	No of samples	W	Mo	Sn
1	1	Buttermilk Bk.	1	3	0.5	1
1	2	Hayden Lk.	2	4	5	1
2	3	Push-and-be-Damned	5	4	11	6
2	4	Miramichi	18	4	1	3

* For samples below 3 ppm W, 2 ppm used for calculating average amount similarly for Mo - 0.5 ppm and Sn - 1.0 ppm

The western belt of the Push-and-be-Damned Formation (3) contains the greatest abundance and variety of unstable constituents and high concentrations of W and Sn were expected in their rocks.

Push-and-be-Damned Formation (3) - Sn is the only element enriched in the carbonaceous strata of the western belt. An unusually high Mo value of 48 ppm was recorded from one sample but this is much higher than the Mo content of other Ordovician strata and is not representative of the unit.

Miramichi Formation (4) - Argillites and quartzites of this map-unit are low in W, Mo and Sn. The distribution throughout the unit is random and these elements do not appear to be concentrated in any particular area. Two anomalous highs of 10 and 20 ppm were obtained at widely separated points. The higher concentration was obtained within six closely spaced sample locations which returned low W values and is therefore interpreted to be a "spot" high with no regional significance.

W, MO AND SN IN THE SEDIMENTARY ROCKS

Tungsten - Except for two isolated high samples, concentrations are consistently low (4 ppm) and show little variation within the map-units (Table 7). W was expected to be enriched in the clastic rocks but appears to be evenly dispersed throughout. It may be highly mobile (Hawkes and Webb, 1962) and the uniform distribution in the sedimentary rocks suggests W may be carried in solution and precipitated or adsorbed under suitable conditions with alumina and clay minerals. The abundance of this element in the Ordovician strata of

the Burnt Hill area corresponds to quantities obtained elsewhere (Table 8) and is slightly higher (at this level of concentration) than the 2 ppm average for sedimentary rocks reported by Krauskopf (1967).

Molybdenum - Mo is not enriched in the argillaceous rocks of the Push-and-be-Dammed and Miramichi Formations (3 & 4) even though high concentrations were expected in these rocks. Other workers obtained comparatively large quantities in carbonaceous rocks (Table 8) but this was not found in the Burnt Hill area. If the single high of 48 ppm is not considered an average of 1 ppm Mo is obtained for the carbonaceous rocks of the Push-and-be-Dammed Formation (3) This is more compatible with the average Mo content of the Miramichi Formation (4) (1 ppm) and the average of 2 ppm for shales quoted by Krauskopf (1967).

Tin - Tin is quite variable (Tables 6 & 7). It was expected in the clastic rocks but the highest concentrations were obtained in the carbonaceous strata of the Push-and-be-Dammed Formation (3). It is possible that Sn is present partly as cassiterite and partly as Sn compounds adsorbed by the argillaceous material. Quantities obtained at Burnt Hill are in good agreement with those obtained elsewhere (Table 8).

THE ORDOVICIAN STRATA AS A POSSIBLE SOURCE FOR THE W, MO AND SN IN THE MINERALIZED VEINS

Several factors must be considered if the argillites and quartzites of the Miramichi Formation (4) were the source of the W, Mo and Sn in the Burnt Hill area: (1)-There is evidence for

Table 8: Average W, Mo and Sn content of rocks from Burnt Hill area and compared to data obtained elsewhere, (expressed in parts per million).

Lithology, location, age, reference	W	Mo	Sn
Carbonaceous greywackes and argillites, Burnt Hill	3.6	10	6
Carbonaceous rocks, Bathurst N.B., Ordovician (Boyle, Tupper, et al, 1966; Tauchid, 1966)		6.5	5
Graphitic schist, Yukon, Precambrian, (Boyle, 1968)	<4	8	4
Graphitic tuff, Yellowknife, Precambrian (Boyle, 1968)	<5	(10-50)*(8-22)*	
Graphitic schist, Cobalt (Precambrian) (Boyle, 1968)	<4	3	
Carbonaceous shale, Walton, N.S., Mississippian (Boyle, 1969) unpublished data)	<4	3.3	6.3
Greywacke, Ovens area, N.S. Ordovician (Boyle, 1968)	<4	<1	
Phosphatic shale, Walton area, N.S. Mississippian, (Boyle, 1969, unpublished data)		11.5	4.45
Shale, average (Krauskopf, 1967)	2	2	6
Crustal average (Krauskopf, 1967)	1.5	1.5	2
Argillites and quartzites, Burnt Hill	3	<1	2
Grey-green shale, Walton, N.S. Mississippian, (Boyle, 1969, unpublished data)		<1	5.2
Limestone, Walton, N.S. Mississippian, (Boyle, 1969, unpublished data)		~1	.1
Red-buff shale, Walton, N.S., Mississippian, (Boyle, 1969, unpublished data)		1.13	0.81
Sandstone, Wolfville, N.S. area, Triassic, (Boyle, 1969, unpublished data)		<1	1.1

* Figures in brackets indicate range of values,
average not available.

enrichment of these elements, (2) - The average concentrations of W, Mo and Sn were sufficient to provide the wolframite, molybdenite and cassiterite that occur in the veins, and (3) - A mechanism is available to drive the elements from the sedimentary rocks into the joints and faults.

(1) - The average W, Mo and Sn content of the argillites and quartzites of the Miramichi Formation (4) corresponds with concentrations found in similar rocks elsewhere (Table 8). There is no evidence for enrichment in any part of this unit, or in the vicinity of the Burnt Hill deposit (except the veins themselves).

(2) - Nearly all the mineralized veins in the Burnt Hill area occur within the zone of retrograde metamorphism produced by the underlying Mine quartz monzonite (6c). Using W as an example, it is possible to compare the amount of metal available in the argillites and quartzites of the Miramichi Formation (4) to the approximate amount in the quartz veins within this zone.

The zone of retrograde metamorphism is approximately 6000 feet in diameter (where exposed at the surface). A square, one mile on each side was drawn within the zone (Figure 16). It extends to a depth of 1000 feet on the southeast where it intersects the surface of the Mine quartz monzonite (6c), and thins out to 0 feet to the northwest where the Burnthill quartz monzonite (6b) is exposed at the surface.

$$\begin{aligned}
 \text{The total volume of rock in this zone} &= \frac{5280 \times 5280 \times 1000}{2} \\
 &= 13,939,200,000 \text{ cu.ft.} \\
 &= 13 \times 10^9 \text{ ft}^3 \\
 \text{Using 175 lbs./cu.ft.} &= \frac{175 \times 13,939,200,000}{2000} \\
 &= 1,344,932,400 \text{ tons}
 \end{aligned}$$

A rough estimate of the total amount of vein material was determined by counting the number of veins and their widths in the main cross-cut of the underground workings. Approximately 1 per cent is estimated to be vein material.

$$\begin{aligned}
 \text{The total tonnage of vein material} &= (1,344,932,400 \times 0.01) \\
 &= 13,449,324 \text{ tons}
 \end{aligned}$$

The wolframite of this zone is predominantly ferberite which contains about 60 per cent metallic tungsten. The average wolframite content of the veins is estimated to be 0.01.

$$\begin{aligned}
 \text{The total tonnage of metallic W in these veins} &= (13,449,324 \times 0.001 \times 0.6) \\
 &= 8,359 \text{ tons}
 \end{aligned}$$

The average W content of the argillites and quartzites of the Miramichi Formation is 4 ppm. There is no evidence for depletion of this element but assuming that 2 ppm has been removed from these strata, the total amount of W then available would be:

$$\begin{aligned}
 &= \frac{(2 \times 1,344,932,400)}{10^6} \\
 &= 2,686 \text{ tons}
 \end{aligned}$$

The figure of 8,359 tons of W in the mineralized veins is minimal as many of them extend 100 feet or more within the Mine quartz monzonite (6c). If all veins are considered, approximately 8 ppm W would have to be removed from the country rock to provide the required amount of metal. This would be over and above the 4 ppm average obtained for the map-unit (Table 7), hence the Miramichi Formation should average 12 ppm. This is well above the average found for any of the sedimentary rocks.

A much larger volume of sedimentary rocks may be considered as the source for the W, Mo and Sn in the Burnt Hill area, but because of the shallow depth to the surface of the granitoid batholiths, it would have to extend for a mile or more beyond the limits of the area outlined on Figure 16 and well beyond the zones of progressive and retrogressive metamorphism.

(3) - A secretion process has been proposed as a possible method of removing the W, Mo and Sn from the sedimentary rocks and introducing them into the joints and faults at Burnt Hill. These elements are believed to migrate into suitable structural sites during metamorphism. It is doubtful if a similar process produced the mineralized veins at Burnt Hill because; (1) - There is insufficient W, Mo and Sn in the country rocks within the metamorphic aureole, and (2) - Structural sites were not available until metamorphic processes had ceased.

A satisfactory process for concentrating the elements within the sedimentary rocks cannot be advanced. The regional association of W, Mo and Sn deposits with Early Palaeozoic pelitic sedimentary rocks cannot be reconciled on the basis of detailed work at Burnt Hill. An indirect association is possible and this will be discussed later with the proposed genetic model for the mineralization of this area.

IGNEOUS ROCKS

The diabasic sills and dykes (5) and quartz monzonites (6) were analysed for their W, Mo and Sn content (Table 9). The mafic constituents of these rocks were separated by bromoform and analysed separately.

Diabase sills and dykes (5) - The W, Mo and Sn content is low and only minor amounts were detected in the mafic constituents. They do not appear to be related to the mineralization at Burnt Hill.

Clearwater quartz monzonite (6a) - The W and Mo content is low (3 ppm and 1 ppm respectively). Their abundance in the mafic constituents (biotite and chlorite predominantly) indicates that these elements may be contained within other rock forming minerals. The Sn content (20 ppm) is higher than the other quartz monzonites and appears to be more abundant in the whole rock rather than the mafic constituents. It is possible that cassiterite or some other Sn mineral may be present within this quartz monzonite.

Burnthill quartz monzonite (6b) - This unit contains anomalous amounts of W, and Mo (average of 19 and 10 ppm respectively). These were not expected as this unit is more than a mile away from the known mineralized area. Sn is less abundant in comparison with the Clearwater

quartz monzonite (6a). All elements were detected in the mafic constituents but they are only partly concentrated there.

Table 9: W, Mo and Sn content of igneous rocks and their mafic constituents, Burnt Hill area (expressed in parts per million)

Sample No.	Map-unit	Lithology	whole rock			mafic mineral		
			W	Mo	Sn	W	Mo	Sn
37	5	Diabase	<3	<1	<2	7	<1	15
43			<3	<1	<2			
38	6a	Clearwater quartz monzonite	3	<1	20	17	13	15
39	6b	Burnthill quartz monzonite	25	14	2	100	550	15
40		" "	13	6	10			
41	6c	Mine quartz monzonite	<3	<1	<2	20	12	15
42	8b	Greisen dyke in Miramichi Form. (4)	20	1100	25			

Mine quartz monzonite (6c) - High concentrations of W, Mo and Sn were expected in this intrusive as it is spatially related to the mineralized veins and is located approximately 600 feet below the Burnt Hill tungsten deposit. The rock is mineralogically homogeneous and the single sample analysed is assumed to be representative. The content was low but all elements were detected in the mafic constituents.

Greisen dykes (7b) - These dykes intrude the Mine quartz monzonite (6c) and appear to be transitional between the granitoid batholiths and the mineralized veins. They are enriched in W, Mo and Sn.

W, Mo AND Sn IN THE IGNEOUS ROCKS

Tungsten: Few data are available for this element but Sandell (1946) found that the W content of eleven granite samples varied between 1.1 and 2.6 ppm. This small variation was confirmed by Vinogradov and others (1958). The data in Table 10 also indicates little variation in the tungsten content of granitic rocks. The average of 19 ppm obtained on the Burnthill quartz monzonite (6b) is distinctly anomalous, particularly when compared to the amounts obtained in other quartz monzonites of the Burnt Hill area and the 2 ppm for granitic rocks obtained by Krauskopf (1967). Analyses of the mafic constituents (Table 9) (mainly biotite and chlorite) suggests that this element is only partly concentrated in these minerals. It is possible that W replaces some elements in other rock-forming minerals.

Molybdenum: Mo, like W, is present in low concentrations within granitic rocks, and the average amount is similar to that for shales (2 ppm) (Table 8). At Burnt Hill, quantities within the Clearwater and Mine quartz monzonites (6a, c) are compatible with those obtained from other areas. Mo appears to be concentrated in the biotites and chlorites. This is particularly true of the Burnthill quartz monzonite 6b (Table 9). The association of molybdenum with mica structure was confirmed as thin films of molybdenite were recognized along cleavage planes in one of the quartz muscovite veins (7b). The Burnthill quartz monzonite (6b) is anomalously high in Mo (10 ppm).

Table 10: Average W, Mo and Sn content of quartz monzonites of the Burnt Hill area as compared to data obtained elsewhere. (expressed in parts per million).

Lithology, location, reference	W	Mo	Sn
Crystal average (Krauskopf, 1967)	1.5	1.5	2
Granite, average, (Krauskopf, 1967)	2	2	3
Felsic rocks, U.S.S.R. (Vinogradov, 1958)	2.4	1.6	
Mafic rocks " " "	1	2.2	
Granites, U.S.S.R., (Vinogradov, 1963)	1.2	1.1	5
Granites, U.S.S.R. (Ivanova, 1963)	1.5	1	3
Clearwater quartz monzonite (6a), Burnt Hill	3	1	20
Burnt Hill quartz monzonite (6b), Burnt Hill	19	10	5
Mine quartz monzonite, (6c), Burnt Hill	<3	<1	<2

Tin - Highest concentrations of this element were obtained in the Clearwater quartz monzonite (6a) (20 ppm), and smaller amounts were detected in the younger (?) Burnthill and Mine quartz monzonites (6b, c). This element is generally enriched in granitic rocks with respect to W and Mo (Table 10), but a reverse relationship was noted within the Burnthill quartz monzonite (6b) where W and Mo are most abundant. Concentrations obtained within this unit are comparable to the relative amounts of wolframite, molybdenite and cassiterite in veins of the Burnt Hill area. Quantities obtained elsewhere in New Brunswick are quite variable. Boyle, Tupper and others (1966) found tin ranging in concentration between 1 - 50 ppm in the Bathurst area and Mulligan (1966) notes 25 - 30 ppm in granitic rocks of the same age about 100 miles south of Burnt Hill. Further work is required

before the significance of the Sn content of the quartz monzonites at Burnt Hill can be determined.

THE GRANITOID BATHOLITHS AS A SOURCE OF W, MO AND SN

The Burnt Hill deposit is spatially related to the Devonian granitoid batholiths, a characteristic common to all other similar deposits elsewhere in the Canadian Appalachian Region. Mineralized veins are restricted to an aureole of retrograde metamorphism at the southeast end of an apophyses of a Devonian batholith. The retrograde aureole and the mineralized veins appear to be associated with an equigranular quartz monzonite about 600 feet below the deposit and a genetic relationship is implied.

Geochemical data shows that the Clearwater and Mine quartz monzonites (6a, c) have W and Mo concentrations similar to the Ordovician sedimentary rocks. Tin is the only element which is concentrated in the former. The Burnthill quartz monzonite (6b) however, contains nearly 10 times as much W and Mo and the quantity of these elements in this unit would be enormous, particularly if compared to tonnages available in the argillites and quartzites of the Miramichi Formation (4) calculated on the basis of 2 ppm. It is the most obvious source for the W and Mo in the area.

There are many mineralogical and chemical similarities between the granitoid batholiths and the mineralized veins (Table 2 and Figure 15). Progressive changes in composition are suggestive of a continuous process of magmatic differentiation or fractional crystallization. This is supported both by field relationships and geo-

chronologic data. These include:

<u>Oldest</u>	increasing silica and free quartz	
	decrease in total Fe	granitoid
	increasing H ₂ O	batholiths
	increasing muscovite	
	decrease in biotite	
	increasing volatile constituents (F)	dykes and veins
	increasing W, Mo and Sn	
<u>Youngest</u>	increasing quantity of sulphide minerals	

The progressive changes toward a residual melt rich in silica and metallic elements that cannot be incorporated readily into the structure of the common rock-forming minerals are in agreement with the commonly held concepts of magmatic evolution. Geochronologic data suggests that the transition from batholiths to mineralized veins took place over a span of time, or about Early to Middle Devonian. The mineralized veins appear to be the last phase of a single magmatic event but process was not a continuous one as different ages of batholithic rocks and veins were emplaced in a pulsatory manner.

Regional, geochemical and mineralogical data indicate the granitoid batholiths are the most obvious source of the W, Mo and Sn in the Burnt Hill area (Model 2). There are problems concerning the mode of concentration and emplacement of the mineralization and these will be discussed later.

METAMORPHISM

Argillites and quartzites of the Miramichi Formation (4) were folded, intruded by quartz monzonites and metamorphosed to spotted rocks with porphyroblasts of cordierite, andalusite and biotite. Water

and other volatile constituents (W, Mo and Sn?) probably migrated outward from the intrusives down the thermal gradient to cooler areas. Isograds are roughly parallel to the contact. There is no evidence for forcible intrusion and fractures did not develop until after the emplacement of the Mine quartz monzonite (6c) which was accompanied by the pervasive introduction of water and the formation of an aureole of retrograde chlorite. Because there was widespread introduction of water, it follows that W, Mo and Sn may have been introduced contemporaneously.

In order to determine if there has been a widespread introduction of W, Mo and Sn into the argillites and quartzites of the Miramichi Formation (4) as a result of intrusion and/or progressive metamorphism and/or retrogressive metamorphism, (introduction of H_2O), samples were collected along a north-south line (approximately) away from the contact with the Burnthill quartz monzonite (6b) Figure 16. The results of these analyses are shown in Table 11:

Table 11: W, Mo and Sn content of argillites and quartzites of the Miramichi Formation (4) with respect to distance from the Burnthill quartz monzonite (6b). (expressed in parts per million).

Sample No.	Map-unit	Lithology	Distance from quartz monzonite	Meta-morphic zone	W	Mo	Sn
18	4	argillite	8000 (feet)		<3	<1	<2
16	4	"	5250		<3	<1	<2
15	4	spotted	3700		<3	<1	<2
14	4	argillite	3500		<3	<1	<2
17	4	"	3250	biotite	<3	<1	5
13	4	"	3000		<3	<1	<2
11	4	"	2500		<3	<1	5
10	4	"	2000		<3	<1	<2
19	4	"	1750	andalusite	<3	<1	<2
24	4	"	6	cordierite	3	3	5
40	6b	quartz monzonite			13	6	10

It is apparent from the above analyses that there is no correlation between the W, Mo and Sn content of the Miramichi Formation (4) and the distance from the Burnthill quartz monzonite (6b). No anomalous variations occur in the contact or retrograde aureole. The erratic distribution in the sedimentary rocks suggests there has been no pervasive introduction of these elements into the country rocks.

Samples of the argillaceous rocks were cut near the walls of two typical veins in order to determine if W, Mo and Sn were removed from, or introduced in the country rock. The results are tabulated below:

Table 12: W, Mo and Sn content of argillites from the Miramichi Formation (4) adjacent to mineralized veins. (expressed in parts per million)

Vein description	Distance from vein (in inches)	Sample No.	W	Mo	Sn
3" quartz-topaz vein with wolfram- ite and molybden- ite	0.5	27	5	<1	5
	1.0	28	5	<1	5
	2.25	29	3	<1	5
	3.25	30	3	<1	<2
	5.25	31	3	<1	5
4" quartz-topaz vein with wolf- ramite	0.5	32	<3	<1	5
	1.25	33	3	<1	5
	2.0	34	<3	<1	5
	2.50	35	3	<1	5
	3.0	36	<3	<1	<2

As trace element values shown above are close to the average values for the Miramichi Formation (4) (Table 7) it is concluded that W, Mo or Sn was not introduced or removed from the country rock.

SUMMARY AND PROPOSED GENETIC MODEL FOR THE BURNT HILL TUNGSTEN VEINS

Several factors must be taken into consideration in the preparation of a genetic model for the mineralized veins at Burnt Hill. These include: (1) - the regional relationships, (2) - the source of the elements, (3) - the mode of concentration, and (4) - the mode of emplacement. The sequence of events established by field relationships forms the basis of this model.

(1) THE REGIONAL RELATIONSHIPS

A study of similar deposits elsewhere in the Appalachians indicated a close relationship between the W, Mo and Sn mineralization and Early Palaeozoic pelitic sedimentary rocks or Devonian granitic batholiths. A genetic association with either one or both is indicated, but the granitic rocks are a most likely source as they are common to all occurrences.

At Burnt Hill, nearly all the quartz veins with muscovite, topaz, wolframite, molybdenite, cassiterite, beryl, fluorite, bismuth, and sulphide minerals occur in southeasterly striking joints and faults within folded and metamorphosed argillites and quartzites of the Miramichi Formation (4). These veins are concentrated near the southeast end of a shallow-dipping apophyses of a Devonian granitoid batholith and are within a zone of retrograde metamorphism produced by an equigranular biotite quartz monzonite about 600 feet below the surface. A spatial, and by inference genetic association with this quartz monzonite is indicated, but this was not confirmed by trace element analyses. This, and the problem the ultimate source of the

FIGURE 17: SCHEMATIC DIAGRAM, PROPOSED GENETIC MODEL BURNTHILL TUNGSTEN VEINS

elements is discussed below.

(2) THE SOURCE OF THE ELEMENTS

The lithologic character of the sediments suggested that W, Mo and Sn could occur within the Ordovician strata at Burnt Hill. These elements could have been derived from a Cambrian-Precambrian source area (Figure 17). Geochemical analyses of clastic rocks of the Push-and-be-Damned Formation (3) were found to be enriched in Sn (probably as cassiterite). W and Mo appear to be evenly distributed throughout different rock types of this unit and the overlying argillites and quartzites of the Miramichi Formation (4) (approximately 4 and 1 ppm respectively). The uniform concentration in these rocks is probably an indication of the general abundance of these elements in one depositional basin. The west to east facies change in the Push-and-be-Damned Formation (3) from greywacke to quartz wacke is not reflected in the concentration of W and Mo.

The regional association of deposits similar to Burnt Hill with Early Palaeozoic sedimentary rocks may not imply direct genetic relationships; in fact the combined association of granitic batholiths and sedimentary rocks is interpreted to be the most significant. It is postulated that the Ordovician strata were incorporated by the intruding mass and the W, Mo and Sn were concentrated by magmatic processes. Geochemical evidence does not contradict this interpretation as the average content of shales (W = 2 ppm, Mo = 2 ppm, and Sn = 6 ppm) is very similar to the average values obtained for granitic rocks (W = 2 ppm, Mo = 2 ppm and Sn = 3 ppm) (Krauskopf, 1967). Although only a few samples were available at Burnt Hill, the W and Mo

content of the Clearwater quartz monzonite (6a) is similar to quantities obtained in the Ordovician strata.

The Burnthill quartz monzonite (6b), which is either younger than, or a marginal phase of the Clearwater quartz monzonite (6a) contains anomalous amounts of W and Mo (19 and 10 ppm respectively). Comparatively small amounts of Sn were found in this unit, but tin minerals are not abundant in the mineralized veins at Burnt Hill. The Burnthill quartz monzonite (6c) is the most obvious source for these elements.

The Ordovician strata may not have provided the total amount of W, Mo and Sn and these elements may have been derived in part from somewhere deep in the crust. It is also possible they were remobilized from other deposits associated with older granitic rocks (Figure 17). Further data are required before conclusions can be made concerning these possible sources.

MODE OF CONCENTRATION

Few data have been published on the role of W, Mo and Sn in magmatic processes and most of the available information is concerned with the abundance of these elements in various rock types. A long history of concentration is evident at Burnt Hill. It was interpreted that the W, Mo and Sn in the sedimentary rocks were incorporated by the batholiths, and were later intruded with quartz in the form of wolframite, molybdenite and cassiterite. The exact reasons for concentration of these elements in various phases of the granitoid rocks are difficult to determine and conclusions made here are based entirely on geological and geochemical data from the Burnt Hill area.

The assimilation of the Ordovician strata by the granitoid batholiths has been discussed above. Geochemical data indicate that the greatest concentration of W and Mo occurs within the Burnthill quartz monzonite (6b) which is either a separate intrusion or a marginal phase of the Clearwater quartz monzonite (6a) to the northwest. The exact relationships of these two units was not resolved in the Hayesville area (Poole, 1963a) but their general distribution shows they are restricted to the southeast flank of the main batholiths and are possibly near-roof phases. If so, they should contain a large amount of assimilated country rock. Lower temperatures and pressures would be expected and W and Mo may have been more readily incorporated in the biotites under these conditions. Analyses of the mafic constituents from the Burnthill quartz monzonite (6b) indicates they contain a higher proportion of W and Mo than other quartz monzonites of the area. The remaining W and Mo could be concentrated in the muscovite or sericite of this map-unit. Only small amounts of Sn were detected and this element was probably not available for concentration or had been segregated earlier. The relative amounts of W, Mo and Sn in the Burnthill quartz monzonite (6b) are roughly similar to the relative amounts of wolframite, molybdenite and cassiterite in the mineralized veins. More data are required before the significance of this can be ascertained.

The Burnthill quartz monzonite (6b) does not appear to be as closely related (spatially) to the mineralized veins as the Mine quartz monzonite (6c) which has low concentrations of W and Mo and Sn. Large amounts of these elements were expected within the Mine quartz

monzonite (6c) as it was emplaced after the Burnthill quartz monzonite (6b) and is cut by mineralized greisen dykes and quartz veins. The concentration of mineralized veins above the Mine quartz monzonite (6c) and within its retrograde aureole suggests that W, Mo and Sn were enriched at depth. The Burnthill and Mine quartz monzonites (6b, c) were in contact at depth (Figure 17) and the former with its anomalous W, and Mo content was probably assimilated by the younger (?) intrusive. It is believed that W, Mo and Sn and other elements plus quartz, H_2O and fluorine were concentrated within the Mine quartz monzonite as a residual fluid. They were removed after complete consolidation (at the upper levels) when fractures developed to a depth which permitted them to be drawn off as hydrothermal solutions.

(3) MODE OF EMPLACEMENT

Vein and dyke filled tension fractures striking about 120 degrees developed throughout the area after metamorphism and after the partial consolidation of the Mine quartz monzonite (6c). They appear to be abundant in the vicinity of Burnt Hill and this may reflect the competency of the Miramichi Formation (4), due in part to: the abundance of quartzite beds, the brittle character of the rock after metamorphism, and the underlying Mine quartz monzonite (6c). It is possible that the axes of regional bending detected in stereograms was centred about this intensely fractured zone.

The dykes and mineralized veins which were intruded along these fractures inherited many mineralogical characteristics of the older quartz monzonites. Progressive mineralogical changes have been

recognized from one to the other (Figure 15). Quartz and muscovite predominate in the younger rocks whereas biotite and feldspar are present only in minor amounts. Volatile constituents are also more abundant, even though much water was removed from the Mine quartz monzonite (6c) during the formation of the retrograde aureole. Its presence together with fluorine is indicated by the abundance of muscovite and fluorite in the dykes and veins. These early quartz muscovite veins yielded Early Devonian ages (375 m.y. and 370 m.y.).

Faults and joints striking about 140 degrees developed after veins were emplaced in the 120 joints. Quartz veins with topaz, wolframite, molybdenite, beryl and locally abundant sulphide minerals were introduced within these new fractures as well as some of the older structures. Faults striking 140 degrees probably developed as a result of slight wrench movement on the Tom McKiel fault. They may have penetrated much deeper than the older tension fractures and mineralized quartz veins are most abundant in areas affected by these younger faults.

In summary, relationships at Burnt Hill point to a complex origin for the W, Mo and Sn minerals. The ultimate source was a hypothetical Cambrian-Precambrian area which effected the first concentration by providing these elements and other clastic material for the Ordovician strata. These rocks were incorporated by the Devonian igneous rocks. W, Mo and Sn were concentrated near the margin or near-roof phases of the intrusive and were probably concentrated again by a younger quartz monzonite prior to emplacement later as the last phase of a single Devonian magmatic event.

Numerous factors control the localization of mineralized veins in the area. Although the granitoid batholiths were the most effective concentrating mechanism, stratigraphic and structural features were equally important in determining which areas were most suitable for vein emplacement.

chapter VI

CONCLUSIONS

Conclusions concerning the Burnt Hill area and its mineralized veins may be made by summarizing the geologic events.

(1)- Ordovician strata at Burnt Hill were deposited during the geosynclinal stage of development of the Appalachian folded belt. Although volcanic rocks are abundant elsewhere in the region, clastic sedimentary rocks predominate in this part of New Brunswick. Two conformable sequences have been mapped.

(2)- Sequence 1- Early Ordovician quartzite pebble conglomerates, sandstones and argillites of the Buttermilk Brook Formation (1) (800 feet thick) are the oldest rocks in the area and were overlain by ferruginous, mangiferous and carbonaceous cherts and argillites of the Hayden Lake Formation (2) (1300 feet thick).

(3)- Sequence 2- Carbonaceous greywackes of the Push-and-be-Damned Formation (3) (5000 feet thick) were laid down conformably on strata of sequence I. These rocks contain abundant clasts of igneous and sedimentary rocks that were probably derived from a Cambrian-Precambrian source area. Similar strata in the eastern part of the area contain fewer unstable constituents. Argillites and quartzites of the Miramichi Formation (4) (6500 feet thick) were deposited conformably on the carbonaceous rocks of unit (3). Clastic material consists almost entirely of quartz. Argillaceous rocks predominate near the top of of this map-unit which is the host for the mineralized veins of the area.

(4)- All strata were folded about northeast striking axes. They were overturned and dip steeply to the northwest. An interpreted strike

fault (the Tom McKiel fault) crosses the central part of the area and separates an overturned anticline in the west from an overturned syncline to the east. Diabasic sills and dykes were emplaced along this fault. Fold patterns in both areas are similar, but there is some suggestion that strata to the west were bent about northwest striking axes.

(5) - After folding, the area was intruded by a coarse grained porphyritic biotite quartz monzonite (the Clearwater quartz monzonite, 6a) and a porphyritic quartz monzonite (the Burnthill quartz monzonite, 6b), both of Early Devonian age. The latter is interpreted to be either a younger intrusive or a marginal, near roof phase of the former.

(6) - Ordovician strata near the quartz monzonites were metamorphosed (by contact metamorphism) and porphyroblasts of biotite, andalusite and cordierite were developed a mile or more from the contact.

(7) - An equigranular quartz monzonite (the Mine quartz monzonite, 6c) is believed to have been intruded later (pre - 375 m.y.) and an aureole of retrograde chlorite developed. Nearly all mineralized veins of the area were emplaced within this aureole (approximately 6000 feet in diameter).

(8) - The region was fractured and tension joints striking approximately 120 degrees were formed. They appear to be particularly abundant in the vicinity of Burnt Hill and their concentration here was probably due to the competency of the Miramichi Formation at this location. This may be due to the abundance of quartzite beds, the brittle character of the rock after progressive and retrogressive metamorphism, and the underlying Mine quartz monzonite (6c). It is possible that the regional bending about northwest axes detected in stereograms may be centred about this intensely fractured zone.

(9)- Quartz-muscovite veins were emplaced within the tension fractures striking approximately 120 degrees. They contain minor amounts of wolframite, molybdenite, beryl, cassiterite, and fluorite. Absolute age determinations on a dyke and a vein of this map-unit yielded 375 m.y. and 370 m.y. respectively (Early Devonian).

(10)- Later faults striking 140 degrees re-opened some of these older tension fractures and quartz-topaz veins with wolframite, Mo, Fe, As, Cu, Zn and Pb sulphides, fluorite, beryl, and native bismuth were introduced. Composite veins with these veins and the older quartz-muscovite veins are common. Repeated movement on the 140 degree faults and the development of late joints and faults striking 040 and 160-180 degrees may have been produced by slight wrench movement on the Tom McKiel fault.

(11)- There are many deposits similar to Burnt Hill in the Canadian Appalachian region. Most are spatially related to (1)- Early Palaeozoic pelitic sedimentary rocks, and (2)- Devonian granitic batholiths. Geological and geochemical data at Burnt Hill indicates a complex genetic relationship between the sedimentary and igneous rocks. The Ordovician strata contain approximately 4ppm W, 1ppm Mo, and 2 ppm Sn. The ultimate source of these elements was probably an old land mass that provided clastic material for the Ordovician sediments. Ordovician rocks were later incorporated by the Devonian batholiths. W and Mo were concentrated within the Burnthill quartz monzonite (6b) which contains nearly 10 times W and Mo as the Ordovician country rocks. Mineralized veins are abundant within the aureole of the younger quartz monzonite (6c) that contains low concentrations of W, Mo and Sn. It is interpreted that ore elements in the Burnthill quartz monzonite(6b) were incorporated by this younger intrusive at depth where they remained until the upper levels had consolidated and regional tension

joints developed. They were then introduced with quartz as wolframite, molybdenite and cassiterite.

(12) - There is no evidence to indicate that W, Mo and Sn were derived directly from the Ordovician strata by secretion. The mineralized veins at Burnt Hill are believed to represent the last phase of a single Devonian magmatic event.

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APPENDIX I

**W, Mo and Sn OCCURRENCES IN THE CANADIAN APPALACHIAN
REGION**

NO.	N.T.S.	PROV.	NAME (includes several similar occurrences if underlined)	HOST ROCKS	AGE	FORM OF DEPOSIT	MINERALS
1.	1-N/7	Nfld.	Witless Bay Line	Granite, granodiorite	Dev?	Vein	Qtz. pyrite, pyrrhotite, chalcopyrite molybdenite, Au, Ag.
2.	1-N/5	Nfld.	Iona Id.				Fluorite
3.	1-L/4	Nfld.	<u>Nfld. Fluorspar</u>	Granite, rhyolite porphyry	Dev	Vein	Quartz fluorite, calcite, pyrite galena sphalerite, chalcopyrite molybdenite
4.	1-M/11	Nfld.	<u>Ackley City</u>	Granite, Microgranite Sed. and volc. rocks	Dev	Vein, disseminations segregations	Molybdenite, pyrite
5.	2-D/6	Nfld.	Berry Hill Pond	Granite	Dev	Vein	Molybdenite
6.	2-E/8	Nfld.	Gander Bay	Slates and quartzites	Sil	Vein	Quartz scheelite
7.	12-I/1	Nfld.	Fleur de Lys	At serpentine - gneiss contact	Ord P.C.?	Vein	Quartz, feldspar, molybdenite, carbonate, pyrrhotite, actinolite, talc
8.	12-B/9	Nfld.	Indian Head	Granite gneiss	P.C.	Dissemination	Molybdenite, beryl
9.	11-P/9	Nfld.	<u>Pomley Cove</u>	Schist and phyllite	Ord.	Vein	Quartz, molybdenite, beryl Bi, Au

10.	11-P/11	Nfld.	<u>Grey River</u>	Schist and Hornfels	Ord?	Vein	Quartz, galena, sphalerite, chalcop- pyrite, arsenopyrite, fluorite, stibnite, molybdenite, wolframite, scheelite, beryl, scapolite, idocrase, Fe-Mn oxides Av.
11.	11-D/15	N.S.	<u>Moose River</u>	Slates and quartzites	Ord?	Vein	Quartz, pyrite, arsenopyrite, scheelite (Au)
12.	11-D/14	N.S.	Oldham	Slates and quartzites	Ord?	Vein	Quartz-scheelite
13.	11-K/1	N.S.	Mariner Mines	Volcanic rocks Granial intrusives	Ord?	Vein	Chalcopyrite, molybdenite
14.	11-F/16	N.S.	<u>Gabarus Bay</u>	Volcanic Rocks	P.C.	Veins	Quartz, molybdenite, chalcoppyrite and bismuth in aplitic rocks.
15.	11-F/16	N.S.	Gaspereaux	Granite	Dev.	Dissemination	Molybdenite
16.	11-F/4	N.S.	Jollota	Slates and quartzites	Ord?	Veins	Quartz fluorite
17.	11-F/5	N.S.	Mile Brook	Slates and quartzites	Ord?	Vein	Pegmatite, with beryl
18.	11-F/6	N.S.	Lazy Head	Slates and quartzites	Ord?	Vein and Dissemination	Quartz scheelite
19.	11-D/15	N.S.	Lk. Charlotte	Slates and quartzites	Ord?	Vein	Quartz, scheelite, gold
20.	11-D/13	N.S.	Waverly	Slates and quartzites	Ord?	Vein	Quartz, scheelite
21.	11-K/15	N.S.	Mackenzie River	Schists	P.C.	Shear zone	Pyrite, arsenopyrite, molybdenite

22.	20-P/13	N.S.	Brazil Lake	Quartzite and slate	Ord?	Vein	Pegmatite with beryl and spodumene
23.	20-P/14	N.S.	Jordan Falls	Schist and quartzite	Ord?	Vein	Pegmatite with molybdenite
24.	20-P/15	N.S.	<u>Western Head</u>			Vein	Pegmatite with garnet, beryl and tourmaline
25.	21-A/10	N.S.	<u>Reeves</u>	Granite	Dev.	Vein	Pegmatite with cassiterite, amblygonite, lepidolite, tourmaline, fluorite, monazite, columbite-tantalite, beryl
26.	21-A/2	N.S.	Baker Settlement	Slate and quartzite	Ord?	Vein	Quartz, arsenopyrite, pyrite, scheelite
27.	21-A/8	N.S.	Indian Path	Slate and quartzite	Ord?	Vein	Quartz, arsenopyrite, galena, scheelite
28.	21-G/1	N.B.	Scotts Dam	Granite	Dev.	Vein?	Molybdenite, chalcopyrite, pyrite
29.	21-G/2	N.B.	Bonny River	Granite	Dev.	Vein	Pegmatite with molybdenite
30.	21-G/7	N.B.	Mt. Pleasant	Rhyolitic flows and intrusives	Miss.	Vein and disseminations	Sphalerite, chalcopyrite, fluorite, cassiterite, topaz, stannite, kaolin, arsenopyrite wolframite, etc.
31.	21-G/7	N.B.	Howard Mtn.	Granite	Dev.	Dissem.	Molybdenite
32.	21-G/8	N.B.	<u>Square Lake</u>	Granite	Dev.	Vein	Quartz-greisen, with wolframite, molybdenite, beryl
33.	21-J/2	N.B.	Zealand Sta.	Granite	Dev.	Vein	Molybdenite, beryl

34.	21-J/3	N.B.	Springfield	Granite	Dev.	Vein	Molybdenite
35.	21-G/14	N.B.	Dumphries	Granite	Dev.	Vein	Molybdenite, wolframite
36.	21-J/10	N.B.	<u>Burnt Hill</u>	Argillite&quartzite granite	Drd. Dev.	Vein	Quartz, topaz, muscovite, wolframite, molybdenite, beryl, fluorite, pyrrhotite, arsenopyrite, chalcopryrite, sphalerite, cassit- esite, bismuth
37.	21-J/10	N.B.	Cleveland	Granite	Dev.	Vein	Muscovite, quartz, sphalerite, fluorite, molybdenite
38.	21-P/12	N.B.	<u>Pabineau Lake</u>	Granite	Dev.	Vein & disseminations	Molybdenite, beryl
39.	21-O/15	N.B.	Popelogan Lake	Limey shales	Sil.	Disseminations	Pyrite, pyrrhotite, chalcopryrite, molybdenite
40.	21-P/12	N.B.	Nicholas Denys	Limey shales	Sil.	Disseminations	Pyrite, molybdenite, scheelite
41.	21-E/15	Que.	St. Robert Metals	Schists	Sil?	Vein	Quartz, galena, pyrite, scheelite, cosalite
42.	21-O/14	Que.	St. Francois	Slates granitic dykes	Ord? Dev?	Disseminations	Bornite, chalcopryrite, molybdenite, Au
43.	21-E/4	Que.	Barnston Twp.	Altered porphyries	?	Disseminations	Scheelite
44.	21-E/15	Que.	Mt. St. Sebastien	Slates	Sil.	Veins	Quartz, chalcopryrite, molybdenite
45.	21-A/14	Que.	Gaspe copper	Limey shales and sandstones	Dev.	Disseminations	Chalcopryrite, bornite, scheelite, molybdenite

46.	21-E/13	Que.	Harvey Hill	Quartz-sericite schists	Ord?	Vein	Quartz, molybdenite
47.	21-F/6	Que.		Schist	Ord	Vein	Quartz, bornite, chal- copyrite, chalcocite, molybdenite

APPENDIX 2

GEOCHEMICAL SAMPLING, PREPARATION AND ANALYTICAL TECHNIQUES

A special effort was made to collect specimens of fresh material for W, Mo and Sn analyses. Their location is shown on Figure 16. Preliminary crushing was done with a geologic hammer. This was followed by the use of a jaw crusher, pulverizer and roller mill. The equipment was cleaned after each sample was prepared by using a brush and compressed air.

Samples were submitted to Bondar-Clegg & Co. Ltd. for analyses. All elements were determined colourimetrically by visual comparison with prepared standards. Zinc dithiol was used as a colour indicator for W and Mo, whereas gallein methylene blue, was used for Sn determinations. The extraction methods and detection limits for W, Mo and Sn are:

Tungsten: This element was extracted by $\text{CO}_3\text{-NO}_3\text{-Cl}$ fusion. The detection limit is 3 ppm.

Molybdenum: A pyrosulphate fusion was employed prior to colourimetric analyses of this element. The detection limit is 1 ppm.

Tin: Tin was extracted by NH_4I fusion. The detection limit was 2 ppm.

UNDERGROUND WORKINGS BURNT HILL T

YORK CO., NEW BRUNSWICK

OGY

BURNT HILL TUNGSTEN MINE

W BRUNSWICK

WEST 1
DRIFT

Information to west from
Burnt Hill Tungsten and
Metallurgical maps.

FIGURE 11
GEOLOGY

WORKINGS BURNT HILL TUNGSTEN MINE

YORK CO., NEW BRUNSWICK

LEGEND

- Outline, underground workings
- Bedding, inclined, tops unknown
- Joint, inclined
- Joint, with quartz, quartz-muscovite, quartz topaz vein and W, Mo, Sn, Be, Fl, Pb, Zn, Cu, Bi minerals. (less than 5 inches, greater than 5 inches.)
- Fault
- Fault showing dip and rake of slickensides
- Fault with quartz vein
- Survey station

Geology by R.R. Potter, 1960, 64, 68 with information in western part of workings obtained from Burnt Hill Tungsten and Metallurgical maps.

Based on surveys by G. F. Flaherty, 1967

feet 50 0 50 100 150 feet

LATE FAULTS AND JOINTS

- Tc veins-Quartz-topaz with wolframite, molybdenite, beryl, pyrrhotite, fluorite, cassiterite, chalcopyrite, sphalerite, pyrite, arsenopyrite, galena bismuth locally includes 7b veins

140 FAULTS AND JOINTS

- 7b veins-Quartz-muscovite with minor wolframite, molybdenite, beryl, cassiterite and fluorite

120 FAULTS AND JOINTS

- Ta veins-Quartz, pyrite, pyrrhotite

LEGEND

CARBONIFEROUS-TRIASSIC
a. FOLDED, b. GENTLY FOLDED
VA - VOLCANIC ROCKS

SILURIAN-DEVONIAN
a. FOLDED, b. GENTLY FOLDED
AV - VOLCANIC ROCKS
G - GRANITIC ROCKS (MAY BE OLDER)

ORDOVICIAN-SILURIAN (MAINLY)
— METABOLIC ROCKS

CAMBRIAN-ORDOVICIAN
a. FOLDED, b. GENTLY FOLDED
AV - VOLCANIC ROCKS

PRECAMBRIAN
a. FOLDED MAINLY IN PRECAMBRIAN
b. FOLDED IN PALAEOZOIC

CARBONIFEROUS

- SPHALERITE, CHALCOPYRITE, FLUORITE, CASSITERITE
KALIN STANNITE, MOLYBDENITE, WOLFRAMITE

GROUP D 30- MT. PLEASANT NB.

DEVONIAN (MAINLY)

- QUARTZ, TOPAZ, WOLFRAMITE, MOLYBDENITE,
BERYL, SPODUMENE, COLUMBITES, TANTALITE,
FLUORITE, CASSITERITE, PYRITE, CHALCOPYRITE,
SPHALERITE, ARSENOPYRITE, MINOR SCHEELITE

- 47- HARVEY HILL QUE.
- 46- (NO NAME) QUE.
- 44- MT. ST. SEBASTIEN QUE.
- 38- PABINEAU LK. N.B.
- 37- CLEVELAND NB.
- 36- BURNTHILL N.B.
- 35- DUMFRIES N.B.
- 34- SPRINGFIELD N.B.
- 33- ZEBLAND STANB.
- 32- SQUARE LK. N.B.
- 31- HOWARD MTH. N.B.
- 29- BONNY AVE. N.B.
- 28- SCOTTS DAM N.B.
- 25- REEVES N.S.
- 24- WESTERN HD. N.S.
- 23- JORDAN FALLS N.S.
- 22- BAZIL LK. N.S.
- 21- MACKENZIE R. N.S.
- 17- MILE BROOK N.S.
- 16- JOLLOTTA N.S.
- 15- GASPEREUX N.S.
- 14- GABARUS N.S.
- 13- MARINER N.S.
- 10- GREY RIVER NFD.
- 9- POMLEY COVE NFD.
- 8- INDIAN HEAD NFD.
- 7- ALGUN DE CYS NFD.
- 5- BERRY HILL POND
- 4- RENOUVEAU E. (BARKLEY CITY) NFD.
- 3- SYLVANIE (NFD ALUMINUM) NFD.
- 2- IONA 10 NFD.
- 1- WITLESS BAY LINE NFD.

DEVONIAN

- QUARTZ-ARSENOPYRITE GOLD

- 43- BRANSTON TWP. QUE.
- 42- ST. ROBERT METALS QUE.
- 41- INDIAN PAIR N.S.
- 28- BARKERS SETTLEMENT N.S.
- 20- WAVERLY N.S.
- 19- LA CHARLOTTE N.S.
- 18- LAY HED N.S.
- 12- OLDMAN N.S.
- 11- MOOSE RIVER N.S.
- 6- GANDERBAY NFD.

SILURIAN OR DEVONIAN

- PYRITE, PYRRHOTITE, CHALCOPYRITE, MOLYBDENITE,
SCHEELITE

- 45- GARDNER COPPER QUE.
- 42- ST. FRANCOIS QUE.
- 40- NICHOLAS DENYS N.B.
- 39- POPELOMAN N.B.

FIGURE 14
METALLOGENIC MAP
CANADIAN APPALACHIANS
W, Mo AND Sn MINERALS

TABLE 5 DESCRIPTION OF VEINS

GENERAL CHARACTERISTICS										
VEINS									QUARTZ	
NAME	MAP-UNIT	AGE	AVERAGE WIDTH	ORIENTATION	CONTACT RELATIONS	RELATIONSHIP TO OTHER VEINS	DISTINGUISHING CHARACTERISTICS	TEXTURE	DESCRIPTION	SIZE (MM.)
QUARTZ- TOPAZ VEINS	8c	MIDDLE DEVONIAN OR YOUNGER	8" LOCALLY UP TO 18"	120-140 DEGREES	SHARP, WELL DEFINED WALLS	YOUNGER THAN Bb AND Ba VEINS COMPOSITE VEINS WITH Bb COMMON MAYBE CUT BY NARROW (1") VEINS CONSISTING OF WOLFRAMITE TOPAZ AND Fe-Pb-Cu SULPHIDES	COMMONLY LARGE IN COMPARISON TO OTHER VEINS. MANY ARE IRREGULAR, PINCH AND SWELL AND DO NOT MAINTAIN UNIFORM WIDTH OR STRIKE. WOLFRAMITES ARE LARGE AND SULPHIDE MINERALS MORE ABUNDANT THAN IN Bb VEINS. TOPAZ COMMON IN CENTRAL PARTS OF VEINS. BERYL AND MOLYBDENITE OCCUR LOCALLY AND MAY BE RESTRICTED TO FEW VEINS ONLY.	COARSE- GRAINED	LARGELY CLEAR GARNET, MINOR MOLYBDENITE OR PYRITE, BERYL, BOYDITE, MUSCOVITE AND ZIRCON	0.5-20 MM 50-90
QUARTZ- MUSCOVITE VEINS	8b	EARLY DEVONIAN	1" GREISEN DYKES 6'+	100-120 DEGREES	SHARP, WELL DEFINED WALLS COMMONLY SILICIFIED	YOUNGER THAN Bb VEINS	QUARTZ-MUSCOVITE VEINS NARROW (PREDOM- INANTLY 1") BUT FEW VEINS UP TO 6" MAPPED. GREISEN DYKES ARE WIDE AND MAY EXCEED 6' IN MANY PLACES. WALLS OF QUARTZ-MUSCOVITE VEINS CAT- ALYZED, SILICIFIED COMMON, AND FLUORITE MAYBE CONCENTRATED ON SHEARED WALL.	FINE-COARSE GRAINED	SMALL, STREAKED DUFFY IN CLUSION OF COUNTRY ROCK	0.5-3.0 50-75
QUARTZ- PYRITE VEINS	8a	LATE SILURIAN- EARLY DEVONIAN	1/2"	040 DEGREES	IRREGULAR	AGE UNCERTAIN BUT OLDER THAN Bb VEINS, CUT BY 120-140 DEGREE JOINTS AND FAULTS	SMALL, IN IRREGULAR ZONES STRIKING 040 ABOUT 2'-4' WIDE. MINOR SULPHIDE MINERAL.	FINE GRAINED		95+

MINERALS PRESENT

[illegible]

[illegible]

2A-Mainly dark grey and grey-green argillite (1300+)
 BUTTERMILK BROOK FORMATION

Green-grey siltstone, sandstone and quartzite, pebble conglomerate (800+)

- Outcrop, angular fragments, area of large number of outcrops
- Geological boundary (defined, approximate, assumed)
- Bedding, tops known (inclined, overturned)
- Bedding, tops unknown (vertical, inclined)
- Cleavage (vertical, inclined, dip unknown)
- Joint (vertical, inclined)
- Fold, syncline
- Lineation, minor fold, plunge unknown, plunge of axis
- Drag fold with plunge of axis
- Fault (defined, approximate, assumed)
- Glacial striae
- Shall
- Adit
- Underground workings
- Diamond drill hole
- Gravel pit
- Metamorphic isograd (approximate, assumed)
- Area of retrograde metamorphism (approximate, assumed)
- Topographic contour
- Building

GEOLOGY BY R.R. POTTER 1960, 64, 67, 68
 ALSO TRAVERSES BY W.H. POOLE AND PARTY 1959, 60

APPROXIMATE MAGNETIC DECLINATION
 TOPOGRAPHY BASED ON NEW BRUNSWICK 20 CHAIN PLANIMETRIC MAPS AND 1:50,000 TOPOGRAPHIC MAPS OF
 SURVEYS AND MAPPING BRANCH, DEPARTMENT OF MINES AND TECHNICAL SURVEYS, OTTAWA.

BURNT HILL AREA

YORK CO, NEW BRUNSWICK

FIGURE 1

LEGEND

DEVONIAN OR YOUNGER

- 7c- Quartz-lapoz veins with wolframite, molybdenite, beryl, pyrrhotite, fluorite, minor cassiterite, chalcopyrite, sphalerite, pyrite, galena, bismuth, chlorite and arsenopyrite, locally includes some 7b
- 7b- Quartz-muscovite, veins and dyes (greisen) minor disseminated molybdenite, fluorite and wolframite and beryl

DEVONIAN

BATHOLITHIC ROCKS

- 6-b-Pink-buff medium-grained porphyritic biotite-quartz-monzonite
- 6a-Pink-grey coarse-grained porphyritic biotite-quartz-monzonite

ORDOVICIAN OR YOUNGER

- 5- Green-grey fine-medium-grained diorase, variable texture

MIRAMICHI FORMATION

- 4a-Quartzite and argillite 4b-mainly argillite 4c-dark grey argillite (6500' +)

MIDDLE & UPPER ORDOVICIAN

PUSH AND BE DAMNED FORMATION

- 3- Dark grey interbedded argillite, siltstone, sandstone and conglomerate (greywacke sequence), locally highly carbonaceous and pyritic, laminated dark grey and with cherry beds. In eastern parts of area, resembles strata of unit 4. (5000' +)

MIDDLE ORDOVICIAN & OLDER

HAYDEN LAKE FORMATION

- Dark grey, morion and green argillite and chert, dark grey cherry argillite cut by numerous quartz veinlets
- 2A-Mainly dark grey and grey-green argillite (1300' +)

BUTTERMILK BROOK FORMATION

- Green-grey siltstone, sandstone and quartzite, pebble conglomerate (800' +)

- Outcrop, angular fragments, area of large number of outcrops
- Geological boundary (defined, approximate, assumed)
- Bedding, tops known (inclined, overturned)
- Bedding, tops unknown (vertical, inclined)
- Cleavage (vertical, inclined, dip unknown)
- Joint (vertical, inclined)
- Fold, syncline
- Lincation, minor fold, plunge unknown, plunge of axis
- Drog fold with plunge of axis
- Fault (defined, approximate, assumed)