Spring 1989

Geology and petrochemistry of the Mount Chase massive sulfide prospect, Penobscot County, Maine

Michael V. Scully

Recommended Citation

Scully, Michael V., "Geology and petrochemistry of the Mount Chase massive sulfide prospect, Penobscot County, Maine" (1989). *Masters Theses*. 733.
https://scholarsmine.mst.edu/masters_theses/733

GEOLOGY AND PETROCHEMISTRY OF THE MOUNT CHASE MASSIVE SULFIDE PROSPECT PENOBSCOT COUNTY, MAINE

BY

Michael V. Scully, 1954-

A THESIS

Presented to the Faculty of the Graduate School of

the

UNIVERSITY OF MISSOURI - ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN GEOLOGY/GEOPHYSICS

1988

Approved by

S. Kerry Grant (co-advisor) Richard D. Hagni (co-advisor)
S. Kerry Grant Richard D. Hagni

John L. Watson

ABSTRACT

The Mount Chase massive sulfide prospect of norththern Penobscot County, Maine was discovered in 1979 by Getty Mining Company. The deposit occurs within a sequence of lower paleozoic metavolcanic and metasedimentary rocks. The footwall units consist of rhyolitic flows, quartz-feldspar crystal tuff, and altered tuffaceous volcanic breccias. These rocks lie unconformably upon intensely folded sediments which are tentatively correlated with the Grand Pitch Formation of probable Cambrian age. The footwall volcanoclastic rocks exhibit a narrow zone of intense chloritic alteration immediately below the massive sulfide horizon, and a broader zone of sericitic alteration below that. A zone of stringer mineralization is associated with the footwall alteration beneath the western side of the deposit. The massive sulfide occurs in two adjacent main lenses occurring approximately within the same stratigrahic horizon. On a microscopic scale, the sulfide minerals exhibit metamorphic recrystallization with porphyroblastic and poikilobastic textures common. The Mount Chase hanging wall units consist of a sequence of relatively unaltered crystal-lithic tuffs, greenstone, and shale. The entire Mount Chase footwall and hanging wall sequence is tentatively correlated with the early to middle Ordovician Shin Brook Formation.

Representative drill core samples were analyzed by x-ray fluorescence for SiO_2, Al_2O_3, Fe_2O_3, MgO, Na_2O, K_2O, TiO_2, P_2O_5, MnO, FeS_2, Ba, Cu, Zn, Rb, and Sr. The chemical systems of Bastin and Ossan indicate a combination of metasedimentary and metavolcanic lithologies for the Mount Chase rocks. These results agreed well with mineralogical and textural interpretations. Harker-type variation diagrams indicate depleted levels of CaO, and somewhat elevated levels of Na_2O. K_2O is generally depleted in the hanging wall rocks and elevated in the footwall rocks. These observations are interpreted to be the result of alkali metasomatism in the hanging wall rocks and a combination of alkali metasomatism and hydrothermal alteration in the footwall rocks. TAS and AFM plots of the Mount Chase igneous rocks indicate subalkalic calc-alkaline affinities though the most mafic rocks plot as tholeiites.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figures Page

Plates

LIST OF TABLES

I. INTRODUCTION

A. PURPOSE AND SCOPE

The Mount Chase massive sulfide deposit was discovered by Getty Mining Company in the fall of 1979. It was subsequently explored and evaluated by Getty until 1985, and since then by Chevron Resources Company. Although these exploration efforts have generally been quite thorough, due to their naturally economic bent, many seemingly academic geologic aspects of the deposit have remained unexplored. The purpose of this study was to complement the above exploration efforts with additional geologic data and observations which might not normally have been considered an important part of the exploration program.

The specific aims of this study were: 1. to review and reinterpret the surface outcrop data and provide an up-to-date geologic map of the immediate prospect area; 2. to provide megascopic and microscopic descriptions of the massive sulfide deposit and its immediate hanging wall and footwall lithologies; 3. to perform whole rock chemical analyses on several representative drill cores amples and provide interpretations of the analytical results obtained; and 4. considering all of the above, to provide an overall geologic model for the Mount Chase prospect.

B. LOCATION

The Mount Chase Prospect lies in northeastern Maine, near the west end of Pickett Mountain Pond, in the southeast quarter of Township T6-R6. The township is uninhabited woodland, and except for 3 small camp lots on Pleasant Lake, the entire prospect is owned by the J. M. Huber Corporation. The prospect lies two miles north of Mount Chase and ten miles north of the village of Patten. Houlton is 30 miles to the east and Bangor 95 miles to the south (Figure 1).

C. ACCESS

The Mount Chase property is accessed via approximately 6 miles of gravel road from Maine Highway 11 to the east. The Bangor and Aroostook Railroad passes within 10 miles of the property, and Pickett Mountain Pond can be used as access for single engine float planes.

D. SETTING

The Mount Chase prospect lies within a ridge of hills which extend from Mount Chase to Shoaler Mountain located 10 miles to the northeast. Mount Chase is the highest topographic point on the ridge with a peak of 2,440′ above sea level. The prospect occurs in the gently rolling topography on the northwest flank of the ridge. The average surface elevation at the prospect is approximately 1,200′ above sea level, with a total relief of about 300′.

The groundwater level is generally high at the site, and two small permanent streams flow along the south and west sides of the prospect area. The woods in the area are a dense hardwood-softwood mix of spruce, maple, beech, and birch with lesser ash, pine, and cedar. Because of

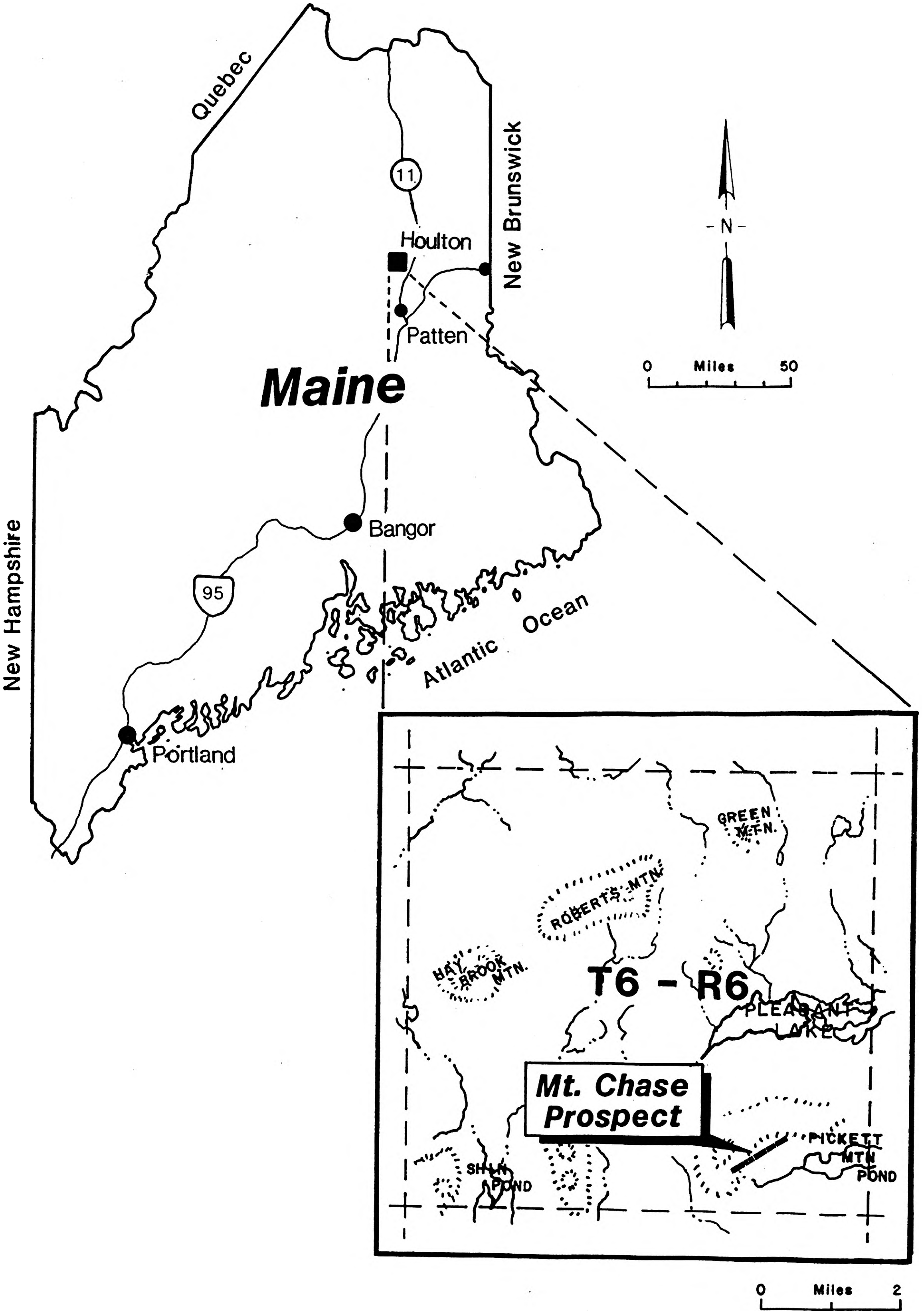


Figure 1. Location of the Mount Chase Prospect.

the fairly low topography, the glacial till cover and the dense vegetation, the amount of outcrop at the prospect is generally less than 1% of the surface area.

II. HISTORY OF EXPLORATION

A. REGIONAL EXPLORATION

Massive sulfide exploration activity in Maine began sometime shortly after the 1953 discovery of the Brunswick #6 deposit in New Brunswick, Canada. Much of the initial work was concentrated in volcanic rocks along the Maine coast and two massive sulfide deposits were eventually mined at Cape Rosier (Callahan Mining) and Blue Hill (Kerr-American).

Exploration efforts in western and northern Maine were intermittent from the mid-1950’s through the early 1970’s. Among the companies involved during this period were: Asarco, Bear Creek, Anaconda, Falconbridge, and Humble. Though some significant prospects were discoverd by their work, none of these have as yet proven to be economically viable.

In 1967 New Jersey Zinc Co., Callahan Mining Co., Superior Mining Co., and J. S. Cummings Inc. formed "The Northeast Joint Venture" to explore for massive sulfides in the northern Appalachians. In late 1977, after 10 years of persistence with some limited success, the joint venture (by then Superior Mining Co., J. S. Cummings Inc., and Louisiana Land and Exploration Co.) announced the discovery of a 36 million ton massive sulfide deposit at Bald Mountain in T12-R8, Maine. Within a few years of this announcement several other companies including Houston Oil & Minerals, Phelps Dodge, Newmont, Noranda, Utah International, and Getty began massive sulfide exploration programs in Maine.

B. THE MOUNT CHASE DISCOVERY

Getty Mining Co. initially got into Maine through a proposal from Lawrence A. Wing, a Maine based geological consultant. Getty began negotiating Maine land leases in late 1978 and began their field work in the spring of 1979. Mr. Wing supplied the field crew and coordinated the work from Bangor.

Getty obtained an exploration lease from J. M. Huber Corporation in late fall of 1978, and regional geochemical sampling work was conducted in the southeast quarter of Township T6-R6 in the early spring of 1979. Several anomalous samples taken from the area west of Pickett Mountain Pond required that a follow-up grid be established over the area. The 5,000′ by 7,200′ "201" grid (after regional sample #201) was set up and sampled by late spring, 1979. Detailed soil geochemistry showed a substantial anomalous zone which was subsequently supported by ground geophysical techniques (Max Min-EM magnetometer, and IP) during the summer of 1979.

The core drilling program began in late September, 1979, and drill hole number one intersected a thin zone of massive sulfides. Five of the following eleven holes drilled through the winter of 1979-1980 intersected at least some massive sulfides. At about the same time that the drilling started, Mr. Wing retired and Getty's Maine consulting work was taken over by F. M. Beck Inc. of Yarmouth, Maine.

Through the summer and fall of 1980 the "west branch" grid was established and sampled immediately to the west of the 201 grid. Additional ground geophysics (VLF-EM, Self Potential, and Applied Potential) were also run over both grids. Ten holes were subsequentially drilled through the spring and summer of 1981 with only minor success.

In May, 1982, Getty Mining company opened a regional exploration office in Bangor. Drilling resumed at the Mount Chase prospect in June, 1982 and continued almost nonstop through 1984. EM-37 was run at the prospect in the summer of 1982. This survey was able to define some deeper conductors which have since been successfully tested by drilling. Thus far, two adjacent main lenses of high grade stratabound massive sulfide have been delineated by the drilling. Drilling continued through 1984 to detail the known lenses and to test the possibility that other massive sulfide lenses might occur along strike and/or down dip of the known mineralization.

Early in 1984 Getty Oil Company was bought by Texaco Inc. Texaco decided to stay out of mineral exploration and mining and shortly thereafter put Getty Mining Company up for sale. The sale of the company still unresolved, all of Getty Mining's Maine activities were terminated in the spring of 1985 and the Bangor office was closed.

In late 1985 Chevron Resources Co. purchased the Mount Chase prospect from Texaco. Chevron also owns the rights to the Bald Mountain deposit and is currently in the process of evaluating both properties.

III. GEOLOGIC SETTING

A. NORTHERN APPALACHIAN OVERVIEW

1. General. The geology of the Mount Chase deposit is set within the broad geologic framework of the northern Appalachian orogenic belt. A very brief review of the northern Appalachian geology will be given here. Comprehensive discussions of the regional geology are given in: Zen (1968, 1983); Rodgers (1970); Bird and Dewey (1970); Page (1976); Osberg (1978, 1983); Schenk (1978); St-Julien and Beland (1982); Williams and Hatcher (1983); Bradley (1983); Williams (1984); and Neuman (1984).

The northern Appalachian orogenic belt consists of mainly late Precambrian through middle Paleozoic sedimentary and volcanic rocks that have undergone multiple stages of deformation, plutonism, and metamorphism. The geology of the region is dominated by several sub-parallel large scale structures. The major structural features of New England and adjacent Canada are shown in figure 2.

2. Geologic Patterns. The western edge of the northern Appalachians is marked by a deformation front where a series of thrusts and slides have transported Cambrian through Middle Ordovician eugeosynclinal shales westward over Middle Ordovician miogeosynclinal carbonates and turbidites (Rodgers, 1970). West of this front the flat-lying miogeosynclinal rocks lap unconformably on

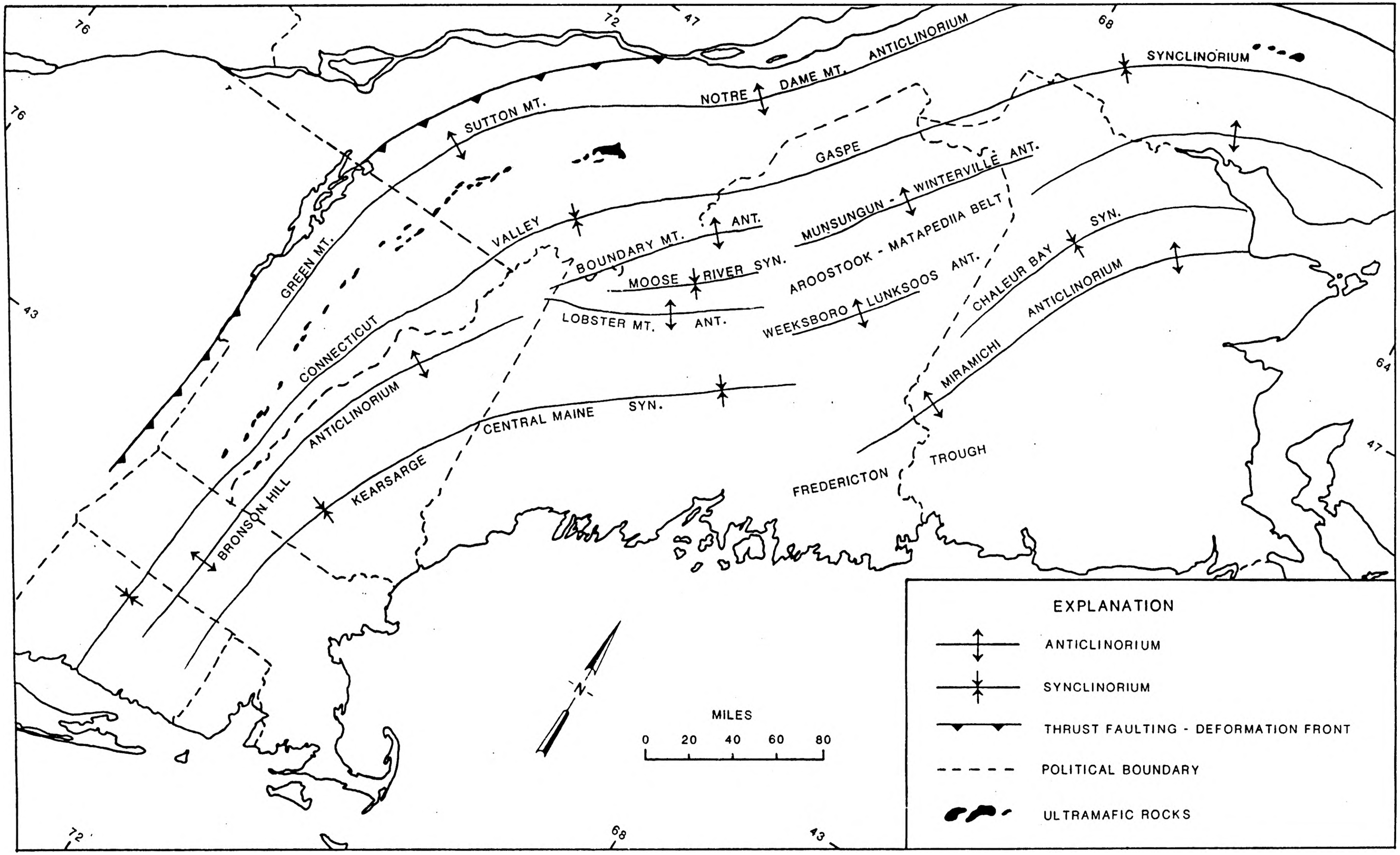


Figure 2. Major Structural Features of the Northern Appalachian Region.

Grenvillian basement which crops out in the Adirondack Mountains of New York and the Laurentian Mountains of Quebec. Grenville rocks crop out again in uplifts in the Berkshire Highlands of western Connecticut and Massachusetts and in the Green Mountains of Vermont. Older Precambrian rocks of the Chain Lakes Massif, dated 1,600 m.y. (Naylor et al, 1973), crop out in the core of the Boundary Mountains Anticlinorium at the Maine-Quebec border.

To the east of the front, the orogen is exposed in a series of broad longitudinal structures where Cambro-Ordovician rocks are exposed in the anticlinoria and Siluro-Devonian rocks are exposed in the synclinoria (St-Julien and Beland, 1982). The Cambro-Ordovician rocks are predominantly miogeosynclinal and exogeosynclinal sediments west of the Green Mountain-Notre Dame Mountain Anticlinoria, and eugeosynclinal and volcanic arc rocks east of this belt (Osberg, 1978).

Early Paleozoic ultramafic rocks occur in a continuous string of outcrops from Connecticut to Quebec and Newfoundland along the east flank of the Green Mountain-Sutton Mountain-Notre Dame Mountain Anticlinoria. Shorter strings of ultramafic outcrops occur in northwestern Maine and on the Maine coast. A few of the larger ultramafic bodies have been interpreted to be ophiolite complexes (Laurent, 1975; Boudette, 1982; Pollock, 1982; Williams, 1984).

Silurian turbidites predominate in the Kearsarge-Central Maine Synclinorium, while to the northwest, Silurian shelf facies are covered by Devonian turbidites. Siluro-Devonian volcanic rocks occur along the Maine-New Brunswick coast, and the Devonian Piscataquis Volcanics outcrop along the southeast limb of the Moose River-Aroostook-Matapedia belt (Osberg, 1978; 1985).

Carboniferous continental sediments fill the Narragansett and Boston basins of Rhode Island and Massachusetts and the Fundy Basin of Atlantic Canada. Undeformed Triassic redbeds and basalts occur in the Connecticut Valley basin of Connecticut and Massachusetts and in the Minas basin of Nova Scotia (St-Julien and Beland, 1982).

Pleistocene glacial deposits and erosional features are common throughout the northern Appalachians. In Maine, the late Wisconsinan continental ice sheet receded between 14,000 and 11,000 years B.P. leaving the present glacially carved topography and numerous varied drift deposits (Thompson and Borns, 1985).

3. Orogenic Features. Five major episodes of deformation are recognized in the northern Appalachians. A late Precambrian Avalonian unconformity is seen along the coastal Avalon terraine (Rodgers, 1970; Williams and Hatcher, 1983). Early Ordovician deformation seen in northern and western Maine is attributed to the Penobscot disturbance (Neuman, 1967). Late Ordovician-Early

Silurian thrusting and folding developed mainly along the western edge of the orogen are attributed to the Taconian orogeny. Taconian deformation becomes less pronounced to the east. In extreme northeastern Maine the Taconian sequence is entirely conformable (Pavlides et al., 1968). Middle Devonian deformation assigned to the Acadian orogeny is prominent throughout the northern Appalachian region. It is generally believed that most of the major structural features of the region were produced during the Acadian deformation. Late Paleozoic Alleghanian unconformities are seen in the Carboniferous basins of southeastern New England and Atlantic Canada (Rodgers, 1970).

Plutonic activity in the region was fairly continuous throughout much of the Paleozic, however pluton ages do occur in clusters that can be associated with the major deformational events (Osberg, 1983). Ordovician quartz dioritic to granitic plutons of the Highlandcroft and Oliverian plutonic series occur along the Bronson Hill-Boundary Mountain Anticlinorial trend (Billings, 1956; Naylor, 1969). These Taconian associated plutons all show a tectonic fabric imparted by later deformational events. Large post-Early Devonian gabbroic to granitic intrusives associated with the Acadian orogeny are assigned to the New Hampshire and Late Devonian plutonic series and are found scattered across much of the region (Page, 1968). Permian Alleghanian-related plutons occur in

Rhode Island (Osberg, 1978, 1983) and Mesozoic plutons of the White Mountain plutonic series are found in New Hampshire, Vermont, and southern Maine (Chapman, 1968).

Ordovician Barrovian metamorphism is seen mainly along the western edge of the orogen in New York, Vermont, and Quebec where the Taconian deformation was most intense (Osberg, 1978). Barrovian and Buchan metamorphism of Mid-Devonian (Acadian) and possibly late Paleozoic (Alleghanian) age has been recognized across most of the central portion of the region. In New England this metamorphism ranges from very weak (Prehnite + Pumpellyite) in northern Maine to high rank amphibolite facies in southern Maine, New Hampshire, and central Massachusetts (Thompson and Norton, 1968; Guidotti, 1985).

4. Tectonic Evolution. It is generally accepted that the Appalachian orogenic belt records the expansion and contraction of the Late Precambrian-Early Paleozoic proto-Atlantic Iapetus Ocean (Wilson, 1966; Bird and Dewey, 1970; Poole, 1974; Kay, 1976, Schenk,1978; Osberg, 1978; Williams and Hatcher, 1983; Zen, 1983). During the closure ophiolitic traces of Iapetus, volcanic island arcs, and possible microcontinents were accreted to the North American continent and its deformed miogeocline (Williams, 1984). Exotic or suspect tectono-stratigraphic terranes have been variously delineated and defined by workers in the region. It is widely believed that the Taconian orogeny marks the beginning of the accretionary

process, while the Acadian orogeny represents the final closure of Iapetus resulting in a continent-continent collision between North America and Africa-Eurpoe (St-Julien and Beland, 1982). Subsequent rifting and formation of the present Atlantic began early in the Mesozoic (Williams, 1984).

B. GEOLOGY OF THE CENTRAL PORTION OF THE WEEKSBORO LUNKSOOS LAKE ANTICLINORIUM

The Mount Chase deposit lies in the Island Falls Quadrangle, Maine along the southeast limb of the northeast-southwest trending Weeksboro-Lunksoos Lake Anticlinorium (WLA) (figure 3). Investigations of WLA geology began with early regional geologic traverses by Jackson (1838), Hitchcock (1861), and Smith (1928). R. B. Neuman(1960, 1967) mapped the geology of the Stacyville and Shin Pond Quadrangles encompassing the western half of the WLA. The Island Falls quadrangle, including most of the eastern half of the WLA, was mapped by Ekren and Frischknecht (1967).

1. Stratigraphy. Occupying the core of the WLA, the Grand Pitch Formation consists of complexly folded gray to black, green, and red shale and siltstone interbedded with light to dark gray quartzite and graywacke (Neuman, 1967). The Grand Pitch formation is tentatively assigned an Early Cambrian (?) age based on the presence of the trace fossil Oldhamia Smithi Ruedemann at several localities within the WLA (Smith, 1928); The base of the Grand Pitch is not

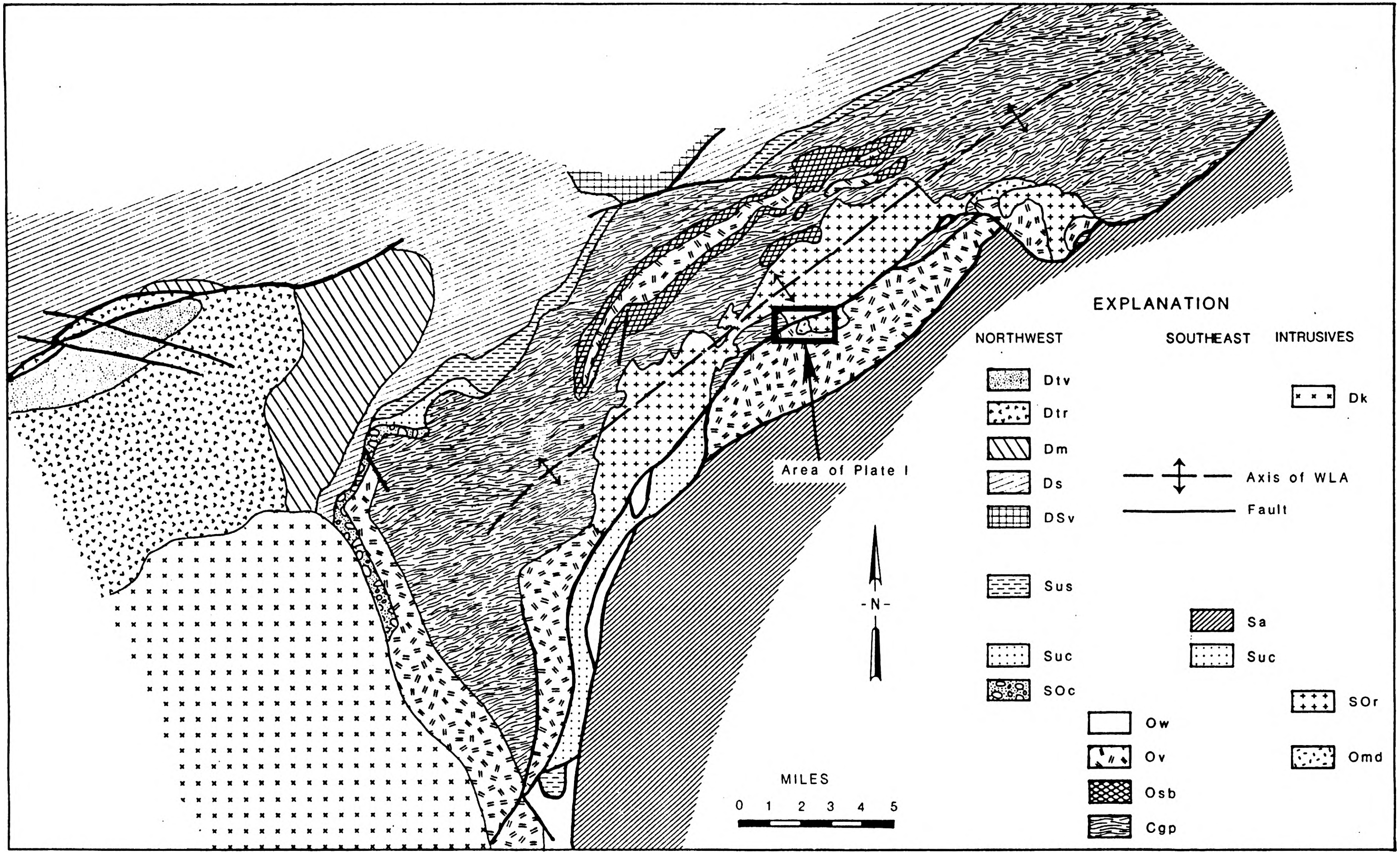
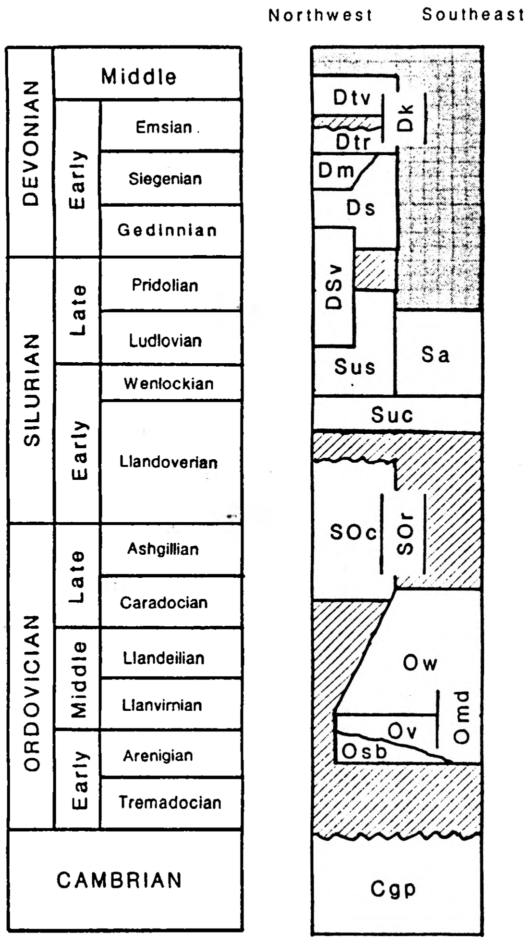


Figure 3. Geology of the Weeksboro-Lunksoos Lake Anticlinorium (after Osberg et al.,1985).



	UNIT NAME	LITHOLOGY
Dtv	Trout Valley Formation	Sandstone, conglomerate.
Dk	Katahdin Granite	Granite, minor granodiorite.
Dtr	Traveler Rhyolite	Rhyolitic pyroclastics, rhyolite.
Dm	Matagamon Formation	Sandstone.
Ds	Seboomook Formation	Sandstone, siltstone, shale.
DSv	unnamed	Mafic volcanics.
Sus	unnamed	Calcareous siltstone, limestone, conglomerate.
Sa	Allsbury Formation	Graywacke, shale, quartzite.
Suc	unnamed	Conglomerate, sandstone.
SOc	unnamed	Conglomerate.
SOr	Rockabema Quartz Diorite	Quartz diorite, quartz diorite porphyry.
Ow	Wassataquoik Chert	Chert, siliceous shale.
Omd	unnamed	Metadiabase.
Ov	unnamed	Basaltic flows, andesite, keratophyre.
Osb	Shin Brook Formation	Crystal tuff, volcanic breccia.
Cgp	Grand Pitch Formation	Shale, siltstone, quartzite, graywacke.

Figure 4. Stratigraphic section for the Weeksboro-Lunksoos Lake Anticlinorium.

exposed, but Neuman (1967) estimates that the unit is a minimum of 5,000 feet thick.

The Grand Pitch shales and quartzites are overlain by a sequence of crystal tuff, tuffaceous conglomerate, volcanic breccia and flows, and fossiliferous tuffaceous sandstone all assigned to the Shin Brook Formation (Neuman, 1964). An assemblage of brachiopods, triolobites, and other fossils found within the tuffaceous sediments dates the Shin Brook as Early Ordovician. Neuman (1967) sums up the significance of the Grand Pitch-Shin Brook contact as follows:

> "The lithic contrasts between the Grand Pitch and Shin Brook formations are accompanied by contrasts in their structural styles. The former, here and elsewhere, contain evidence of multiple deformation, while the latter was deformed only once, presumably by Acadian events of Devonian age. Quartzite clasts in conglomerate at the base of the Shin Brook Formation confirm that this contact is an important unconformity, the result of the Penobscot orogeny,..."

Boone et al. (1984) correlate the Grand Pitch Formation with the Hurricane Mountain Formation of the Lobster Mountain Anticlinorium in western Maine, the Chase Brook Formation of the Munsungan Anticlinorium in central northern Maine, and the St. Daniel Formation of the Notre

Dame anticlinorium of the northwestern Maine and Quebec. They also postulate that these similar Middle Cambrian to Early Ordovician rocks are tectonic melanges associated with the development of immature island arc(s) during the initiation of closure of the Iapetus Ocean. They equate this fore-arc deformation with the onset of the Penobscot disturbance. The Grand Pitch Formation has also been correlated with the lower portion of the Tetagouche group of the Miramichi Anticlinorium in New Brunswick (Roy, 1980).

On the southwest flank of the WLA, the Ordovician strata are overlain by up to 5,000 feet of Early Silurian unnamed conglomerate and fossiliferous sandstone. Cobbles of Mount Chase greenstone Grand Pitch sediments, and Rockabema quartz diorite are abundant within the conglomerate (Neuman, 1967). The conglomerates are, in turn, overlain by approximately 10,000 feet of Early Silurian graywacke, slate, and quartzite of the Allsbury Formation (Ekren and Frischknecht, 1967).

Overlying the Shin Brook Formation and probably in part coeval with it is an unnamed unit of predominantly mafic volcanic rocks (Ekren and Frischknecht, 1967). This unit consists mainly of spilitized augite basalt flows with lesser andesite, keratophyre, shale, and diabase sills and dikes. The mafic flows are described as fine-grained, dark green ophitic spilite that is often vesicular or amygdaloidal and occasionally shows pillow structures. These rocks are commonly referred to as greenstones due to the preponderance of epidote, chlorite, and actinolite produced during spilitization and low grade regional metamorphism. The unnamed greenstones appear to be over 10,000 feet thick at Mt. Chase but are entirely absent at the northeastern end of the WLA.

At the southern end of the WLA the unnamed mafic volcanics are overlain by the Wassataquoik Chert. The unit consists of 300 to 1,500 feet of gray, green, and red chert with minor interbedded siliceous shale and tuff (Neuman, 1967). Middle Ordovician graptolites and conodonts occur within the thin shaley interbeds effectively dating this unit and providing a minimum age for the underlying greenstones.

The stratigraphic sequences above the Wassataquoik Chert are markedly different on the northwest and southeast flanks of the WLA. Conglomerates are abundant in basal portions of the overlying strata on both sides though, indicating late Middle to Upper Ordovician Taconian uplift and erosion. This also accounts for the absence of Ordovician strata in some parts of the structure (Neuman and Rankin, 1980).

On the northwestern flank of the WLA, the Ordovician volcanics are overlain by several unnamed latest Ordovian through late Silurian units. Late Ordovician and Early Silurian fossiliferous polymict conglomerates are followed upward by late Silurian fossiliferous calcareous siltstone, limestone, conglomerate, and mafic volcanics. The volcanics are next overlain by dark gray sandstone, siltstone, and slate of Early Devonian Seboomook Formation (Neuman and Rankin, 1980).

To the southwest, this sequence is capped by three units whose field relationships have proven to be important to interpretations of Acadian events. Here, the Seboomook is overlain by the Matagamon Sandstone of Early Devonian (Siegenian) age which is, in turn, overlain by the unfossiliferous Traveler Rhyolite. Both of these units are folded along with the older rocks. The Traveler is composed of welded crystal tuffs and is believed to be comagmatic with the undeformed Katahdin Granite which intrudes it and several of the older units (Hon, 1980). Finally, the Traveler Rhyolite is unconformably overlain by undeformed fossiliferous sediments belonging to the Trout Valley Formation of late Early Devonian Emsian to early Middle Devonian (Eifelian) age (Neuman and Rankin, 1980). The Trout Valley sediments and the Katahdin Granite are nowhere in contact, but overall field relationships and radiometric dates on the granite suggest that it predates the Trout Valley (Louiselle et al., 1983). Thus, the extrusion of the Traveler Rhyolite, the Acadian deformation, and the intrusion of the Katahdin Granite are all closely bracketed between Siegenian and Eifelian time (Louiselle et al., 1983; Neuman and Rankin, 1980).

2. Intrusives. Two major intrusive bodies occur in the area of the WLA. The Rockabema Quartz Diorite forms a large stock and a few smaller bodies within the core of the anticlinorium (Ekren and Frischknecht, 1967, Neuman, 1967). The Rockabema occurs in medium grained, equigranualar, and coarsely porphyritic varieties and ranges in composition from quartz diorite to granodiorite. Phenocrysts of quartz and plagioclase up to 10 mm long typify the porphyritic phase. Neuman (1967) describes granophyric texture in the equigranular phase, suggesting that it is a hypabyssal intrusive. Both varieties of Rockabema are characteristically strongly sheared and altered. Apophyses of Rockabema porphyry crosscut Grand Pitch sediments and the unnamed greenstones, and xenoliths of these rocks in the quartz diorite are described at several localities. The age of the Rockabema has been estimated as post-Early Ordovician and pre-Early Silurian by its intrusion into the Early to Middle Ordovician unnamed greenstones and its presence as cobbles in Early Silurian conglomerates (Neuman, 1967).

The Katahdin Granite cuts across the southwest end of the WLA. Hon (1980) describes the Katahdin Pluton as a "homogeneous, massive, medium to fine-grained biotite granite of constant chemistry and mineralogy...". He estimates that the pluton is a flat laccolith approximately 25 miles across and 3 miles thick that is only partially unroofed to the north west. The age of the

Katahdin Granite is well established as late Early Devonian (Emsian) (Loiselle et al, 1983). Its age and its lack of internal structure or alteration suggest that the Katahdin is a late product of the Acadian orogeny.

3. Structure and Metamorphism. The Weeksboro-Lunksoos Lake Anticlinorium is a complex northeast-southwest trending structure with a gentle southwesterly plunge. The anticline is probably asymmetic with nearly vertical bedding in the southeastern limb and more gentle dips in the northwestern limb (Ekren and Frischknecht, 1967). A small, doubly-plunging syncline, trending parallel to the main structure, occurs within the northwestern limb of the anticline. A single strong axial planar cleavage is developed throughout the WLA, except in the Grand Pitch Formation where an earlier folded cleavage is also present.

Three separate orogenic episodes are clearly evidenced within WLA rocks. The Early Ordovician Penobscot disturbance tightly folded and foliated the Cambrian Grand Pitch sediments now exposed in the core of the structure (Neuman, 1967). Following the subsequent deposition of Ordovician conglomerate, volcanics and chert, mild Taconian movements produced an ancestral form of the present anticline and the Rockabema Quartz Diorite intruded its core. Through Silurian and Early Devonian time the emergent Cambrain and Ordovician rocks were eroded while sediments were deposited in separate basins to the northwest and southeast. During the intense Acadian deformation vertical upright folds and a pervasive vertical cleavage were developed in the Siluro-Devonian rocks and were superimposed upon the preexisting Cambro-Ordovician structures (Ekren and Frischknecht, 1967). Intrusion of the Katahdin Granite and deposition of the Trout Valley sediments closely followed the Acadian deformation.

Ekren and Frischknecht (1967) report that the rocks in the WLA have undergone high pressure-low temperatutre chlorite zone regional metamorphism. Richter and Roy (1976) describe prehnite-pumpellyite facies metamorphism in the Munsungan-Winterville anticlinorium immediately to the northwest of the WLA. And, Guidotti, (1985) shows the boundary between the prehnite-pumpellyite and greenschist facies zones as passing through the southern end of the WLA. This metamorphism is considered to be of Acadian age or younger (Osberg, 1983). No distinct Penobscotian or Taconian metamorphism is evident in the Cambro-Ordovician rocks of the WLA.

IV. METHODS OF STUDY

A. GENERAL STATEMENT

The principal methods employed in this study were, (1) geologic mapping, (2) drill core logging, (3) thin section petrography, (4) ore microscopy, and (5) x-ray fluorescence. All outcrop and drill core samples were initially examined magascopically for their mineralogical and textural characteristics and tentative rock names were assigned. Several representative outcrop samples and 103 drill core samples were subsequently examined by thin section petrography. The same 103 drill core samples were also chemically analyzed using x-ray fluorescence. Sixty-three polished sections were prepared from samples of massive sulfide drill core and these were examined using standard ore microscopic techniques. Sulfide mineralogy was confirmed by electron microprobe analysis of several grains in two of the polished sections.

The geologic mapping and drill core logging took place in 1981 through 1988, while the x-ray fluorescence, ore microscopy, and most of the thin section petrography were performed on samples collected in the summer of 1982. A brief summary of each of the research methods used is given below.

B. GEOLOGIC MAPPING

Geologic mapping at the Mount Chase prospect has been an ongoing effort involving F. M. Beck, Getty, and Chevron personnel. Outcrop descriptions and map compilations on the project were completed by: T. Longley, 1981; M. Scully, R. Peale, T. Longley, and G. Runyan, 1982; J. Telford and J. Reid, 1983; M. Scully, 1983; M. Scully, R. Peale, L. Myers, and P. Newberry, 1984; R. Eisenberg, 1986; and M. Scully, 1988. The map presented on Plate I evolved through the efforts of all of those listed above, however, it is a revised compilation and any mistakes or misinterpretations it bears are the sole responsibility of the author.

Outcrop mapping was done along and between cleared grid lines which were compassed and taped from a surveyed base line. Outcrops were located by compass and tape measurements from 100′ stations along the grid lines. Many of the outcrop locations were also checked using nearby surveyed drill collars. All outcrops were described in the field and hand samples were collected. The samples were later reexamined and correlated in the office where the various map versions were then compiled. In several are as of the prospect where outcrops are sparse, geologic contacts were projected to the surface using drill hole information.

C. DRILL CORE LOGGING

As of this writing 107 drill holes have been completed at the Mount Chase prospect. All of the drill collar locations and drill hole paths have been surveyed using standard surface and down-hole surveying techniques. As the holes were drilled, the drill core was transported to a warehouse-logging area where detailed geologic logs were then prepared. In addition to core recovery data all mineralogical, textural, and structural features of the core were described and compiled into continuous logs. Care was taken to be consistent with the use of rock unit names throughout the drilling program.

As with the geologic mapping, core logging on the project was a team effort. Throughout the life of the project geologic logs were prepared by T. Longley, M. Scully, R. Peale, D. Bond, D. Doughty, L. Meyers, and B.Guay. All drill holes referred to specifically herein were either logged or relogged by the author.

D. THIN SECTION PETROGRAPHY AND ORE MICROSCOPY

One hundred and three thin sections and sixty-three polished sections were prepared by the author from samples of drill holes 1, 2, 8, 9, 11, 23, 28 and 34. Additional thin sections of outcrop and drill core samples prepared by a commercial lab were also used in this study. The mineralogical and textural characteristics of all of the samples were examined using a Nikon petrographic microscope with both transmitted and reflected light capabilities.

E. X-RAY FLUORESCENCE SPECTROSCOPY

X-Ray fluorescence spectroscopy was used to determine the chemical composition of the original 103 drill core samples also studied by thin section petrography. Each rock sample was ground into a homogeneous minus 400 mesh powder. A small sample of the powder was then pressed into a thin wafer in the center of a steel mold. The wafer was then covered with boric acid and both were pressed in the mold producing a coherent disk with the rock powder sample on one side. A Philips PW 1410 x-ray spectrometer was used to measure the k-alpha fluorescent intensity of each element analyzed. All elements were measured for a period of 10 seconds except for magnesium and sodium which were measured for 20 and 80 seconds respectively. All chemical data obtained as described below are tabluated in the appendices.

1. Major Elements. Each sample was analyzed for silicon, aluminum, iron, magnesium, calcium, sodium, potassium, titanium, phosphorous, manganese, and sulfur. An internal monitoring standard was analyzed with each run of three samples to correct for machine drift and to provide a means to convert from peak intensity to concentration. Matrix factor techniques were inherent in the data reduction. Working curves were established using USGS rock powders. The conversion from peak intensity to percent oxide content for each element except sulfur was calculated on a computer using equations derived and programmed by Dr. S. K. Grant. The program also calculated the CIPW normative minerals for all samples. Fused beads were prepared from four of the study samples and analyzed to check the accuracy of the pressed powder results. Beads were produced from a mixture of flux,

absorbant, and sample in an induction furnace. The two techniques produced similar results, validifying the pressed powder technique for the rocks of this study area.

A special set of pyrite sulfur standards were prepared and analyzed to establish the intensity-concentration relationship for sulfur. Based on the observed common occurrence of disseminated pyrite in the Mount Chase rocks, it was assumed that most of the sulfur detected in the samples was in the form of pyrite. Thus, the sulfur concentrations were converted to and expressed as FeS2 and the Fe2O3 concentrations were corrected accordingly.

2. Trace Elements. The trace elements barium, zinc, copper, strontium, and rubidium were also analyzed in each sample using x-ray fluorescence. Because of the much more significant effects of background response upon trace element analyses, the background intensity was recorded on both sides of each peak measured. The background values were averaged and subtracted from the peak intensities leaving a net peak intensity. The process was supported by a monitoring standard used to detect and correct for fluctuations in operating conditions. The corrected peak intensities were then converted to elemental concentrations in parts per million using a computer program developed by Michael Pace, a former UMR Geology graduate student. The program related corrected intensities to concentrations through a varying working curve sensitive to sample absorption properties. USGS

rock standards were employed.

V. GEOLOGY OF THE MOUNT CHASE PROSPECT

A. STRATIGRAPHY

The geologic units at the Mount Chase prospect show an overall strike of N66E and dips ranging from nearly vertical on the southwest end, to 65SE on the northeast end of the deposit area. These trends are fairly tightly controlled using both surficial and abundant downhole geologic information. Discernible bedding features are rare in outcrop in the prospect area, but where recognized they generally show close agreement with the gross lithologic pattern. As will be discussed further below, the Mount Chase lithologies appear to represent an upright stratigraphic package which faces to the southeast.

A geologic map of the Mount Chase prospect is presented at a scale of one inch equals two hundred feet on plate I. Two cross sections through the deposit showing the immediate hanging wall and footwall litholigies are given on plate II. The following is a unit by unit discussion of the straigraphy of the prospect. The units will be discussed in approximate stragigraphic order beginning with the oldest rocks in the map area, that is, generally from the northwest to southeast. A stratigraphic section is shown on Figure 5 which includes proposed regional stratigraphic correlations.

1. <u>Shale and Quartzite (Sqp)</u>. This unit consists of medium gray to black shale and siltstone interbedded with

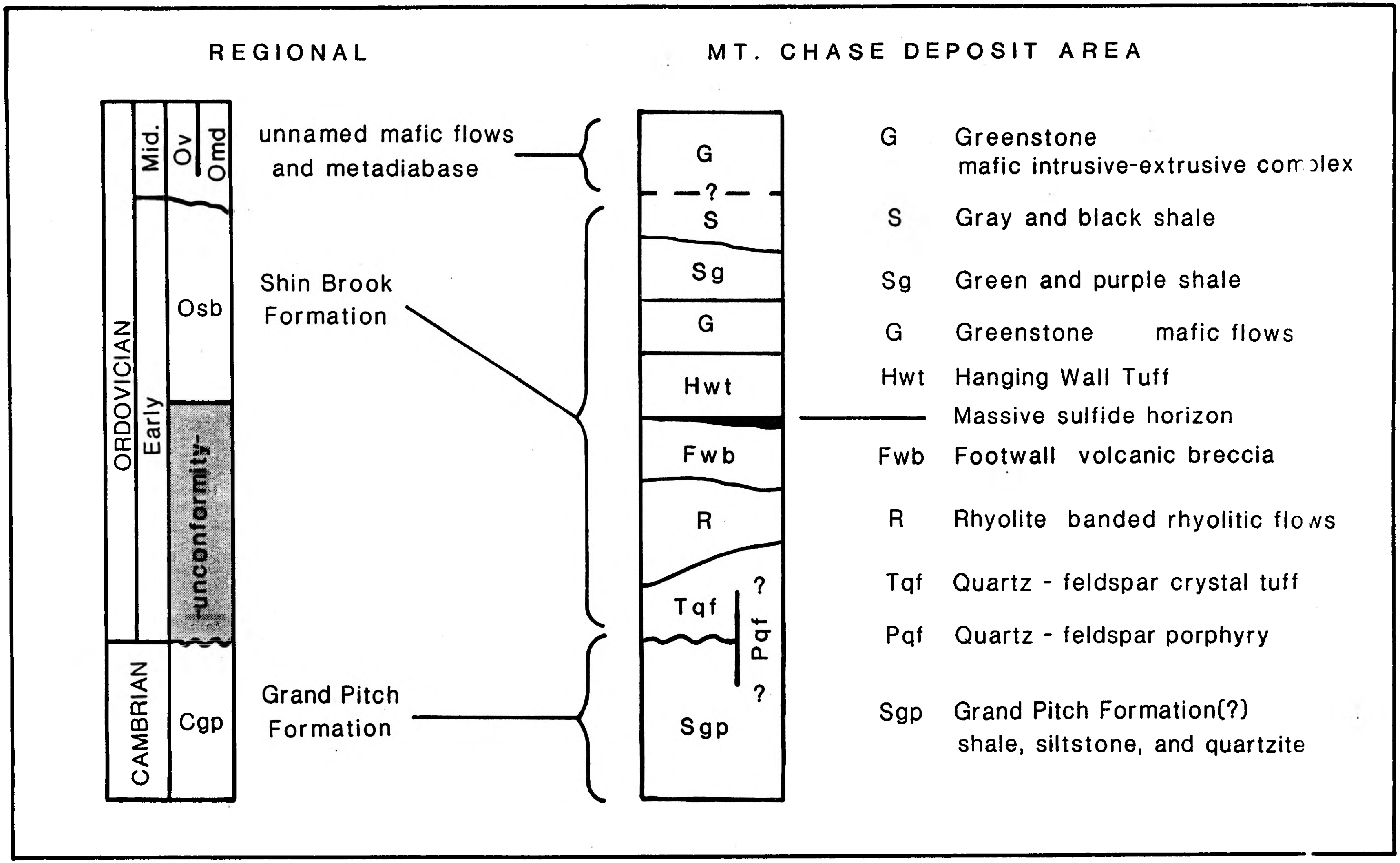


Figure 5. Stratigraphic section for the Mount Chase Prospect area.

light to medium gray fine grained quartzite. Individual beds range in thickness from approximately one inch to tens of feet. Where bedding is thin, the rock has a distinctive striped appearance and graded bedding commonly occurs between the shale and quartzite laminae. The unit also displays a complex folding pattern not evident in any of the other units at the prospect.

Where shale predominates the unit, outcrops are rare and it is generally only exposed in stream beds, along logging trails, and along the main access road. Where the unit is mainly quartzite, it is erosionally resistant and outcrops are more common.

The stratigraphic base of the unit is not exposed in the map area. The contact between this unit and the porphyry shown in the northwest corner of the map area is considered to be intrusive. This contact is exposed in a stream bed just west of the map area. At its upper boundary to the southeast the unit is in contact with two younger units, one of which forms the immediate footwall to the massive sulfide deposit. This upper contact is considered to be an unconformity as suggested by the presence of laminated quartzite and shale clasts in the overlying volcanic breccia and by the obvious difference in structural styles between this and the overyling units. It is evident that the shale and quartzite beds were intensely deformed and then partially eroded prior to the deposition of the younger lithologies.

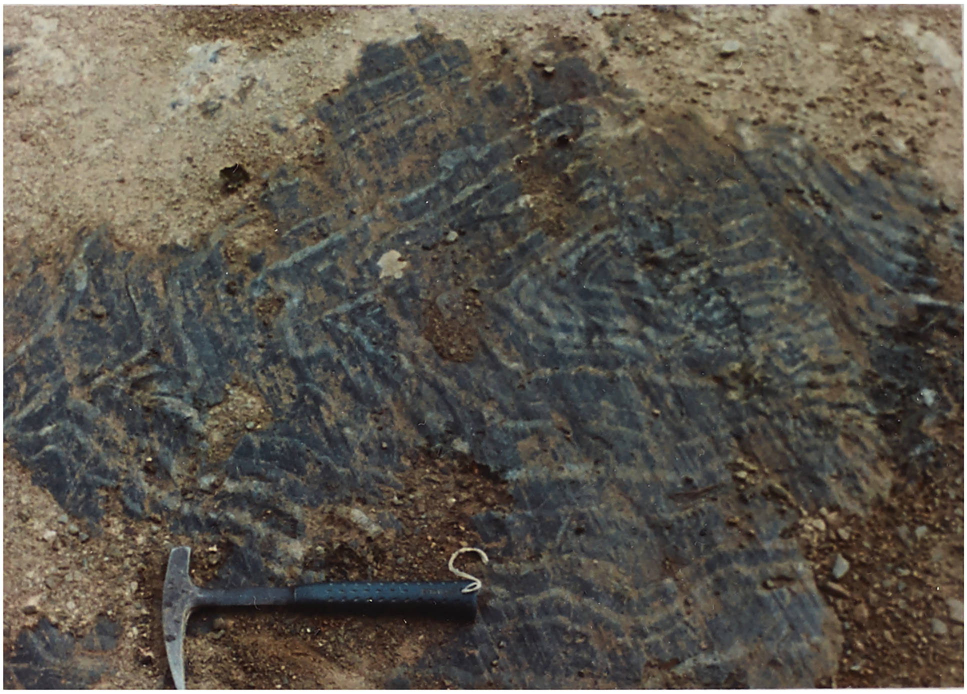


Figure 6. Photograph showing outcrop of folded Sgp unit. Hammer handle points east.

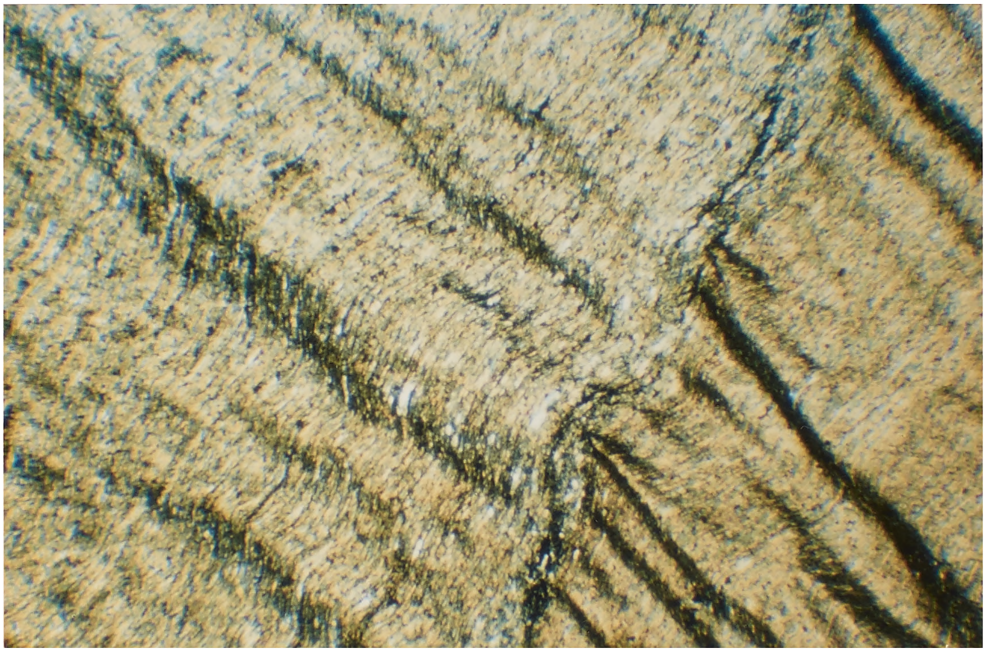


Figure 7. Photomicrograph showing kink banding in siltstone of the Sgp unit. Taken with crossed polars at 50X.

Thin sections of the shales and siltstones reveal compositions of approximately 70 to 80 percent quartz and 5 to 10 percent plagioclase as equidimensional, subangular to subrounded clastic grains less than .05 mm in diameter. Fine intergranular sericite showing a strong preferred orientation parallel to bedding makes up as much as 10 percent of the rock. Fine black opaque carbonaceous material occurs in thin (<0.03 mm) discontinuous laminae composing 5 to 25 percent of the rock. The abundance of carbonaceous material in the rock is often distinctly graded on both megascopic and microscopic scales. Fine disseminated cubic pyrite and lesser octahedral magnetite are ubiquitous, composing up to 3 percent of the rock.

The quartzite portion of the unit is composed of approximately 80 to 90 percent quartz and 5 to 7 percent plagioclase as poorly sorted to moderately well sorted, equant, subangular to subrounded clastic grains ranging in size from 0.1 to 1.5 mm in diameter. Minor detrital zircon and fine disseminated cubic pyrite are common. Trace amounts of rutile, sericite, and chlorite after biotite are also present.

This unit is tentatively correlated with the Grand Pitch Formation as described and mapped by Neuman (1967) and Ekren and Frischknecht (1967). The lithology and complex structure of the unit closely resemble that of several outcrops of Grand Pitch Formation in the region as mapped by the above authors. Also, Ekren and Frischknecht

(1967) mapped an area of Grand Pitch Formation along strike to the southwest which extends approximately into the area mapped as Grand Pitch here. The unconformity noted above most likely represents the Penobscot disturbance as described by Neuman (1967).

Boone (1988) tentatively correlates distinctive portions of the rocks broadly mapped as Grand Pitch Formation in the Weeksboro-Lunksoos Lake Anticlinorium with the Southeast Cove and Hurricane Mountain Formations of the Lobster Mountain Anticlinorium in western Maine. The Southeast Cove Formation is composed of thin to thick bedded metasiltstone and quartzite, and the Hurricane Mountain formation is believed to be a tectonic melange. On a guided field trip through the Mount Chase prospect area, Dr. Boone (1988) noted that the thin bedded portion of the unit described here was identical to a unit he has mapped near Sugarloaf Mountain on the southwestern side of the WLA. He loosely termed the unit "zebrarock" (due to its black and white striped appearance) and suggested that it possily belonged to the Southeast Cove portion of the Grand Pitch group.

2. Quartz Feldspar Crystal Tuff (Tqf). This unit forms sparse low jagged outcrops of buff colored foliated crystal tuff. Quartz and feldspar crystals up to 6 mm in diameter set in a strongly foliated aphanitic felsic matrix are the most obvious megascopic features of this rock. Outcrop samples show abundant iron oxide staining

in thin wispy streaks parallel to the rock formation. In drill core this iron generaly occurs as wisps of unoxidized fine disseminated pyrite.

In thin section this rock is composed of 10 to 30 percent 0.2 to 6 mm severely broken and embayed quartz crystals; 0 to 25 percent to 0.2 to 4 mm subhedral to anhedral plagioclase and potassium feldspar crystals in roughy equal proportions; and 1 to 3 percent 0.3 to 1 mm broken and bent biotites all set in a fine grained foliated matrix of quartz, feldspar, and sericite. The feldspar cyrstals show varying degrees of sericitization and albitization while the biotites are generally entirely relict by epidote and chlorite. Minor fine disseminated cubic pyrite occurs in thin wisps parallel to foliation. Trace amounts of zircon, rutile, and apatite are also present, and thin veinlets of quartz plus calcite and chlorite are common. Most groundmass textures diagnostic of genesis are absent possibly due to the combined effects of welding, devitrification, and the recrystillization and shearing associated with low grade regional metamorphism.

Geologists involved with the Mount Chase project have generally concurred only that this unit constitutes a felsic porphyritic igneous rock. Whether it originated as extrusive flow, pyroclastic, or subvolcanic intrusive has been a matter of debate. Because this unit appears to have cut off the eastern end of the massive sulfide horizon, the interpretation of its mode of emplacement has

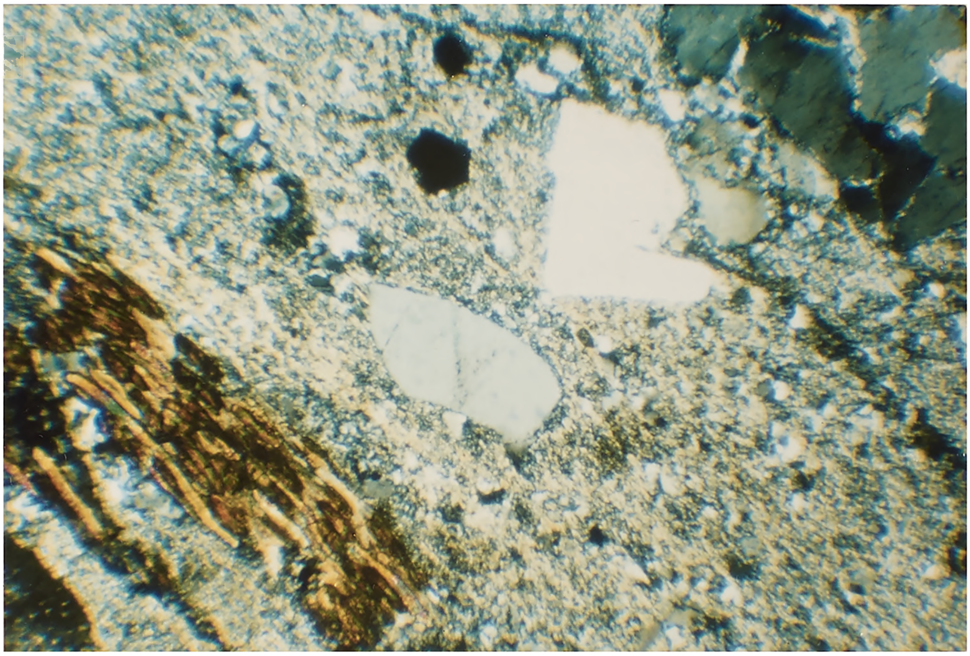


Figure 8. Photomicrograph showing common textures of the quartz-feldspar crystal tuff unit. Taken with crossed polars at 50X.

been an important factor in exploration efforts around this portion of the deposit. Three possible interpretations are considered feasable. First, that the unit is a late subvolcanic intrusive which has intruded through and probably assimilated a portion of the massive sulfide horizon. Second, that the unit, whether flow or pyroclastic, is an extrusive rock upon which the massive sulfides with their immediate host rocks were later deposited. In this case sulfide deposition could have lapped against a paleotopographic high on a typically irregular volcanic terrane. Or third, that regardless of its genesis, the unit was structurally emplaced across the eastern end of the massive sulfide horizon. Of course, combinations of the above cases are also possible, including that the unit is made up of both intrusive and extrusive phases.

It is proposed here that this unit is mainly a pyroclastic volcanic rock of rhyo-dacitic composition. The extremely broken nature of the crystals indicates an extrusive origin and thin, wavy, discontinuous compositional laminae common in the rock are probably ghosts of devitrified flattened shards and pumice fragments. The strong, pervasive foliation in the rock also indicates an original tuffaceous matrix. The rhyolite flow unit which immediately overlies the crystal tuff is quite dense and shows very little evidence of the same tectonic foliation. It seems most likely that the eastern termination of the massive sulfide lense represents one edge of the shallow paleotopographic basin in which the sulfides were deposited. Dikes of a compositionally very similar porphyritic rock (Pqf) occur along the northern edge of the map area. The quartz and feldspar crystals in this rock tend to be larger and less fractured than those of the crystal tuff and its groundmass is somewhat coarser grained and less foliated. It is tempting to suggest that these dikes may have formed part of the volcanic feeder system for the extrusion of the crystal tuff unit. However, no convincing field evidence for this relationship has been recognized.

3. Rhyolite (R). A unit of medium gray to dark purplish gray rhyolite outcrops in the western half of the prospect area . The rock is quite hard and resistant forming many outcrops which generally show a thin white weathering rind and break with subconchoidal fracture. Megascopically, the rhyolite is an aphanitic siliceous rock with only a few small phenocrysts of quartz and feldspar. Outcrops typicaly exhibit a fine compositional banding which is often intensely contorted. These features are interpreted to be flow banding and flow folding common to rhyolite flow units. Occasional thin black laminae of nearly massive fine grained magnetite occur throughout the unit. Structural foliation is generally absent in the rhyolite due to its highly competent nature.

Figure 9. Photograph showing outcrop of rhyolite unit.

In thin section the rhyolite is typically composed of 1 to 5 percent 0.1 to 1 mm anhedral to subhedral phenocrysts of quartz and lesser plagioclase. The rock groundmass is composed of approximtely 40 percent quartz, 35 percent feldspar, and 15 percent sericite in very fine grained (<.01 mm) granular to felty intergrowths. Where it is recognizable on a microscopic scale, flow banding occurs as a result of groundmass constituents being segregated into laminae of predominantly quartz alternating with laminae of mainly feldspar plus sericite. Fluidal orientation of elongate crystals and crystal fragments parallel to flow laminae is common in portions of the unit. Trace amounts of fine disseminated pyrite, chlorite, and epidote occur throughout.

The rock's dense unfoliated aphanitic groundmass, the presence of flow banding and fluidal textures, and the lack of relict pyroclastic textures combine to suggest that the unit originated as an extrusive rhyolitic flow. The limited areal extent of the unit also tends to support this interpretation as pyroclastic deposits normally tend to be more laterally extensive.

4. Footwall Volcanic Breccia and Lapilli Tuff(Fwb). A sequence of intensely altered tuffaceous volcanic breccias, and lapilli tuffs form the immediate footwall to the massive sulfide deposit. The unit forms jagged outcrops of strongly foliated whitish to greenish gray rocks with characteristic coarse fragmental textures. The

designation of this unit as mainly tuffaceous is somewhat speculative as strong pervasive alteration of the rock by chlorite, sericite, and silica have masked its original textures and composition. It is entirely possible that the unit contains an important component of sedimentary material.

Two main textural varities are distinguishable within the unit. The bulk of the unit is composed of an altered lapilli tuff originally logged in drill core as "globby tuff". Megascopically, the rock exhibits up to 30 percent 3 to 10 mm flat cuspate altered lithic fragments in a whitish, fine grained, variously silicified and chloritized tuffaceous matrix. The lithics vary in color from greenish black to light gray and include fragments of siltstone, crystal tuff, and rhyolite. The so-called "globby" texture of this rock is believed to be an aberration caused by the secondary chloritic alteration pervasive throughout the unit. A network of intersecting indistinct veins and wisps of blackish chlorite surround areas of lighter rock altered mainly by quartz plus sericite. The result is that the rock matrix appears to be made up of elliploidal "globs" of light colored tuffaceous material separated by dark chloritic interstices.

In thin section the unit exhibits a very fine grained (<.3mm) foliated matrix composed of approximately 40% quartz, 25% sericite, 20% chlorite, 10% feldspar, and up

Figure 10. Photograph showing outcrop of tuffaceous footwall breccia unit.

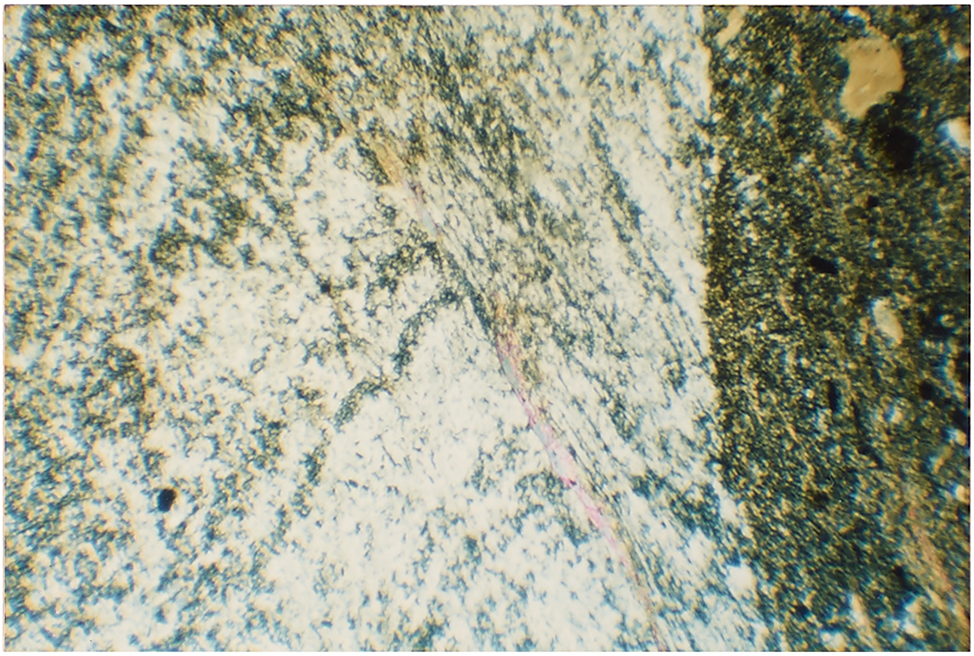


Figure 11. Photomicrograph showing banded rhyolite fragment in footwall breccia unit. Taken with crossed polars at 50X.

to 5% disseminated pyrite. Minor broken to subhedral .5 to 1 mm quartz crystals are scattered throughout. On the western side of the deposit area a broad zone of stringer mineralization occurs immediately below the massive sulfide body where the rock contains up to 30% disseminated and veined pyrite plus chalcopyrite with minor sphalerite and galena. Due to the strong pervasive alteration of the rock, often lithic fragments quite obvious on a megascopic scale are nearly indistinguisable microscopically.

On the eastern side of the deposit area the lapilli tuff grades upward into tuffaceous volcanic breccia. The main difference between these rocks is clast size, although alteration in the breccia is somewhat less intense than in the lapilli tuff. Because of larger clast size and weaker overall alteration of the rock, original clast lithologies are much more discernible here than in the lower portion of the unit. With a similar foliated tuffaceous matrix, the breccia contains 30 to 70% 5 mm to 10 cm flat to blocky angular fragments of altered siltstone, quartz feldspar crystal tuff, and flow banded rhyolite. Large clasts of pinkish banded rhyolite are distinctive of this rock. Breccia clasts typicaly show 1 to 3 mm alteration rims of either greenish black chlorite or whitish silica surrounding a relatively fresh core.

5. Massive Sulfide Horizon. Two adjacent main lenses of stratabound massive sulfide occurring approximately

within the same stratigraphic horizon have been delineated by diamond drilling at the Mount Chase prospect. In addition, at least two other smaller lenses of massive sulfide occur at slightly different stratigraphic levels within the hanging wall tuff unit immediately above the main lense on the western side of the deposit. A total of 6.0 million tons of massive sulfide are inferred from drilling on the deposit. Of that, approximately 3.2 million tons is high grade material occurring in the two main lenses averaging 1.3% Cu, 4.5% Pb, 10.2% Zn, 2.7 oz/t Ag, and 0.02 oz/t Au. The main sulfide horizon ranges from zero to just over fifty feet in total thickness. The high grade sulfides typically occur along the stratigraphic base of the horizon and range from zero to twenty six feet thick. Figure 6 is a vertical longitudinal section showing the approximate lateral limits of each lense within its stratigraphic horizon.

No outcrops of the massive horizon sulfide have been found in the prospect area, but surface trenches have shown that the edges of both main lenses do extend updip to subcrop beneath five to fifteen feet of glacial till. No significant gossan or enriched zones occur over the Mount Chase deposit. Presumably, had these features ever developed over the deposit, they were subsequently removed by glacial erosion. A few pieces of gossan float have been found on the surface near where the massive sulfide subcrops.

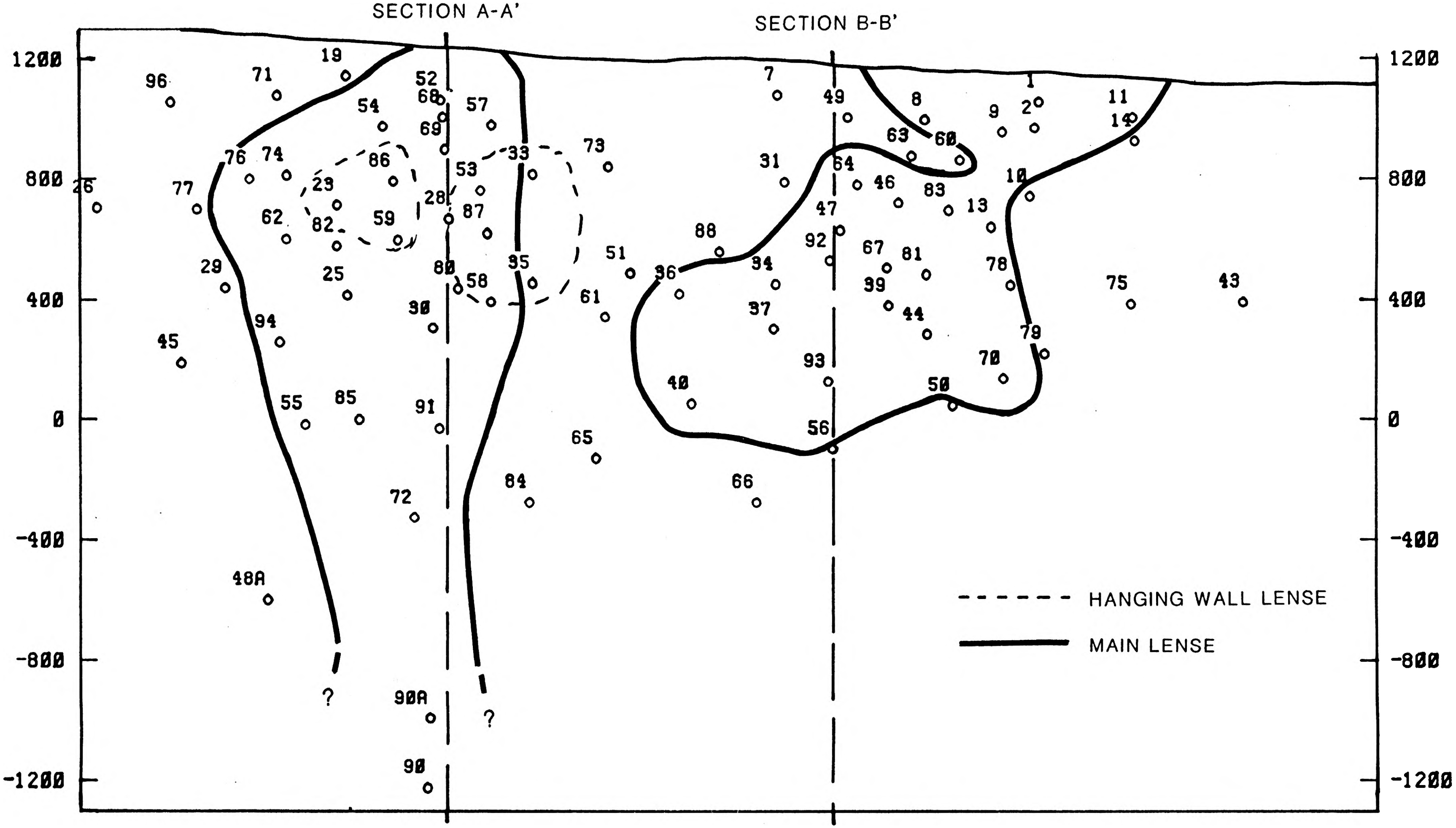


Figure 12. Vertical longitudinal section showing limits of massive sulfide lenses.

a. <u>General Description</u>. Detailed logging of massive sulfide drill core has repeatedly revealed two principal types of stratabound sulfides within the deposit: low grade massive pyritic sulfides, and high grade laminated zinc-lead-copper sulfides. Both types of sulfides are not necessarily present in all intercepts drilled, but they do generally show a similar lateral distribution within each sulfide lense. With some exceptions, the high grade sulfides normally occur along the stratigraphic base of the horizon and are overlain by low grade massive pyrite. The contact between the two types of sulfide is typically quite sharp, and the mineralogical and textural differences between them are interpreted to be essentially primary depositional features.

The low grade pyritic unit is composed of 60 to 75 percent fine grained granular pyrite with 20 to 35 percent fine intergranular quartz and sericite with lesser calcite and chlorite. Minor amounts of disseminated chalcopyrite, sphalerite, galena, and magnetite are common throughout. Bedding features are generally poorly developed in this portion of the sulfide, but occasional laminated zones do occur. Most commonly the unit exhibits massive featureless bedding with zones of brecciation and disturbed bedding which appear to be the result of soft sediment slumping within the original massive sulfide mound. These slump features are most commonly observed in the thickest portions of the massive pyritic unit where slumping of a building sulfide mound would be expected.

Where bedding features do occur in the low grade sulfide they are typically expressed as minor variations in pyrite grain size and/or changes in the abundance of non-sulfide gangue minerals. A few relatively rare occurrences of graded bedding and cross-stratification have been identified in the pyritic suflides which tend to support other evidence for a southeasterly facing section.

The high grade sulfide beds have an overall composition of 45 to 60 percent pyrite, 15 percent sphalerite, 5 percent galena, and 4 percent chalcopyrite, with 15 to 30 percent quartz plus sericite plus chlorite and lesser calcite. Minor amounts of tetrahedrite-tennantite, arsenopyrite, magnetite, and barite are also present. These high grade beds are normally made up of several 2 mm to 5 cm compositionally defined laminae of fine grained (<0.3mm) sulfides and intergranular gangue. These compositional laminae are generally composed of either: 1) sphalerite plus galena with lesser chalcopyrite, pyrite and gangue; 2) pyrite plus chalcopyrite with monor sphalerite, galena, and gangue; or 3) pyrite plus gangue with minor base metals. The tetrahedrite and magnetite occur mainly in the Pb-Zn laminae while the arsenopyrite is normally associated with the barren pyritic laminae.

Analysis of the base metal distribution at the Mount

Chase deposit shows no well developed zonation either vertically or laterally within the deposit, aside from the high grade-low grade relationship previously mentioned. Computer correlations of all of the Mount Chase assay results are shown in Table I. A strong positive relationship is indicated only between lead and zinc which is in general agreement with the mineralogical associations noted above.

Table I. Mount Chase Assay Correlation Coefficients

	Zn	Pb	Cu	Ag	Au
Zn	1.00	.92	.08	.69	.41
Pb	.92	1.00	.03	.69	.39
Cu	.08	.03	1.00	.34	.16
Ag	.69	.69	.34	1.00	.42
Au	.41	.39	.16	.42	1.00

b. Ore Microscopy. Polished sections of the Mount Chase sulfides were mineralogically and texturally described using properties and nomenclature as summarized by R. D. Hagni (1981). In addition, the sulfide mineral identifications were verified by electron microprobe analysis of several sulfide grains. The electron microprobe data is tabulated in Appendix D. With the exception of the single tennantite grains, which had been opitcally identified as tetrahedrite, all of the other minerals had been correctly identified using optical techniques.

Although fine primary compositional banding and a very fine grain size are preserved megascopically in the Mount Chase sulfides, microscopic inspection reveals many intergranular textures indicative of metamorphic recrystalization. Similar metamorphically controlled textures have been discribed in many other stratabound massive sulfide deposits around the world. (Stanton, 1960; Kalliokoski, 1965; Hagni, 1981; Craig, 1983). Of the commonly banded textures Stanton (1960) states:

> "The gross banding...probably represents original differences in the amount and composition of the sulfide precipitated during sedimentation i.e., is a sedimentary bedding phenomenon. The finer structure...developed within individual bands...is, on the other hand, possibly metamorphic in origin, representing sulfide metamorphic differentiation."

Stanton also recognized that the mineral habits and intergranular relationships seen in metamorphosed massive sulfide deposits are controlled according to a sulfide "crystalloblastic series" rather than the normal paragenetic sequence ascribed to replacement type deposits. These types of intergranular relationships have long been recognized in metamorphic petrology. Spry (1969) discusses the positive relationship between the surface energy of a crystal and its tendency to form large, euhedral porphyroblasts. In order of decreasing surface energy, some of the most common minerals (also seen at Mount Chase) are: pyrite, arsenopyrite, magnetite, quartz, sphalerite, calcite, chalcopyrite, and galena (Spry, 1969). The grain size and textures exhibited by a massive sulfide deposit will ultimately depend upon the grade of metamorphism it has been subjected to, if any at all. Unmetamorphosed deposits such as those of the Kuroko District of Japan show very fine grained, laminated textures, while intensely metamorphosed deposits such as at Broken Hill, Australia show only a crude banding and coarse, granular textures (Hagni, 1981).

On a microscopic scale the Mount Chase sulfides exhibit only a few relict primary textural featues. The fine laminations seen megascopically are present as crude discontinuous compositional bands. As suggested by Stanton (1960) of other massive sulfide deposits, these bands are probably relicts of original sedimentary compositional variations in the sulfides as they were deposited. In general, the mobilization and recrystalization of the sulfide minerals at Mount Chase appears to have occurred over very short distances within the bounds of the original compositional laminae.

Another relict primary feature occasionally seen in the Mount Chase sulfides is colloform pyrite. These subspherical bodies are composed of successive shells of very fine grained pyrite which commonly have inclusions or

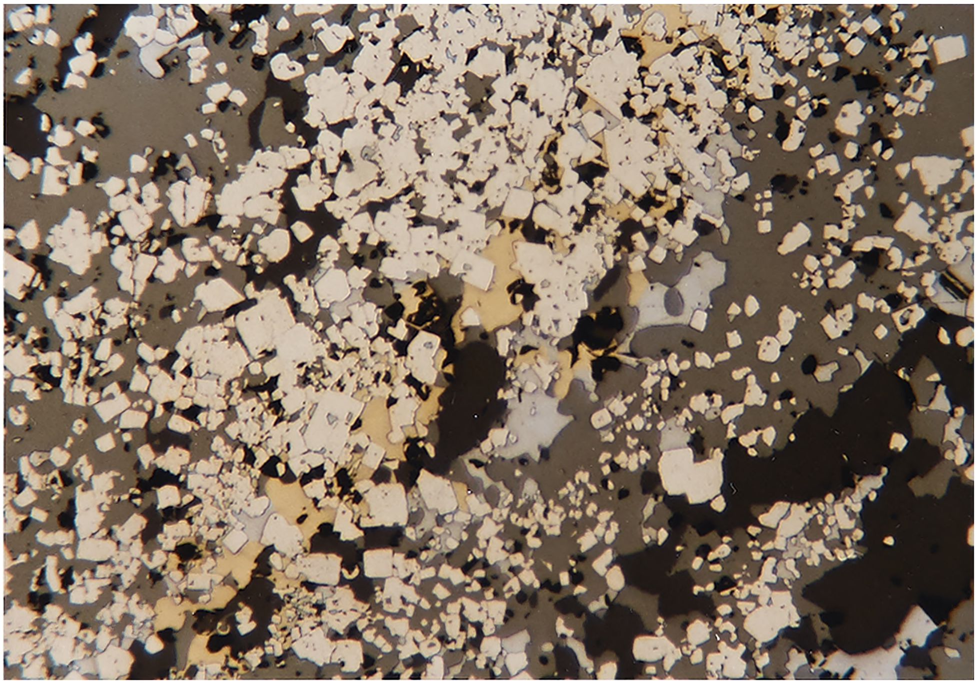


Figure 13. Photomicrograph of polished section number 28-679 at 50 x showing the relict compositional banding present in the Mount Chase high grade massive sulfides.

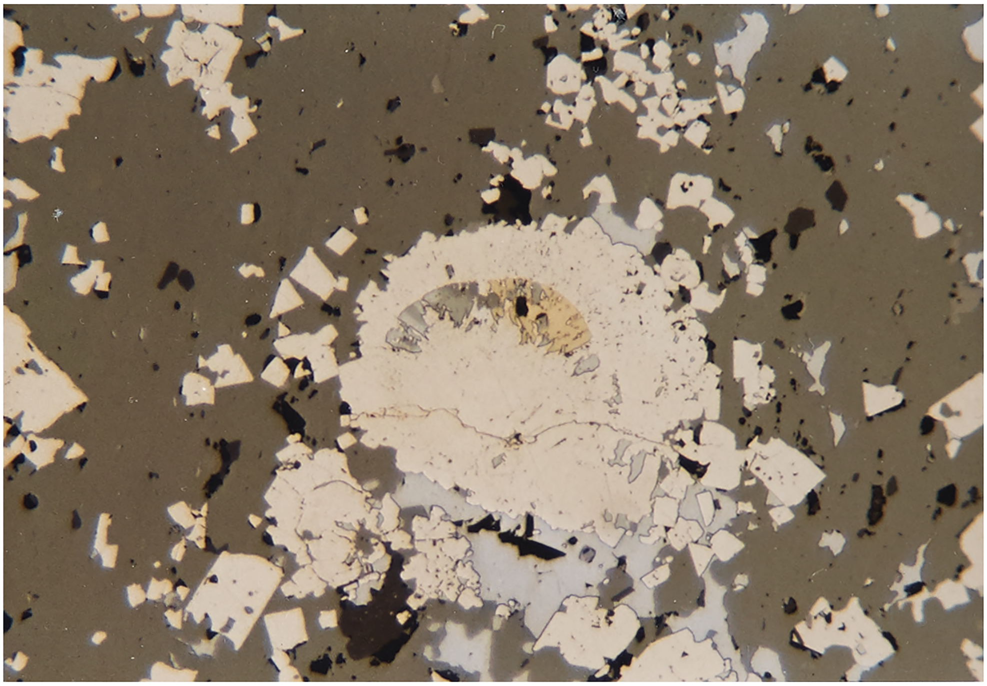


Figure 14. Photomicrograph of polished section number 34-846 at 100 x showing colloform pyrite with entrapped inclusions of sphalerite, galena, tetrahedrite, and chalcopyrite.

concordant zones of other sulfide minerals entrapped during the pyrite deposition. Similar primary colloform textures are common in the unmetamorphosed massive sulfide deposits of the Kuroko District of Japan (Eldridge et al., 1983).

The texture of the Mount Chase sulfides is dominated by porphyroblastic pyrite. The pyrite occurs as <0.1 to 1mm subhedral to euhedral cubes which commonly have poikiloblastic inclusions of chalcopyrite, sphalerite, and galena. These inclusions apparently become entrapped within the growing pyrite crystals during the episode of metamorphic recrystalization. They generally have ovate shapes and sharp, smooth boundaries which would not be expected if they represented secondary replacement of the pyrite. This strong porphyroblastic nature of the pyrite at Mount Chase is likely a function of its high rank in the metamorphic crystalloblastic series mentioned above as well as its abundance relative to the other sulfide minerals. The pyrite tends toward euhedralism regardless of what mineral it is in contact with sphalerite is the second most abundant sulfide mineral at Mt. Chase and it occupies an intermediate place in the textural relationships among the sulfides.

At low magnifications, sphalerite appears to define crude amorphous bands which are dotted with pyrite cubes and irregular shapped masses of chalcopyrite, galena, and gangue minerals. At higher magnifications more

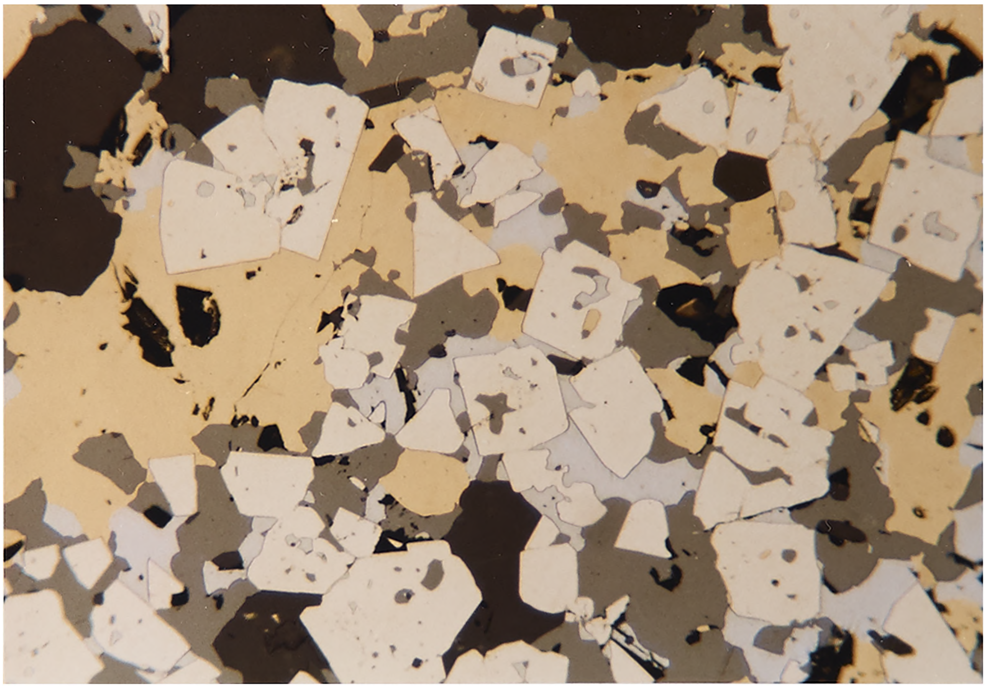


Figure 15. Photomicrograph of polished section number 8-294 at 100 x showing poikiloblastic pyrite with inclusions of sphalerite, galena, and chalcopyrite.

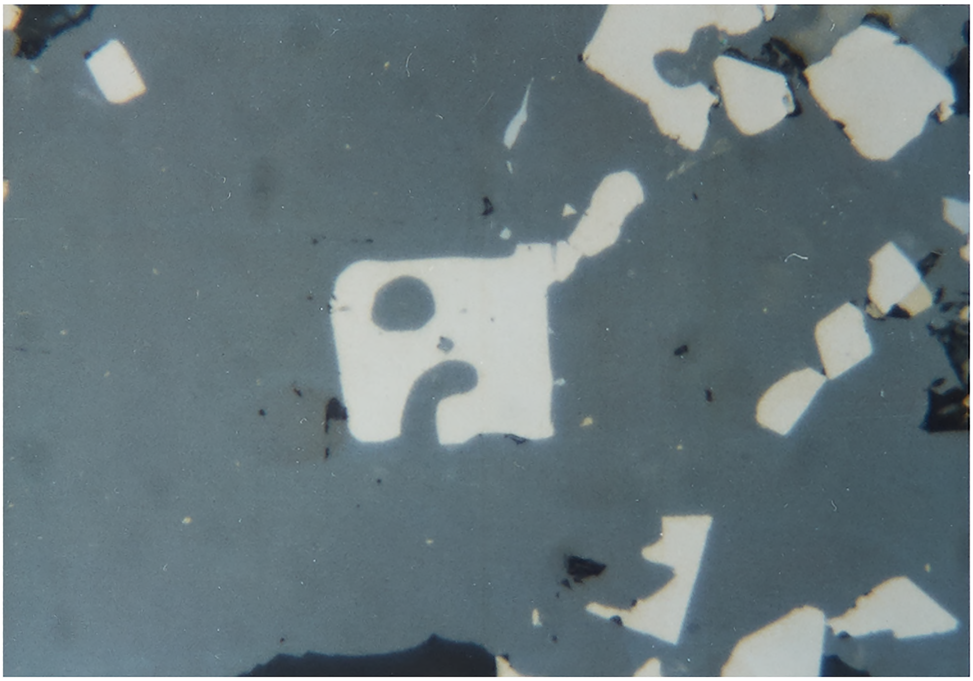


Figure 16. Photomicrograph of polished section number 2-214 at 400 x showing poikiloblastic pyrite porphyroblast engulfing a second inclusion of sphalerite.

interesting relationships are evident. Sphalerite is always anhedral where it is in contact with pyrite. The pyrite obviously has a much stronger crystalloblastic tendancy than does sphalerite. Where sphalerite contacts chalcopyrite or galena however, it generally exhibits the rotund tetrahedral crystal shapes common to sphalerite formed in open spaces. Where sphalerite contacts tetrahedrite their crystalloblastic strenths appear to be approximately equal placing the two intermediate between that of pyrite and the other sulfides.

Chalcopyrite and galena are present in nearly equal proportions at Mount Chase and tend to occur in nearly equal shaped anhedral masses within the sulfide laminae. Chalcopyrite shows a strong association with sphalerite where it occurs as small poikiloblastic segregations within the sphalerite or as rims around porphyroblastic sphalerite crystals. Where chalcopyrite is in contact with galena, crude tetrahedral chalcopyrite crystal shapes are seen growing into the galena mass. Obviously chalcopyrite has a somewhat stronger crystalloblastic tendancy than does galena. Galena is always anhedral in the Mount Chase sulfides. Galena and chalcopyrite are occasionally seen filling discordant fractures cutting across the sulfide laminae as well as minute fractures rarely seen cutting individual pyrite crystals. The softer sulfide minerals such as chalcopyrite and galena reportedly can flow into such fractures even under low

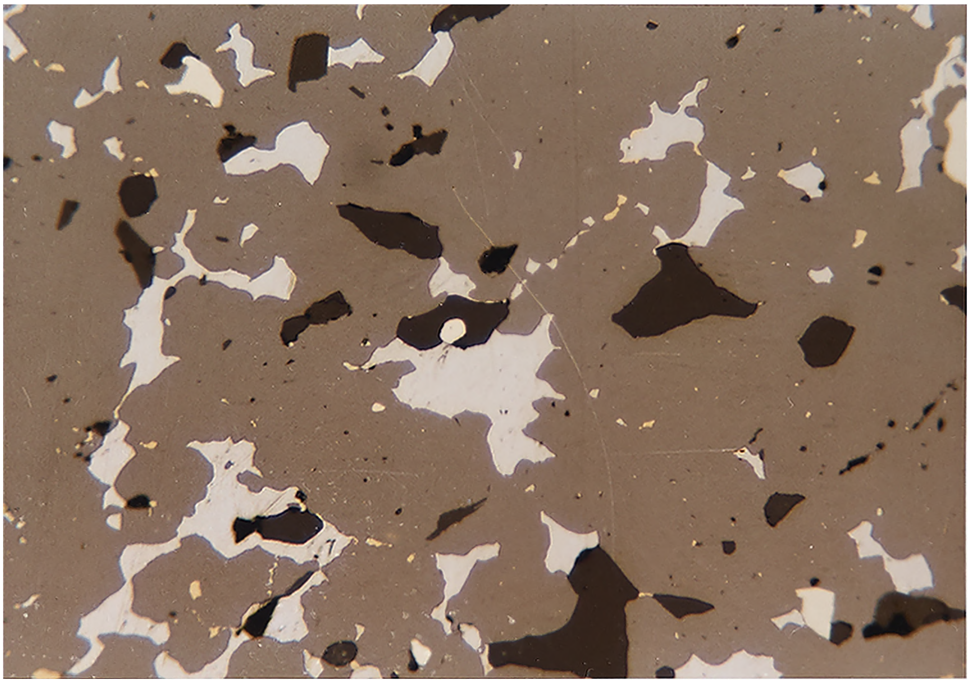


Figure 17. Photomicrograph of polished section number 8-299 at 100 x showing typical rotund sphalerite crystals growing into anhedral galena masses.

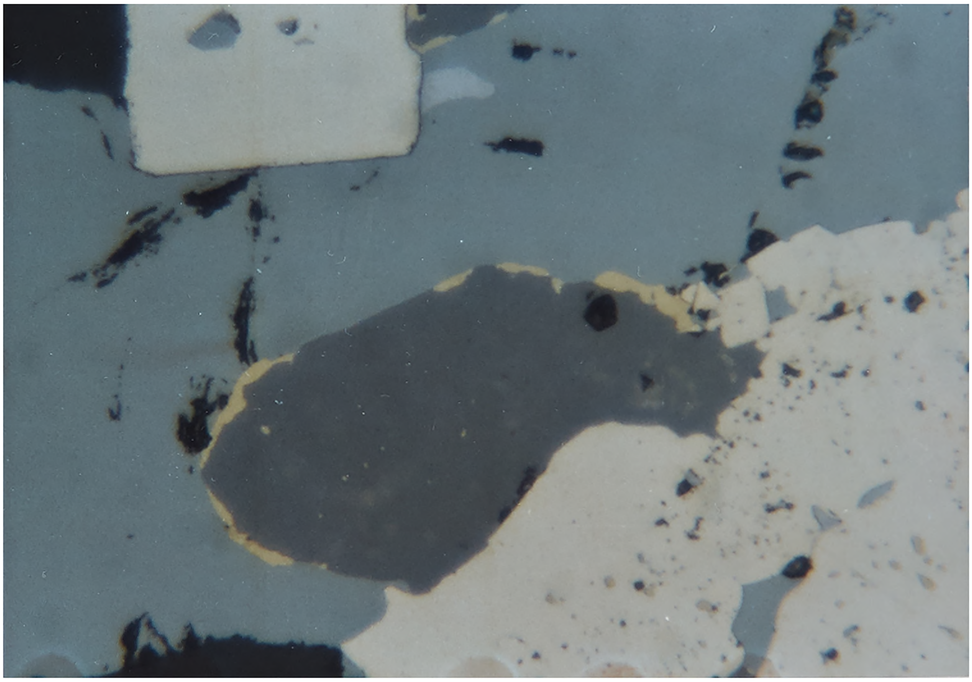


Figure 18. Photomicrograph of polished section number 2-244 at 400 x showing chalcopyrite as tiny inclusions and rimming porphyroblastic sphalerite. The sphalerite is flanked by pyrite and tetrahedrite.

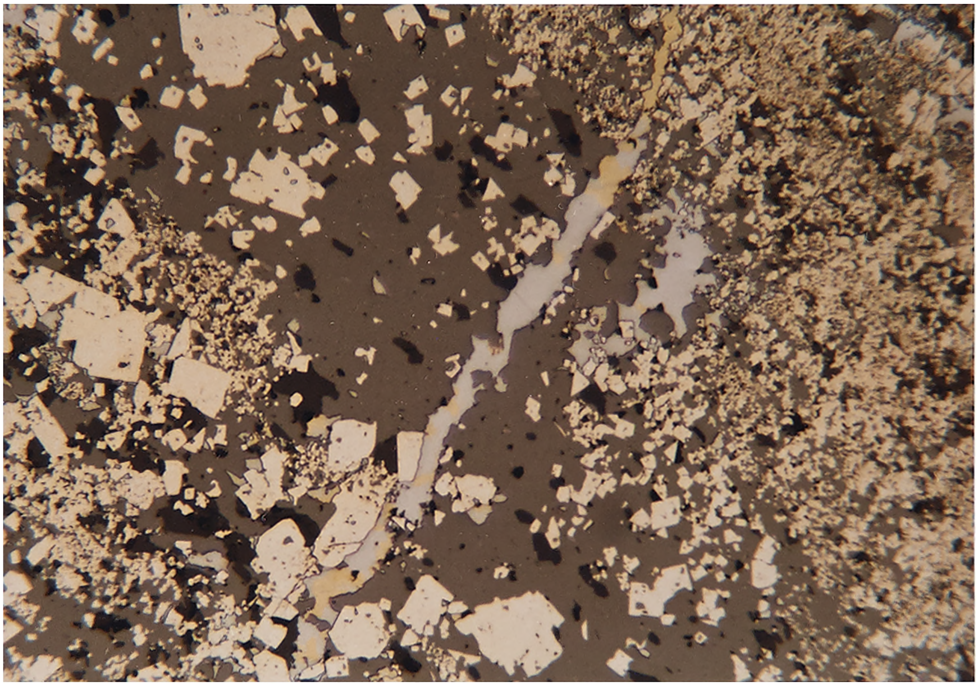


Figure 19. Photomicrograph of polished section number 34-836 at 50 x showing galena and chalcopyrite filling fracture discordant to laminae.

grade metamorphic conditions (Hagni, 1981). The textural evidence at Mount Chase would support this observation.

Magnetite and arsenopyrite occur in very minor amounts at Mount Chase and both show strong tendancies toward euhedralism. They appear to have crystalloblastic strengths approximately equal to that of pyrite. Magnetite occurs as small isolated octahedral crystals within the high grade Pb-Zn-Cu laminae, while the arsenopyrite is typically associated with pyrite in the low grade pyritic laminae.

6. Hanging Wall Tuffs (Hwt). The Mount Chase main massive sulfide horizon is immediately overlain by a sequence of variably textured tuffs and tuffaceous sediments. The unit includes up to a dozen individual beds of lithic to crystal-lithic tuffs with a total thickness of 50 to 350 feet. On the eastern side of the deposit area, the unit also includes a basal greenstone flow and two ferrugenous chert horizons. On the western side of the deposit area, the unit includes at least two small massive sulfide lenses as well as lithic tuff beds containing massive sulfide lithic fragments. Though it is normally unaltered relative to the footwall units, the hanging wall tuff unit occasionally exhibits moderate to intense sericitic and chloritic alteration. Evidently, the massive sulfide-producing hydrothermal activity continued sporadically and then eventually waned through the period of hanging wall tuff deposition.

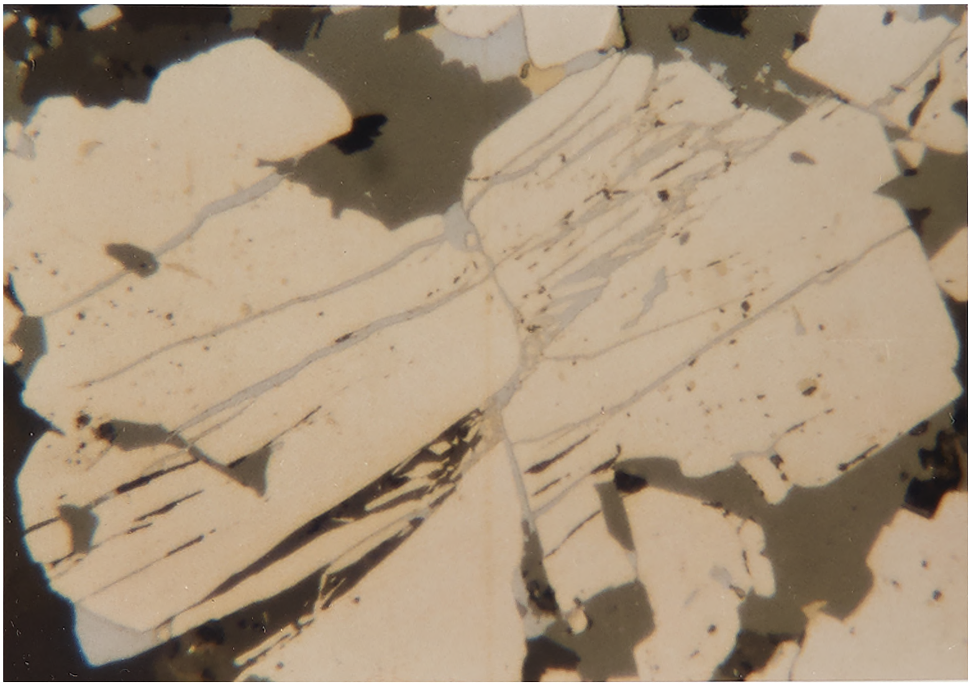


Figure 20. Photomicrograph of polished section number 34-836 at 400 x showing galena filling fractures in large brecciated pyrite cubes.

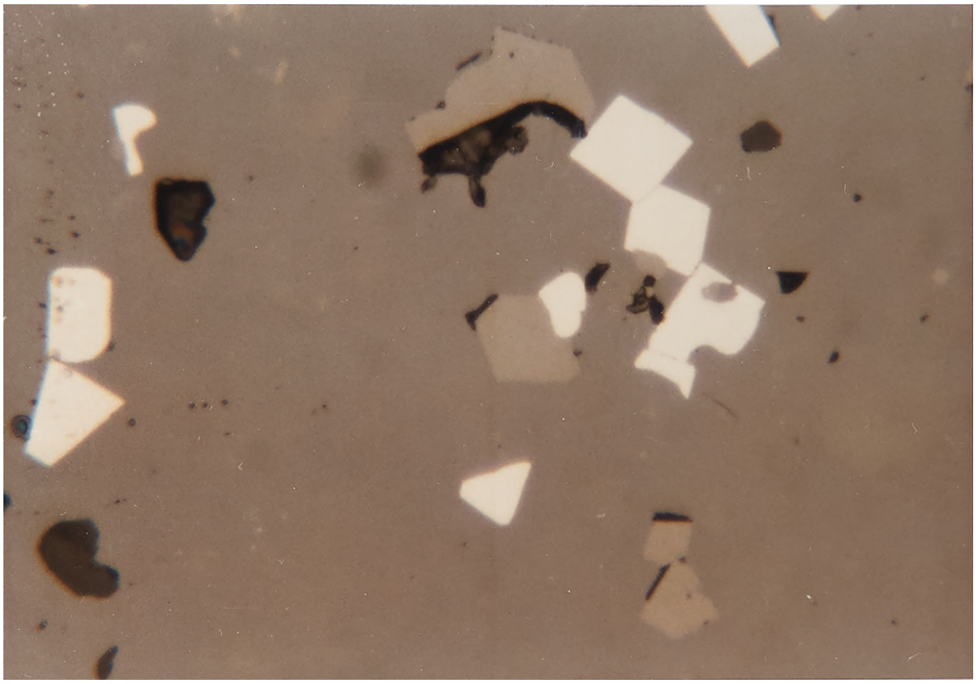


Figure 21. Photomicrograph of polished section number 34-842 at 400 x showing octahedral magnetite and cubic pyrite porphyroblasts surrounded by sphalerite.

Only a few outcrops of the hanging wall tuffs have been found in the deposit area, and these have typically been exposed along haul roads. Exposures occur as low smooth humps or pavement outcrops with glacially striated surfaces. Outcrop and drill core samples of the unit display a strong foliation which is subparallel to bedding as defined by the alignment of lithic fragments in the rock.

Megascopically the hanging wall tuffs range in color from light gray to dark greenish and purplish gray. Lithic and crystal-lithic textures are dominant throughout the unit. Angular, elongate lithic fragments of greenstone, crystal tuff, shale, and massive sulfide, ranging in size from 1 mm to 3 cm, make up from 10 to 40 percent of the rock. The tuff matrix is typically composed of fine grained (< 1 mm) devitrified ash or crystal-ash material. Matrix crystals are normally anhedral broken feldspars and lesser quartz. The tuffs generally have a mafic to intermediate composition, though a few thin beds of light colored felsic crystal tuff and possible rhyolite flows occur near the top of the unit on the eastern side of the deposit area.

Again, as in the footwall tuffaceous units, microscopic textures in the hanging wall tuffs have been severely affected by post-depositional processes such as welding, devitrification, hydrothermal alteration, regional metamorphism, and deformation. The rock matrix

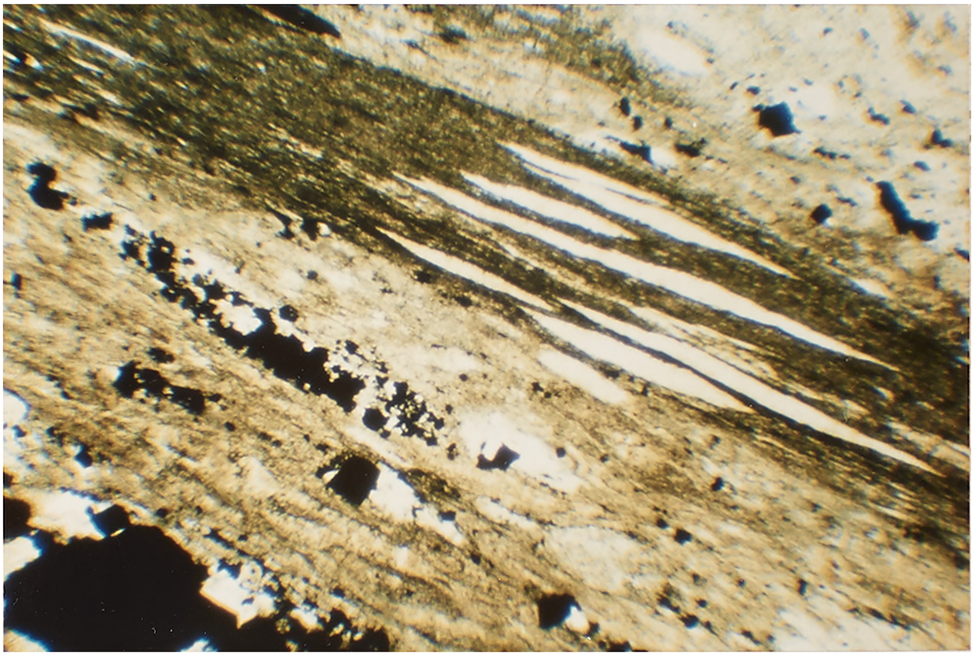


Figure 22. Photomicrograph showing sulfide lithics and possible relict shard texture in hanging wall tuff unit. Taken in plane polarized light at 50X.

is a very fine grained mixture of granular quartz and feldspar with varying amounts of feathery wisps of chlorite and sericite. Occasionally, larger wisps of sericite or chlorite appear to be relicts of flattened glass shards. Lithic fragments are defined by various compositional changes and are often somewhat indistinct in thin section due to the affects of metamorphism and alteration. Small knots and spherulites of epidote are common throughout the unit. Disseminated cubic pyrite and massive pyritic lithics make up as much as 5% of the rock. In the purple tuffs, fine disseminated hemitite is also abundant.

The basal greenstone within the hanging wall tuff unit is a dark greenish gray to greenish black aphanitic rock interpreted to be a mafic flow. It is typically a massive unfoliated rock with abundant veins and patches of epidote plus chlorite. Though somewhat finer grained, this rock is essentially identical to the main greenstone unit described below.

Two beds of dusky red to brick red laminated ferrugenous chert occur within the hanging wall tuff sequence on the eastern side of the prospect. The lower bed is up to 25 feet thick and occurs approximately in the middle of the tuff unit. The upper bed occurs near the top of the unit and can be as much as 80 feet thick. The chert is generally a very hard competent rock with an aphanitic texture, although soft gritty tuffaceous or

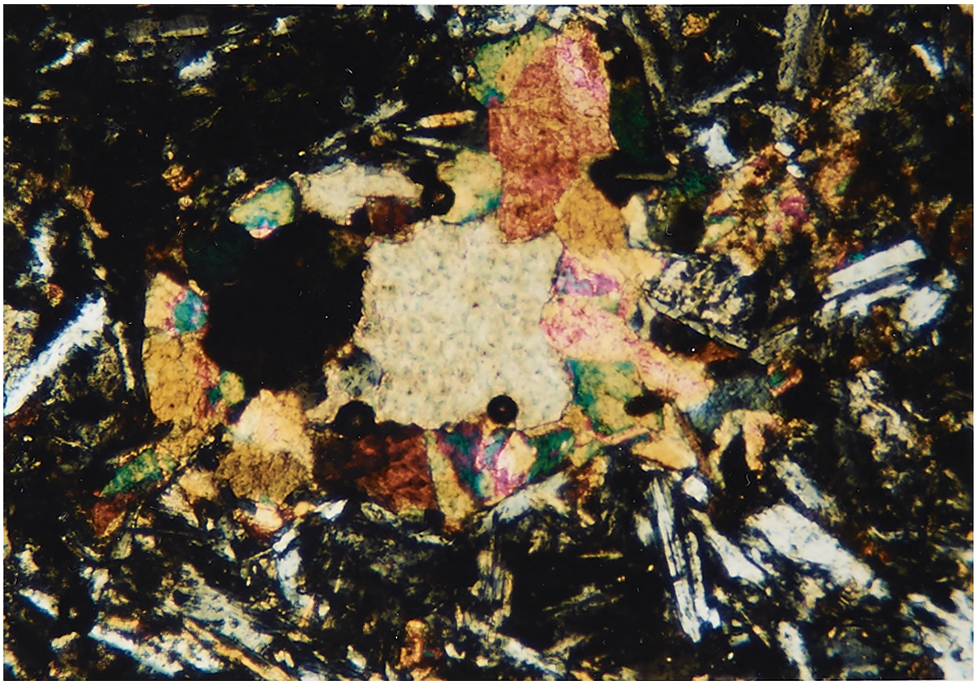


Figure 23. Photomicrograph showing zoned amygdule in lower greenstone unit. Taken with crossed polars at 100X.

muddy laminae are occasionally interbedded with the chert. Though not included in the chemical analyses of this study, assays of the chert horizon show Mn contents of up to 4.0%. Similar iron-manganese chert horizons are often found capping, or in association with volcanogenic massive sulfide deposits throughout the world (Ohmoto and Skinner, 1983).

7. Greenstone (G). The hanging wall tuff unit is next overlain by a massive, fine grained, dark mafic volcanic unit commonly refered to as greenstone. The greenstone is typically much more resistant to erosion than the surrounding units so that it tends to form many small knobs and long, low ridges revealing abundant exposures. As can be seen on Plate I, the map pattern of the unit shows a distinct correlation to topographic highs in the prospect area.

Megascopically, the greenstone unit is a dark greenish gray to greenish black, fine to medium grained, massive, unfoliated rock. It often contains locally abundant veins and irregular shaped knots of epidote, calcite, chlorite, and lesser quartz. Spherical to oval, 2 to 5mm amydules of calcite and epidote are also locally abundant. Typically, in drill core, these amygdules are most abundant in finer-grained portions of the unit which have been interpreted to be chilled tops of individual flow units. Minor amounts of fine disseminated pyrite, pyrrhotite, and magnetite are common throughout the unit.

The unit exhibits a moderate to strong magnetic signature on ground magnetic surveys which has been used as valuable mapping tool in the area.

In thin section, the greenstone is typically composed of 40 to 60 percent subhedral to euhedral, occasionally broken plagioclase laths; 25 to 35 percent anhedral to euhedral augite, and up to 15 percent each of chlorite and epidote as thin veins and irregular clots. Where amygdules are present, they typically show compositional zoning with a core of calcite rimmed by an outer shell of epidote. Minor leucoxene, and trace amounts of magnetite, ilmenite, and pyrite are also present. Occasionally, ophitic texture is seen in the coarser grained sections where large euhedral augite surrounds smaller euhedral plagioclase laths. Irregular shadowy patches of fine grained plagioclase commonly seen replacing larger plagioclase laths is interpreted to represent albitization of the originally intermediate plagioclase compositions.

The greenstone unit is interpreted to be a series of submarine basaltic to andesitic flows which are essentially conformable with the overlying and underlying stratigraphic units. Portions of the unit may be intrusive diabasic feeder dikes or sills, but none are seen crosscutting other units in the immediate prospect area.

A second unit also mapped as greenstone crops out farther to the southeast, stratigraphically above the hanging wall shale units described below. This greenstone lies outside of the area originally sampled for this study, but its relationship to the underlying units seems to merit some discussion. Like the lower greenstone, this unit is generally a massive, dark colored rock of mafic composition. Textures range from that of a fine grained basalt to that of a medium to coarse grained diabase or gabbro. Coarse, ophitic textures are common in the unit, and occasionally the rock bears hornblende rather than pyroxene. Traverses by the author and the mapping of Ekren and Frischknecht (1967), indicate that this greenstone unit is a thick mafic complex which crops out fairly continuously from the prospect area for at least two miles to the southeast. They describe the unit as consisting mainly of ophitic spilite, but they do show a small body of hornblende diabase in approximately the correct location just to the southwest of Picket Mountain Pond. Thus, this upper greenstone unit of the deposit area is here correlated with the unnamed Ordovician volcanic unit described by Neuman (1967) and Ekren and Frischknecht (1967).

The base of the upper greenstone unit is in fault contact with the underlying hanging wall shales to the northwest. This fault contact has been drilled through several times now, and is typically defined by a two to ten foot gouge-breccia zone. Ekren and Frishknecht (1967), also show a major fault zone in a similar

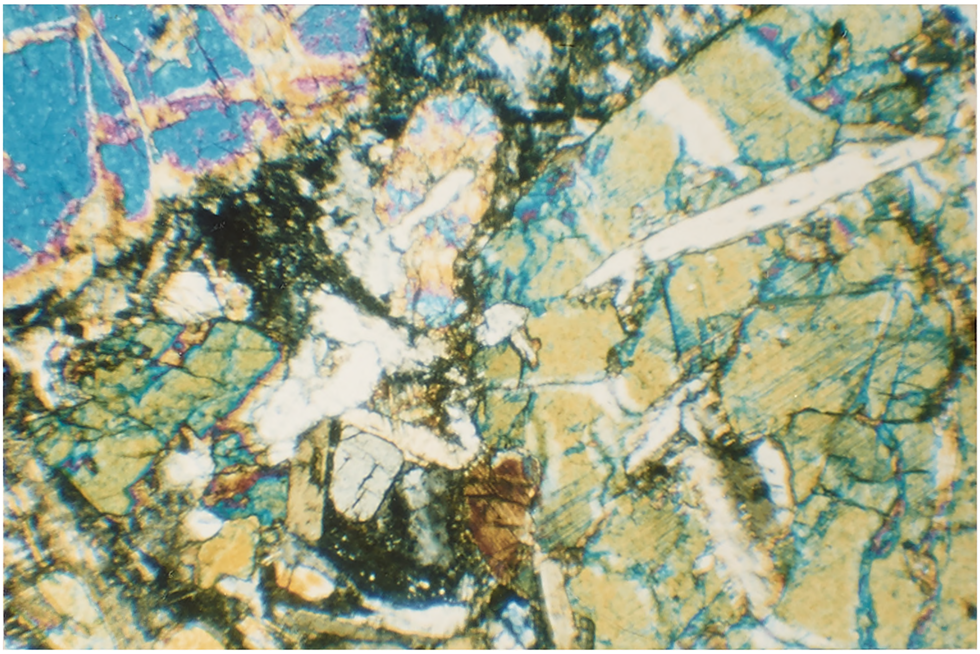


Figure 24. Photomicrograph showing ophitic texture in upper greenstone unit. Taken with crossed polars at 50X.

stratigraphic position. Though the relative movement along the fault is not definitely known, it seems likely, given the local tectonic history, that it may have developed during the intense regional folding event due to the contrasting competency of the shale and greenstone units.

8. <u>Hanging Wall Shales (Sg,S)</u>. The lower greenstone unit is conformably overlain by a sequence of shales consisting of a lower unit of green and purple shales (Sg) which then grade upward into a unit of gray and black shales (S). Few outcrops of the hanging wall shales are found in the prospect area. Most of the exposures in the area are glaciated pavements which have been uncovered along skidder trails or logging roads. The shales are typically quite fissile and outcrops show a well developed slaty cleavage.

The green and purple shales are composed of a very fine grained strongly foliated mixture of feldspar, quartz, sericite, and chlorite, with minor amounts of calcite, epidote, and disseminated pyrite. Large (2-5mm) pyrite cubes are scattered throughout the unit, and curious lensoidal masses of spherulitic calcite are locally abundant. The purple shales contain abundant fine disseminated hematite which is apparently responsible for their color.

The gray and black shales are composed predominantly of very fine grained foliated feldspar, quartz, and sericite with minor chlorite, calcite, and fine opaque carbonaceous material. In the black shales, the carbonaceous material becomes a dominant component, and graphite is commonly seen on cleavage surfaces. The large cubic pyrites and spherulitic calcite masses are also locally abundant in the gray and black shales.

B. STRUCTURE

According to the mapping of Neuman (1967),and Ekren and Frischknecht (1967) the Mount Chase massive sulfide deposit lies within the southeast limb of the northeast-southwest trending Weeksboro-Lunksoos Lake Anticlinorium. They describe tight complex folding and a folded early cleavage in the Cambrian Grand Pitch sediments in the core of the structure, and simple homoclinal folding and a single vertical cleavage in the younger units on the flanks of the structure. They have identified only a few major faults which tend to be steeply dipping and parallel to the regional strike. One of these faults is shown passing through the Mount Chase prospect area.

In general, the limited structural observations made in this study agree well with those summarized above. The Mount Chase deposit host units show an average strike of N66E and dips ranging from vertical to 65SE. With the exception of the Sgp unit, which is correlated here with the Grand Pitch Formation, the host rocks occur as relatively simple, steeply dipping beds on the flanks of major anticlinal structure whose axial plane is to the northwest of the prospect area. Little evidence for any well developed minor folding in the units has been found. All but the dense rhyolite and greenstone units exhibit a strong slaty cleavage which dips vertically and strikes N10-25E. This tectonic foliation is also often expressed as a slip cleavage in the bedded units where 3 mm to 1 cm displacements offset individual laminations. Ekren and Frischknecht (1967) propose that this regional foliation is slightly younger than the major folds, and was develloped after a minor change in the applied direction of the tectonic forces.

The Sgp unit of interbedded shale, silstone, and quartzite is structurally more complex than the other units in the prospect area. Minor folds have been exposed in pavement outcrops along the main access road through the prospect area (Figure 6), and small scale kink bands have been identified in thin sections of shaley portions of the unit (Figure 7). Although the presence of these features does not necessarily indicate polydeformation, the Sgp unit does appear to be more complexly deformed than overlying beds.

The major, steeply dipping fault which Ekren and Frischknecht (1967) propose strikes through the Mount Chase Prospect area, does appear to be a real structural feature. The fault has been intercepted several times in project drill holes in approximately the same location as indicated by their regional mapping. As discussed in the previous section, the contact between the hanging wall shales and the upper greenstone complex is defined by a two to ten foot fault gouge zone. The relative movement on the fault is not known, but it does appear to be an important regional scale structural feature. The same fault has been drilled in holes more than a mile along strike to the northeast of the main drilling site. The structure may be, at least in part, responsible for the thinning and eventual dissapearance of the massive sulfide host units in that direction.

The four north-south trending cross-strike faults shown on Plate I are somewhat conjectural features which are indicated by abrupt offsets of the geologic units along strike. The parallel structures dip 80-90 NE and have an apparent strike-slip sense of offset. Since most of the project drill holes have been drilled roughly parallel to the proposed faults, the structures have not been closely defined by the drilling. However, a few fault gouge intercepts do correlate well with the proposed fault traces, and their locations are fixed between relatively close-spaced drill hole paths. The faults are also indicated by distinct offsets in the patterns of several ground geophysical surveys including magnetics, Max-Min, and Mise-A-La-Masse. These faults are considered to be later than the northeast-southwest trending fault described in the previous paragraph.

C. METAMORPHISM

As suggested by the work of Ekren and Frischknecht (1967), and Thompson and Norton (1968), the Mount Chase rocks have been subjected to high pressure-low temperature, low grade regional metamorphism. The metamorphic mineral assemblage of the rocks is dominated by chlorite, sericite, and epidote. Trace amounts of a mineral tentatively identified as pumpellyite in the lower greenstone unit tends to suggest that the metamorphic grade of the rocks is possibly just over the very low/low grade boundary. Interpretations of the metamorphic assemblage at the prospect are complicated by the effects of hydrothermal alteration which changed the composition of the rocks prior to the metamorphic event. Therefore, any simple mineralogical interpretation of the metamorphism of the prospect area would be considered suspect. However, there are no mineralogical indications that these rocks experienced anything greater than greenshist facies, low grade regional metamorphism.

D. HYDROTHERMAL ALTERATION

A broad zone of intense hydrothermal alteration occurs immediately below the Mount Chase massive sulfide horizon in the footwall fragmental and tuffaceous units. This alteration is characterized by chloritization, sericitization and minor silicification of the units by the massive sulfide-producing hydrothermal solutions. Similar alteration halos occur below virtually all of the volcanic-associated massive sulfide deposits described throughout the world (Franklin et al., 1981). Intense chloritic alteration generally occurs in the first five to twenty feet below the main sulfide horizon at Mount Chase. Below that, a zone of intense sericitic alteration continues for well over fifty feet then gradually subsides over the next fifty to one hundred feet. This sericitic zone alteration also includes lesser amounts of silicification and chloritization. Intense silicification is only locally evident at Mount Chase and is essentially restricted to the coarse volcanic breccia unit beneath the eastern side of the deposit area. A broad zone of pyite plus chalcopyrite stringer mineralization is associated with the alteration pipe beneath the western side of the prospect area.

Zones of moderate to intense chloritic and lesser sericitic alteration are also occasionally found within the hanging wall tuff unit at Mount Chase. As previously discussed, these hanging wall alteration zones indicate continuation of the sulfide producing hydrothermal system during the deposition of at least a portion of the hanging wall tuff units. This process is also suggested by the presence of at least two thin massive sulfide lenses within the hanging wall tuffs. Multiple, stacked lenses and hanging wall alteration halos are not uncommon in other volcanogenic massive sulfide deposits (Franklin et al., 1981).

A second type of alteration seen at Mount Chase is the apparent replacement of calcic plagioclase by fine grained albite in the mafic volcanic units. This phenomenon is typically the result of a process commonly refered to as spilitization or alkali metasomatism and involves the alteration of submarine volcanic rocks by seawater. Commonly, the chemical composition of the rock is altered by the removal of calcium and the addition of sodium by this process (Vallance, 1973; Humphris and Thompson, 1978). At Mount Chase original calcic or intermediate plagioclase is often partially pseudomorphed by fine grained cloudy masses of albite. Chemical evidence for this process at Mount Chase will be discussed in the following section.

VI. PETROCHEMISTRY

A. GENERAL DISCUSSION

Representative drill core samples of the immediate hanging wall and footwall lithologies at the Mount Chase deposit were analyzed by x-ray fluorescence for SiO2, Al2O3, Fe2O3, MgO, CaO, Na2O, K2O, TiO2, P2O5, MnO, FeS2, Ba, Cu, Zn, Rb, and Sr. The results of these analyses appear in Appendix A. The majority of the analyses show acceptable pre-normalization totals of greater than 95%. Where the totals are lower than 95%, petrographic analysis indicates that the low results are likely due to the presence of carbonaceous material as well as carbonate and hydrous minerals. The analyses were obtained using pressed powder discs and these results checked favorably with several analyses obtained using fused beads as shown in Appendix B.

The chemical analyses of the Mount Chase rocks were initially performed for three main purposes: 1. to aid in the gross classification of the foliated rocks as being originally either sedimentary or igneous units, 2. to qualitatively characterize the affects of alteration upon the rocks, and 3. to attempt to chemically identify the original rock types and magmatic affinities of the igneous lithologies. The following is a discussion of the procedures used to attain these ends, and of the conclusions that were reached.

B. METAVOLCANIC VS. METASEDIMENTARY ROCKS

At Mount Chase the combined effects of hyrothermal alteration, alkali metasomatism, and regional metamorphism have so altered the original mineralogy and textures of the fine grained rocks, that it is often difficult to confidently distinguish metavolcanic from metasedimentary lithologies. Petrographic analysis shows that the greenstone, rhyolite, and crystal tuff units are certainly of igneous origin, and that the footwall Sgp and hanging wall shale units are of sedimentary origin. Questions remained however as to the original nature of the footwall breccia and hanging wall tuff units. Megascopic and petrographic inspection suggested that the footwall breccia was a tuffaceous volcanic rock with occasional clasts of sedimentary rock. The hanging wall tuff unit was considered to be a complex of pyroclastic rocks probably containing significant amounts of sedimentary material as lithic fragments.

Two chemically-based systems were employed to help distinguish between original metavolcanic and metasedimentary rocks at Mount Chase. The systems were applied to all of the available chemical analyses regardless of the relative certainty of the rock origin. The footwall rhyolite and Sgp units had not been drilled or mapped at the time of sample collection, so they are not represented in the chemical analyses. The application of these techniques to the Mount Chase rocks has been interpreted with care, as they were designed only to distinquish between metasedimentary and metavolcanic rocks where bulk compositions have remained relatively constant. The quantitative chemical affects of hydrothermal and metasomatic alteration upon the Mount Chase rocks are unknown, but are thought to be locally significant.

Bastin (1909) recognized several chemical characteristics of normal sedimentary rocks. Based upon these observations, he designed a set of criteria which makes it possible to chemically recognize metasedimentary lithologies. Bastin's criteria are listed below.

1. $K_2O > Na_2O$: typically sedimentary.
2. $MgO > CaO$: strongly suggestive of sedimentary origin.
3. Both 1. and 2.: very strong evidence of sedimentary origin.
4. Excess normative Al_2O_3: suggestive of sedimentary origin.
5. $SiO_2 > 60\%$: suggestive when supported by other criteria.

When Bastin's criteria are applied to the Mount Chase rocks, predictably mixed results are obtained. The hanging wall shale units and the footwall breccias are strongly suggested to be of sedimentary origin. They typically pass at least four of the five criteria listed above. The footwall crystal tuff and especially the greenstone units show little evidence of sedimentary affinities. The crystal tuffs generally pass one or two criteria, while the greenstone rarely passes one. Mixed results were obtained for the hanging wall tuffs.

C. A. Ossan, as described by Johannsen (1931), developed a system to recognize meta-igneous rocks based on observations of the basic chemical principles involved in magmatic crystallization. Ossan's system involves the use of two ternary diagrams where meta-igneous and metasedimentary rocks plot in separate fields. The ternary endpoints of the two diagrams are occupied by chemical terms whose relative abundances were found by Ossan to be diagnostic of the original nature of the rock. The two systems which he used were: 1. the S:AL:F System, where S = SiO2 + TiO2 + P2O5, AL = Al2O3, and F = Fe2O3 + CaO + MnO + MgO ; and 2. the AL:C:ALK System, where AL = Al2O3, C = CaO, and ALK = Na2O + K2O. Molecular proportions of the oxides are used to calculate Ossan's chemical terms, then the results are normalized and plotted as a point on the diagram.

The Mount Chase rock analyses were recalculated to molecular proportions and plotted on Ossan's diagrams. The results are shown on Figures 25 and 26. As can be seen on the figures, distinctly contrasting results were obtained from the two plots. Many of the Mount Chase rocks plotted within the sedimentary field on the AL:C:ALK diagram except for most of the greenstones and crystal tuffs, and a few of the hanging wall tuffs. The hanging

AL – C – ALK SYSTEM

KEY TO SYMBOLS USED:
(all figures in this section)

- □ Hanging Wall Shales
- + Greenstone
- ⊙ Hanging Wall Tuffs
- △ Footwall Tuff-Breccia
- ✱ Crystal Tuff

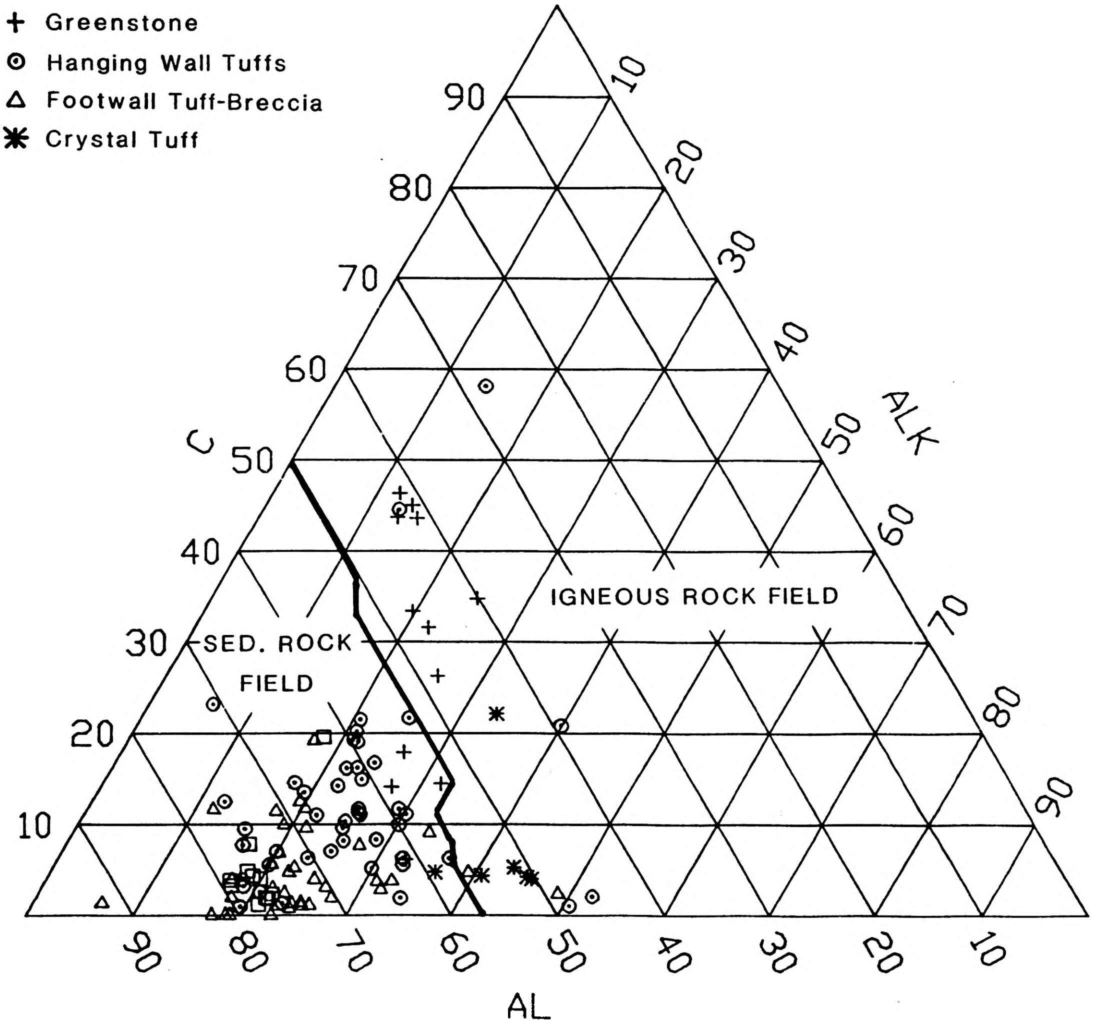


Figure 25. Mt. Chase rocks plotted on Al:C:Alk diagram. Al = Al2O3, C = CaO, Alk = Na2O + K2O, all in molecular proportions.

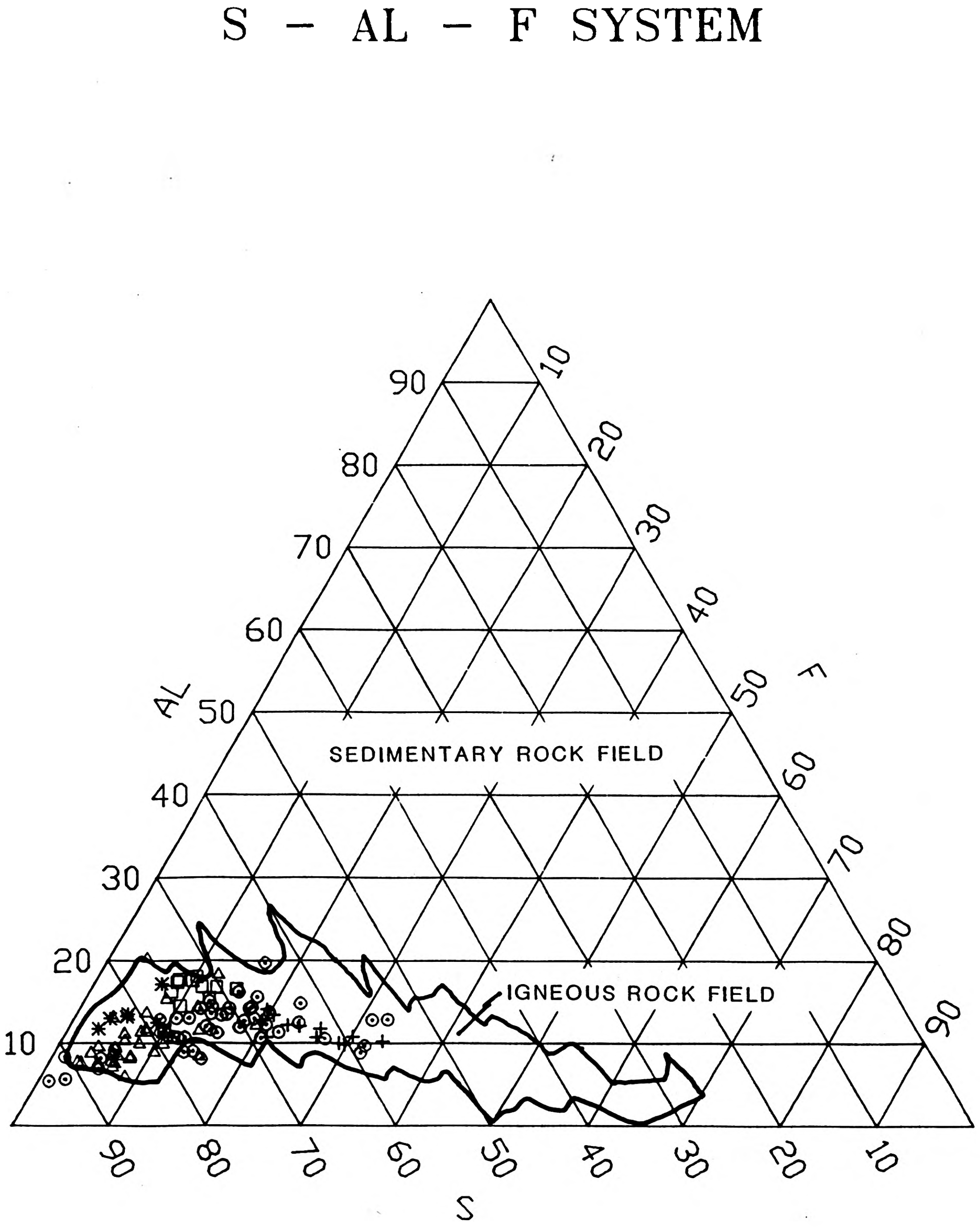


Figure 26. Mt. Chase rocks plotted on S:Al:F diagram. S = $SiO_2 + TiO_2 + P_2O_5$, Al = Al_2O_3, F = $Fe_2O_3 + CaO + MnO + MgO$, all in molecular proportions.

wall shales, footwall breccias, and most of the hanging wall tuffs plot well within the sedimentary field. In general, these results agree quite well with those obtained using Bastin's criteria, even to the extent that the same hanging wall tuff samples are indicated to be of igneous affinity.

On the S:AL:F diagram shown in Figure 26, nearly all of the Mount Chase rocks plot as igneous rocks, including the hanging wall shales. Because of the drastic difference in the results between this and the other techniques, and the fact that obvious sediments plot here as igneous rocks, use of the S:AL:F diagram for the Mount Chase rocks does not appear to be valid.

As previously mentioned, the systems of Bastin and Ossan do not to take into account the affects of hydrothermal alteration or metasomatism which may have altered the bulk chemistry of the rocks. Hydrothermal alteration associated with massive sulfide deposits typically removes Na, Ca, and K, from the host rocks (Goodfellow, 1975), and causes a subsequant relative increase in Al. Spilitic metasomatism of submarine volcanics generally leaches Ca from the rocks resulting in relative increases in elements such as Na, K, and Al (Humphris and Thompson, 1978). Since both of these processes have apparently altered the Mount Chase rocks, it is likely that the Ossan AL:C:ALK, and Bastin systems show somewhat misleading results. In both of these systems, however, the chemical changes described above would cause altered igneous rocks to appear to be of sedimentary origin. Thus it seems likely that more of the Mount Chase hanging wall tuffs and footwall breccias may have originally been volcanic than is suggested by the Ossan and Bastin systems.

C. VARIATION DIAGRAMS

Silica-based Harker variation diagrams were constructed using only those rocks which were indicated to be of igneous origin as described above. These include all of the greenstone and crystal tuff samples, as well as the five hanging wall tuff samples which plotted as igneous on Figure 25. The diagrams for the major and minor elements are shown on Figures 27 and 28 respectively. These diagrams were constructed in order to determine if any characteristic igneous variation trend exits, and to more fully reveal the proposed affects of alteration upon the rocks.

The variation diagrams for the Mount Chase volcanic rocks reveal significant scatter for several elements which is considered to be the result of chemical alteration of the rocks. All of the rocks show somewhat elevated levels of Na2O and Al2O3, along with severely depleted levels of CaO relative to normal igneous rock trends. K2O is enriched in the footwall crystal tuffs but severely depleted in the hanging wall rocks, and MgO shows somewhat elevated levels in the greenstone unit.

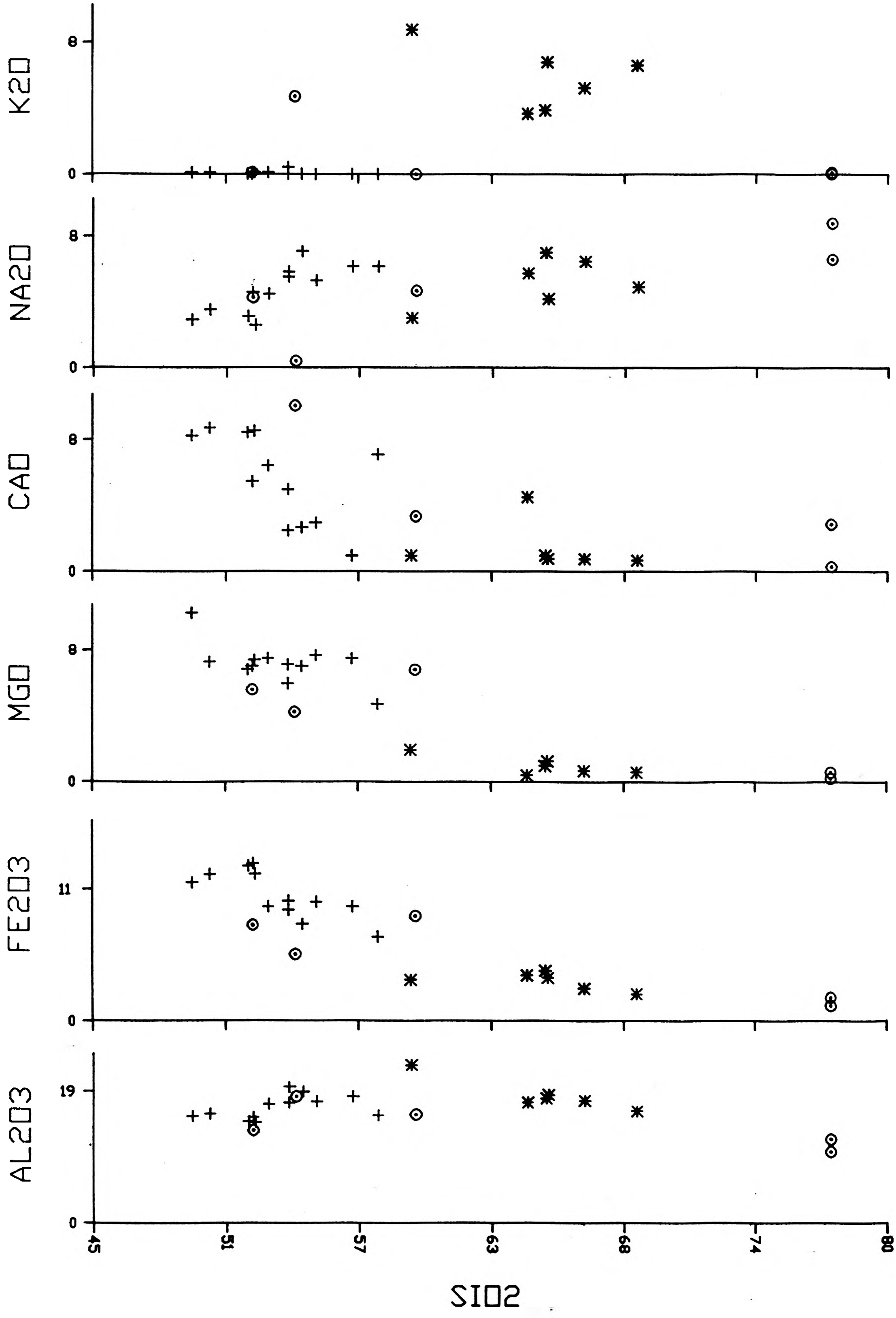


Figure 27. Variation diagrams of the major elements (in wt.%).

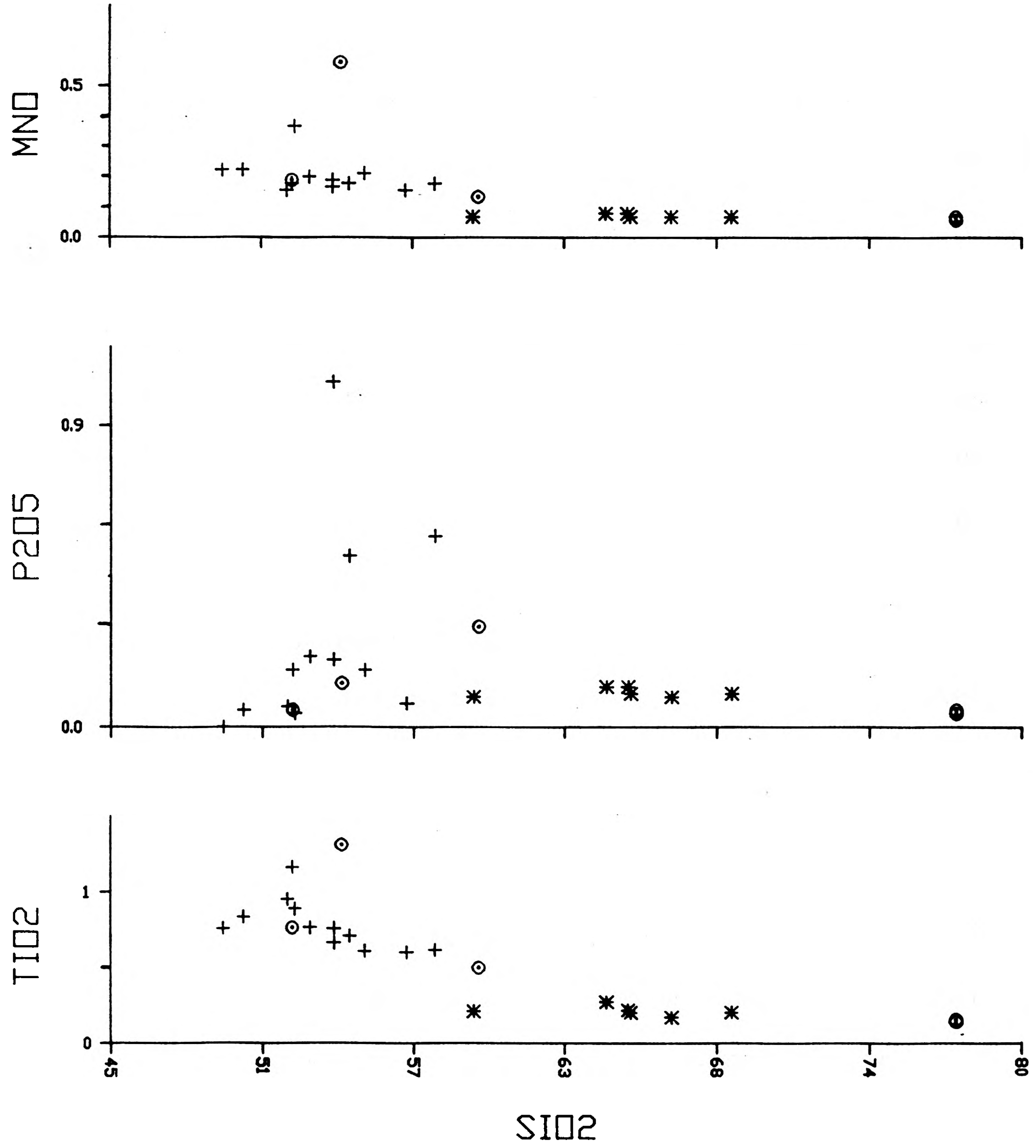


Figure 28. Variation diagrams of the minor elements (in wt.%).

This somewhat confusing alteration pattern appears to be the result of the combined effects of intense hydrothermal alteration and alkali metasomatism in the footwall rocks, and mainly of spilitic alkali metasomatism in the hanging wall rocks. This interpretation is consistant with the typical bulk chemical changes produced by these processes as outlined in the above section.

Despite the scatter produced by secondary chemical alteration, the Harker variation diagrams tend to exhibit overall trends expected for calc-alkalic volcanic rocks. The trends of Fe2O3, and in particular TiO2 and MnO are well defined. Even the severely altered element plots have a few samples which fall on the expected curves.

D. ROCK TYPES AND MAGMATIC AFFINITIES

Despite the apparently altered nature of the Mount Chase volcanic rocks, an attempt was made to chemically define the original rock types and their magmatic affinities using two of the standard major element discriminant plots described by Irvine and Baragar (1971). A TAS (Total Alkali vs. Silica) plot of the Mount Chase volcanic rocks was constructed and is shown on Figure 29. This type of plot has long been used to distinguish between the major alkalic and subalkalic igneous rock trends (Irvine and Baragar, 1971) but also more recently to approximately define the original igneous rock types. Le Maitre (1976) published a compilation and summary of world-wide igneous rock chemical data which includes

T A S PLOT

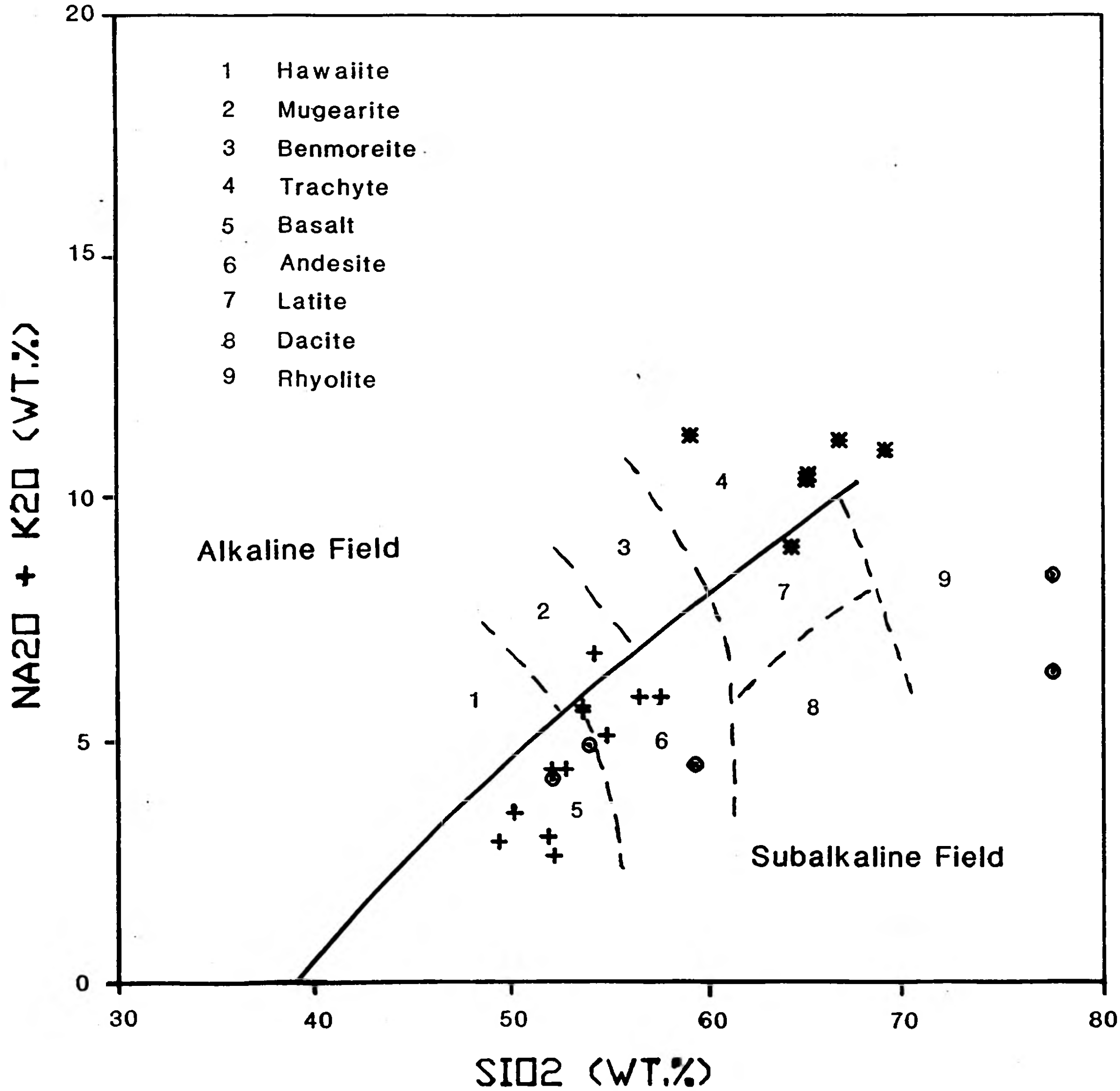


Figure 29. Total Alkali vs. Silica Plot. Solid line dividing alkaline and subalkaline fields after Irvine and Bargar (1971). Rock fields derived using data from Le Maitre (1976).

average compositions of the major intrusive and extrusive rock-types. These data were used here to approximately define several volcanic rock fields on the TAS plot shown on Figure 29. In general, the average rock composition falls in the center of the field shown. Only those fields significant to this study are given.

The Mount Chase rocks show basaltic through rhyolitic compositions on Figure 29. They generally fall within the subalkaline field. The apparent alkaline nature of the footwall crystal tuffs on the diagram is most likely an anomaly produced by the alteration discussed above. These rocks exhibit elevated levels of both Na2O and K2O, and probably represent altered dacitic to rhyolitic volcanic rocks. The hanging wall tuff and greenstone units show depleted levels of K2O, but elevated levels of Na2O. These effects appear to approximately average-out such that the plot of these units should be close to correct on the TAS diagram. The greenstones plot as basalts and andesites, while the hanging wall tuffs appear to be somewhat bimodal, plotting as basalts, andesites, and rhyolites. There is no indication of significant silicification in these units to cause horizontal movement of the points plotted.

Figure 30 shows the Mount Chase volcanic rocks plotted on an AFM diagram which are commonly used to distinguish between the calc-alkalic and tholeiitic suites of subalkalic igneous rocks (Irvine and Baragar, 1971). The

A F M PLOT

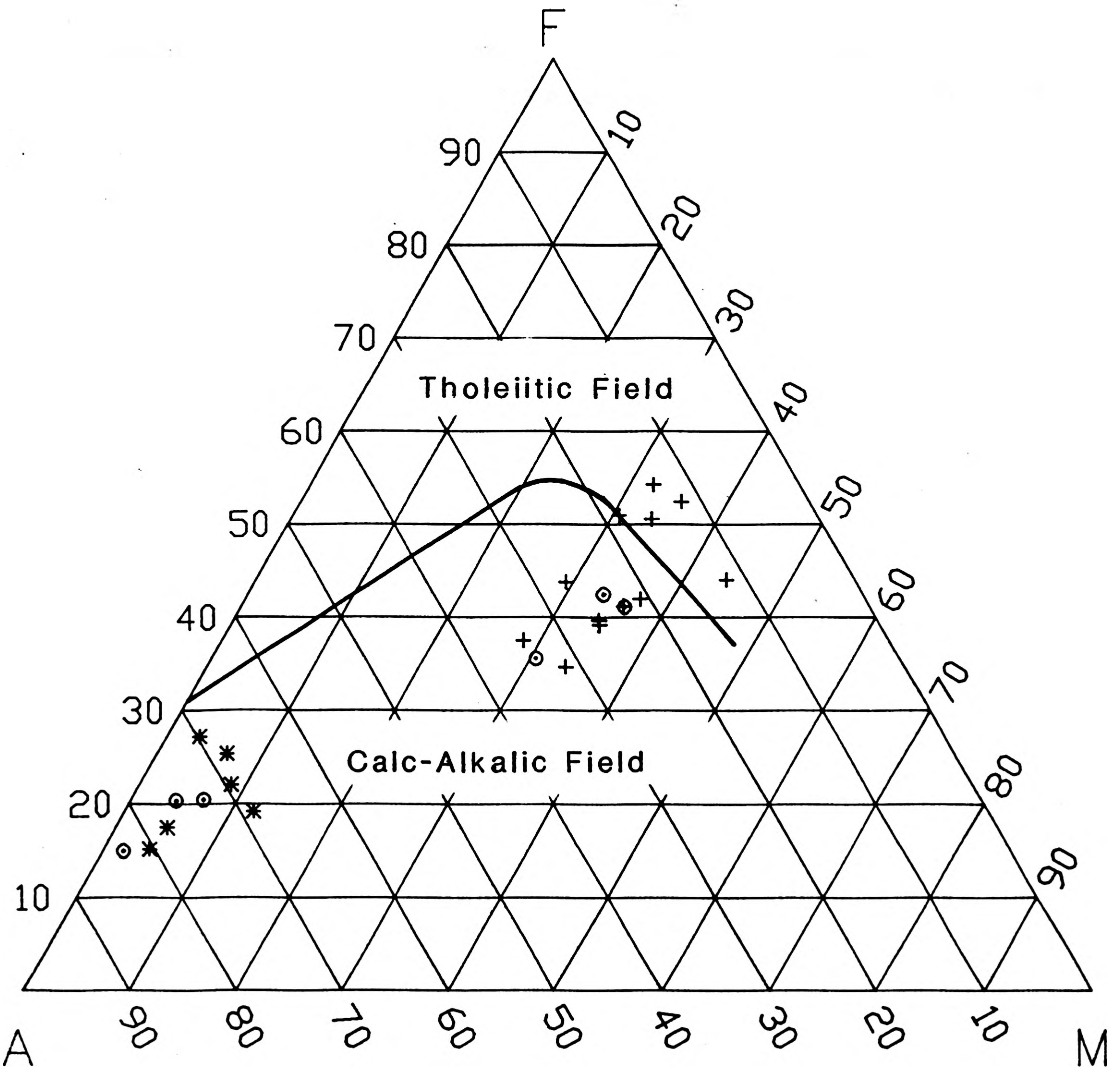


Figure 30. AFM Plot of Mount Chase rocks. A = Na2O + K2O, F = FeO + 0.8998Fe2O3, M = MgO, all in wt. %. Solid line separating tholeiitic and calc-alkalic fields after Irvine and Baragar, 1971.

andesitic through rhyolitic rocks of Mount Chase plot in the calc-alkalic field, while the basaltic rocks plot in the tholeiitic field. Hynes (1976) has also found the Mount Chase area basaltic rocks to be of mainly tholeiitic composition. The association of tholeiitic basalts with andesitic through rhyolitic calc-alkaline rocks is not unusual, and tends to suggest a relatively mature island arc setting for the Mount Chase volcanic rocks (Miyashiro, 1974).

VII. GEOLOGIC MODEL OF THE MOUNT CHASE PROSPECT

The Mount Chase massive sulfide prospect of northern Penobscot County, Maine is a fairly typical volcanogenic massive deposit which occurs in a sequence of Ordovician submarine volcanic and sedimentary rocks. The immediate footwall units consist of rhyolitic flows, quartz-feldspar crystal tuff, and altered tuffaceous volcanic breccias. These rocks lie unconformably upon intensely folded sediments which are tentatively correlated with the Grand Pitch Formation of probable Cambrian age. The footwall volcanoclastic units exhibit a narrow zone of intense chloritic alteration immediately below the massive sulfide horizon and, an underlying broader zone of sericitic alteration. A zone of pyrite plus chalcopyrite stringer mineralization is associated with the footwall alteration beneath the western side of the deposit area. The massive sulfide occurs in two adjacent main lenses occuring approximately within the same stratigraphic horizon. The basal portion of the massive sulfide is typically laminated high grade sulfide consisting of pyrite, sphalerite, galena, and magnetite. This is generally overlain by massively bedded and brecciated low grade pyritic sulfide. On a microscopic scale, the sulfide minerals exhibit metamorphic recrystallization with porphyroblastic and poikiloblastic pyrites as the dominant textural features. The Mount Chase hanging wall units consist of a sequence of relatively unaltered crystal-lithic tuffs, greenstone, and shale. The entire Mount Chase footwall and hanging wall sequence is tentatively correlated with the early to middle Ordovician Shin Brook Formation. An upper greenstone unit consisting of intrusive and extrusive mafic rocks is in fault contact over the hanging wall shale units. This unit is correlated with the middle Ordovician unnamed mafic volcanic unit mapped to the southeast of the prospect area.

The Mount Chase deposit host rocks show petrochemical characteristics indicative of mixed sedimentary and igneous lithologies. Interpretion of the petrochemical data indicates strong calcium depletion, and elevated levels of sodium in the rocks. Potassium is generally depleted in the hanging wall rocks, and elevated in the footwall rocks. These observations are interpreted to be the result of alkali metasomatism in the hanging wall rocks, and combination of alkali metasomatism and hydrothermal alteration in the footwall rocks. TAS and AFM plots of the Mount Chase igneous rocks indicate subalkalic calc-alkalic affinities for the andesitic through rhyolitic units. The basaltic rocks plot as tholeiites. A mature island arc setting is suggested for the Mount Chase volcanic rocks.

ACKNOWLEDGEMENTS

I would like to thank Chevron Resources Company for providing me with the information, resources, and time to complete this thesis. In particular, I am grateful to Peter G. Dunn and Ronald D. Luethe whose patience and knowledgeable suggestions were helpful during the final stages of the writing.

I am also grateful to John F. Snyder, formerly of Getty Mining Company, and Frederick M. Beck for my initial exposure to mineral exploration work and for allowing me to pursue my interests in the Mount Chase project. Many thanks also to Dr. Frank Howd of the University of Maine who sparked my interest in economic geology and initially steered me toward graduate studies at U. M. R.

I would also like to thank Dr. Richard D. Hagni for reviewing the thesis and providing many helpful suggestions, especially during the interpretation of ore textures.

I am particularly indepted to Dr. S. Kerry Grant who freely invested many hours of his own time toward the completion of this thesis. Dr. Grant has often gone out of his way to offer helpful guidance and assistance which were critical to the study.

I especially thank my beautiful wife Debra. Without her patience and moral support this work could never have been possible.

BIBLIOGRAPHY

Bastin, E. S., 1909, Chemical composition as a criterion in identifying metamorphosed sediments: Econ. Geol., v. 17, p.445-450.

Beck, F. M., 1988, Personal communication.

Billings, M. P., 1956, The geology of New Hampshire, Part II, Bedrock geology: Concord, New Hampshire State Plan. and Dev. Comm., 203 p.

Bird, J.M., and Dewey, J. F., 1970, Lithosphere plate-continental margin tectonics and the evolution of the Appalachian Orogen: Geol. Soc. Amer. Bull., v. 81 p.1031-1060.

Boone, G. M., 1988, Personal communication.

Boone, G. M., Boudette, E. L., Hall, B. A., and Pollock, S.G., 1984, Correlation and tectonic significance of pre-Middle Ordovician rocks of northwestern Maine: Geol. Soc. Amer. Abstracts with Programs, v. 16, p. 4.

Boudette, E. L., 1982, Ophiolite assemblage of Early Paleozoic age in central western Maine: in St. Julien, P., and Beland, J., eds., Major structural zones and faults of the Northern Appalachians: Geol. Assoc. Can., Spec.Paper 24, p. 209-230.

Bradley, D. C., 1983, Tectonics of the Acadian Orogeny in New England and adjacent Canada: Journal of Geology, v. 91, p. 381-400.

Chapman, C.A., 1968, A comparison of the Maine coastal plutons and the magmatic central complexes of New Hampshire: in Zen, E-an, et al., eds., Studies of Appalachian Geology, Northern and Maritime: Interscience, New York, p. 385-396.

Craig, J. R., 1983, Metamorphic features in appalachian massive sulfides: Mineralogical Magazine,, v. 47, p. 515-525.

Ekren, E. B., and Frischknecht, F. C., 1967, Geological-geophysical investigations of bedrock in the Island of Falls quadrangle, Aroostook and Penobscot Counties, Maine: U. S. Geol. Survey Prof. Paper 527, 36 p.

Eldridge, C. S., Barton, P. B., Jr., and Ohmoto, H., 1983, Mineral textures and their bearing on formation of the Kuroko orebodies: in Ohmoto, H., and Skinner, B. J., eds., The Kuroko and related volcanogenic massive sulfide deposits: Econ. Geol. Monograph 5, p. 241-281.

Franklin, J. M., Lyndon, J. W., and Sangster, D. F., 1981, Volcanic-associated massive sulfide deposits: Econ. Geol. Seventy-fifth Anniversary Volume,p. 485-627

Goodfellow, W. D., 1975, Major and minor element holos in volcanic rocks at Brunswick No. 12 sulfide deposit, N. B., Geol. Seventy-Fifty Anniversary Volume, p. 485-627.

Guidotti, C. V., 1985, Generalized map of regional metamorphic zones: in Osberg, P. H., et al., eds., Bedrock geologic map of Maine: Maine Geological Survey, Augusta, ME, scale 1:500,000.

Hagni, R. D., 1981, Applied ore microscopy: unpublished manuscript, Department of Geology and Geophysics, University of Missouri-Rolla, Rolla,MO 478 p.

Hitchcock, C. H., 1861, Geology of the wild lands: Maine Board of Agriculture, 6th Ann. Rept., p. 377-442.

Hon, R.,1980, Geology and petrology of igneous bodies within the Katahdin pluton: in Roy, D. C., and Naylor, R. S., eds., Guidebook to the geology of northeastern Maine and neighboring New Brunwick: N.E.I.G.C., 72nd Annual Meeting, p. 65-9.

Humphris, S. E., and Thompson, G., 1978, Hydrothermal alteration of oceanic basalts by seawater: Geochimica et Cosmochimica Acta, v. 42, p.107-125.

Hynes, A.,1976, Magmatic affinity of Ordovician volcanic rocks in Northern Maine, and their tectonic significance: Amer. Jour. Sc., v. 276. p. 1208-1224.

Irvine, T. N., and Baragar, W.R.A., 1971, A guide to the chemical classification of the common volcanic rocks: Can. Jour. Earth Sc., v. 8, p. 523-548.

Jackson, C. T., 1838, Second annual report on the geology of the public lands belonging to the two states of Massachusetts and Maine: Augusta, ME, 100 p.

Johannsen, A., 1931, a descriptive petrology of the rocks: Vol. I., University of Chicago Press, 315 p.

Kalliokoski,J., 1965, Metamorphic features in North American massive sulfide deposits: Econ. Geol., v. 60, p. 485-505.

Kay, M., 1976, Dunnage Melange and subduction of the Protoacadic Ocean, Northwest Newfoundland: Geol. Soc. Amer. Spec. Paper 175, 50 p.

Laurent, R., 1975, Occurrence and origin of the ophiolites of southern Quebec, northern Appalachians: Can. Jour. of Earth Sci., v. 12, p. 443-455.

Le Maitre, R. W., 1976, The chemical variability of some common igneous rocks: Jour. of Petrology, v. 17, part 4, p. 589-637.

Loiselle, M., Hon, R., and Nylor, R. S., 1983, Age of the Katahdin Batholith, Maine: Geol. Soc. Amer. Abstracts with Programs, v. 15, p. 146.

Miyashiro, A., 1974, Volcanic rock series in island arcs and active continental margins: Amer. Jour. Sc., v. 274, p. 321-355.

Naylor, R. S., 1969, Age and origin of the Oliverian Domes, central western New Hampshire: Geol. Soc. Amer. Bull., v. 80, p. 405-428.

Naylor, R. S., Boone, G. M., Boudette, E. L. Ashenden, D. D., and Robinson, P., 1973, Pre-Ordovician rocks in the Bronson Hill and Boundary Mountains anticlinorium, New England, U.S.A. (Abs.): Amer. Geophys. Union Trans., v. 54, p. 495

Neuman, R. B., 1960, Pre-Silurian stratigraphy in the Shin Pond and Stacyville quadrangles, Maine: in Short papers in the geological sciences: U. S. Geol. Survey Prof. Paper 400-B, p. B166-168.

Neuman, R. B., 1964, Fossils in Ordovician tuffs, northeastern Maine, with a section on Trilobita by H. B. Whittington: U. S. Geol. Survey Bull. 1181-E, 38 p.

Neuman, R. B. , Bedrock geology of the Shin Pond and Stacyville quadrangles, Penobscott County, Maine: U. S. Geological Survey Professional Paper 524-I, 37 p.

Neuman, R. B., 1984, Geology and paleobiology of island in the Ordovician Iapetus Ocean : review and implications: Geol. Soc. Amer. Bull., v. 95, p. 1188-1201.

Neuman, R. B., and Rankin, D. W., 1980, Bedrock geology of the Shin Pond-Traveler Mountain region: in Roy, D. C., and Naylor, R. S.., eds., Guidebook to the geology of northeastern Maine and neighboring New Brunswick: N.E.I.G.C., 72nd Annual Meeting, p. 86-7.

Ohmoto, H., and Skinner, B. J., 1983, Introduction and summary of new findings: in Ohmoto, H., and Skinner, B. J., eds., The Kuroko and related volcanogenic massive sulfide deposits: Econ. Geol. Monograph 5, p. 1-8.

Osberg, P. H., 1978, Synthesis of the geology of the northeastern Appalachians: in IGCP Project 27, Caledonian-Appalachian orogen of the North Atlantic Region: Geol. Surv. Canada, Paper 78-3, p. 137-47.

Osberg P. H., 1983, Timing of orogenic events in the U. S. Appalachians: in Schenk, P.E., ed., Regional trends in the geology of the Appalachian- Caledonian-Hercynian- Mauritanide Orogen: Proc. of the NATO Advanced Study Institute, Atlantic Candaa, D. Reidel Pub. Co., Dordrecht, Netherlands, p. 315-333.

Osberg, P.H., Hussey, A. M., II, and Boone, G. M., eds., 1985, Bedrock Geologic map of Maine: Maine Geological Survey, Augusta, ME, scale 1:500,000

Page, L. R., 1968, Devonian plutonic rocks in New England: in Zen, E-an, et al., eds., Studies of Appalchian Geology, Northern and Maritime: Interscience, New York, p.371-83.

Page, L. R., 1976, Introduction and summary: in Contributions to the Stratigraphy of New England: Geol. Soc. Amer., Memoir 148, p. 1-24.

Pavlides, L., Boucot, A. J., and Skidmore, W. B., 1968, Stratigraphic evidence for the Taconic Orogeny in the northern Appalachians: in Zen, E-an, et al., eds., Studies of the Appalachian Geology, Northern and Maritime: Interscience, New York, p. 129-140.

Pollock, S. G., 1982, Stratigraphy of the Caucomgomoc Lake area, northern Maine: Example of an obducted ophiolite- melange complex: Geol. Soc. Amer., Abstracts with Programs, v. 14, p. 73

Poole, W. H., 1976, Plate tectonic evolution of the Canadian Appalachian region: Geol. Survey of Canada, Paper 76-1B, p. 113-126.

Richter, D. A., and Roy, D. C., 1976, Prehnite-pumpellyite facies metamorphism in central Aroostook County, Maine: in Lyons, P. C., and Brownlow, A. H., eds., Studies in New England geology, Geol. Soc. Amer. Memoir 146, p. 113-126.

Rodgers, J., 1970, The tectonics of the Appalachians, Wiley Interscience, New York, 271 p.

Roy, D., C., 1980, Tectonics and sedimentation in northeastern Maine and adjacent New Brunswick: in Roy, D. C., and Naylor, R. S., eds., A guidebook to the geology of northeastern Maine and neighboring New Brunswick: N.E.I.G.C., 72nd Annual Meeting, p. 1-21.

St. Julien, P., and Beland, J., 1982, Introduction: in St.Julien, P., and Beland,J., eds., Major structural zones and faults of the Northern Appalachians: Geol. Assoc. Canada, Spec. Paper 24, p. 1-11.

Schenk, P. E., 1978, Synthesis of the Canadian Appalachians: in IGCP Project 27, Caledonian-Appalachian orogen of the North American Region: Geol. Survey Canada, Paper 78-13, p.111-136.

Smith, E. S. C., 1928, The Cambrian in northern Maine: Am. Jour. Sci., 5th ser., v. 15, p. 484-486.

Spry, Alan, 1969, Metamorphic Textures: Pergamon Press, New York, 350 p.

Stanton, R. L., 1960, General features of the comformable "pyritic" orebodies, Parts I and II: Can. Min. and Met. Bull., v. 53, p. 24-29 and 66-74.

Thompson, J. B., J r., and Norton, S. A., 1968, Paleozoic regional metamorphism in New England and adjacent areas: in Zen, E-an, et al., eds., Studies of Appalachian geology, northern and Maritime: Interscience, New York, p. 319-327.

Thompson, W. B., and Borns, H. W., eds., 1985, Surficial Geologic map of Maine: Maine Geological Survey, Augusta, ME, scale 1:500,000.

Vallance, T. G., 1973, Spilitic degradation of a tholeiitic basalt: Jour. Petrology, v. 15, part 1, p. 79-96.

Williams, H., 1984, Miogeoclines and suspect terranes of the Caledonian-Appalachian Orogen: tectonic patterns in the North Atlantic region: Can. Jour. Earth Sci., v. 21, p.887-901.

Williams, H., and Hatcher, R. D., Jr., 1983, Appalachian suspect terranes: in Hatcher, R. D., Jr. et al., eds., Contributions to the tectonics and geophysics of mountain chains: Geol. Soc. Amer. Memoir 158, p. 33-53.

Zen, E-an, 1968, Nature of the Ordovician orogeny in the Taconic area: in Zen, E-an, et al., eds., Studies of Appalachian Geology, Northern and Maritime: Interscience, New York, p.129-140.

Zen, E-an, 1983, Exotic terranes in the New England Appalachian-limits, candidates, and ages: A speculative essay: in Hatcher, R. D., Jr. et al., eds., Contributions to the tectonics and geophysics of mountain chains: Geol. Soc. Amer. Memoir 158, p. 55-81.

VITA

Michael Vincent Scully was born January 25, 1954, in Toronto, Ontario, Canada. He spent his youth in several different localities in the northeastern United States and eastern Canada and eventualy completed his secondary education in New Hartford, New York. On March 22, 1980 he married Debra J. England of Bangor, Maine. He earned a B. A. degree in Geology from the University of Maine at Orono in the spring of 1980. He enrolled at the University of Missouri-Rolla in the spring of 1981 and earned his M. S. degree in Geology in December of 1988.

APPENDIX A
PETROCHEMICAL DATA - MAJOR ELEMENTS
In Weight Percent

Sample #	Rock Type	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	MnO %	FeS_2 %	Total %
1-28	Hwt	54.1	19.8	11.5	5.5	1.6	1.8	4.2	1.31	.01	.12	-	100.51
1-35	Hwt	61.3	18.2	9.1	3.0	1.6	.6	5.5	.74	.04	.10	-	102.05
1-37	Hwt	53.2	21.5	8.6	4.2	4.4	.8	5.9	1.26	.01	.15	-	99.90
1-50	Hwt	50.7	20.6	12.3	8.3	1.4	4.0	1.3	.98	.21	.15	-	94.86
1-69	Hwt	56.1	17.5	10.2	7.5	1.9	5.2	.1	.95	.50	.11	-	97.19
1-81	Hwt	61.5	16.6	7.5	5.7	1.0	6.5	-	.82	.15	.09	-	97.86
1-119	Hwt	77.5	12.1	1.3	.2	.3	8.4	-	.18	.05	.05	-	102.62
1-160	Fwb	65.5	17.0	6.9	5.1	1.5	.6	3.0	.18	.03	.15	-	99.65
1-222	Fwb	72.9	16.5	2.5	2.6	.5	1.1	3.7	.16	.03	.06	-	99.92
1-246	Fwb	76.4	12.8	2.9	3.1	.3	2.7	1.7	.11	.03	.07	-	100.44
1-265	Fwb	73.8	15.4	1.8	2.7	1.0	1.8	3.3	.12	.03	.07	-	100.45
1-291	Fwb	75.4	13.1	2.2	2.6	.6	5.0	.9	.06	.01	.07	-	100.52
2-20	Hwt	57.7	18.6	11.4	3.3	1.8	2.6	3.1	1.28	.01	.11	.2	99.20
2-31	Hwt	56.9	18.4	11.8	3.2	2.7	2.0	3.4	1.52	-	.13	-	98.56
2-50	Hwt	54.9	19.3	12.0	3.3	2.6	2.2	3.7	1.53	.34	.15	-	98.40
2-68	Hwt	55.1	18.1	12.3	5.2	2.6	2.0	2.9	1.47	.23	.23	-	97.92
2-86	Hwt	56.0	18.5	11.7	3.3	2.9	2.5	3.3	1.41	.39	.16	-	98.42
2-105	Hwt	53.2	19.2	13.0	3.6	3.4	1.5	4.2	1.49	.30	.15	-	96.99
2-118	Hwt	53.3	19.1	10.9	5.7	3.4	1.8	3.5	1.41	.60	.19	-	98.30
2-125	Hwt	54.0	22.1	12.5	4.7	.5	.2	4.6	1.11	.11	.17	5.3	95.46
2-141	Hwt	65.6	15.4	7.0	3.8	1.6	3.5	2.0	.92	.09	.10	-	100.21
2-154	Hwt	52.0	13.3	8.2	5.8	15.4	4.1	.1	.98	.05	.17	-	89.53
2-163	Hwt	77.5	10.3	2.0	.6	3.0	6.3	.1	.20	.04	.06	-	99.87
2-176	Hwt	59.2	15.6	9.0	7.1	3.5	4.5	-	.64	.30	.12	-	94.95
2-187	G	54.2	18.9	8.3	7.3	2.8	6.8	-	.91	.51	.16	-	96.18
2-198	G	52.7	17.1	9.8	7.8	6.7	4.3	.1	.98	.21	.18	-	94.15
2-204	G	57.5	15.5	7.2	4.9	7.4	5.9	-	.79	.57	.16	-	94.94

APPENDIX A (cont)

Sample #	Rock Type	SiO2 %	Al2O3 %	Fe2O3 %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %	MnO %	FeS2 %	Total %
2-258	Fwb	60.2	18.0	9.6	7.7	1.5	.3	2.1	.15	.04	.26	-	97.79
2-271	Fwb	60.3	27.3	1.4	1.4	.4	1.9	7.0	.13	.03	.06	-	96.49
2-283	Fwb	75.3	14.1	4.0	2.2	.5	.7	2.9	.16	.05	.07	4.3	100.65
2-292	Fwb	77.2	12.9	2.3	2.8	.4	2.7	1.6	.09	.02	.07	-	100.01
2-306	Fwb	78.0	11.6	2.0	2.9	1.0	3.5	.9	.07	.02	.07	.2	100.54
2-326	Fwb	81.0	9.5	2.2	4.3	.9	1.2	.8	.06	.01	.06	.3	101.64
2-329	Fwb	72.3	17.1	1.7	3.2	1.3	1.2	3.1	.08	.01	.06	-	99.43
2-336	Fwb	74.2	15.2	2.1	4.0	.5	1.3	2.4	.09	.03	.06	-	100.32
2-360	Fwb	74.5	13.9	2.7	5.4	.3	1.1	2.0	.07	.02	.07	-	100.34
2-378	Fwb	70.7	16.9	2.4	4.6	1.3	.8	3.0	.09	.02	.07	-	99.10
8-285	Hwt	56.9	17.9	11.6	5.3	2.2	2.0	2.7	1.21	.02	.13	-	99.38
8-308	Fwb	67.7	19.8	3.1	3.1	.2	.8	5.0	.18	.03	.09	-	98.57
9-192	G	56.4	18.2	9.8	7.8	1.0	5.9	-	.77	.07	.14	.5	96.28
9-235	G	53.6	17.3	9.5	7.4	5.2	5.6	-	.97	.20	.17	-	95.08
9-250	G	54.8	17.5	10.2	8.0	3.1	5.1	-	.78	.17	.19	-	94.27
11-31	Hwt	75.5	13.8	2.7	2.2	1.0	2.2	2.5	.10	.01	.08	-	100.03
11-36	Hwt	68.4	16.6	4.7	3.3	1.7	2.1	3.0	.22	.03	.12	-	99.22
11-72	Hwt	61.8	21.1	4.8	6.4	.2	1.2	4.2	.25	.04	.12	-	97.53
11-85	Hwt	61.7	20.3	4.6	5.1	1.0	5.6	1.4	.25	.05	.09	-	96.55
11-107	Hwt	69.6	17.1	3.9	4.3	.9	.4	3.7	.13	.03	.07	-	99.16
11-122	Hwt	68.4	16.1	4.3	5.0	.7	3.2	2.0	.22	.03	.11	.3	97.92
11-136	Hwt	84.7	8.3	1.1	.3	.1	5.2	.1	.09	.02	.05	-	103.07
11-154	Hwt	61.8	16.4	8.1	4.7	3.1	2.5	1.6	1.18	.39	.12	-	98.87
11-165	G	53.6	19.6	10.3	6.2	2.6	5.3	.4	.85	1.03	.15	-	96.13
11-195	Fwb	70.7	16.9	2.8	3.9	.4	1.3	3.9	.19	.04	.06	-	99.12
11-206	Fwb	78.5	13.3	2.1	1.7	.1	.2	3.9	.09	.04	.05	.5	101.05
11-219	Fwb	75.7	12.4	2.9	3.9	.4	2.8	1.6	.13	.03	.07	-	100.42
11-261	Fwb	78.4	11.4	1.6	1.1	.3	6.8	.2	.11	.03	.05	.1	102.01
11-270	Fwb	56.1	25.1	5.1	5.2	.2	.5	7.5	.22	.06	.09	-	97.35
11-302	Tqf	64.9	17.9	4.3	1.0	1.0	6.7	3.7	.28	.12	.07	-	99.75
11-311	Tqf	66.6	17.6	2.8	.7	.8	6.2	5.0	.22	.09	.06	-	99.54

APPENDIX A (cont)

Sample #	Rock Type	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	MnO %	FeS_2 %	Total %
11-338	Tqf	64.1	17.3	3.9	.4	4.7	5.5	3.5	.35	.12	.07	-	100.53
11-361	Tqf	59.0	22.7	3.5	2.0	1.0	2.9	8.4	.27	.09	.06	-	97.27
11-383	Tqf	65.0	18.4	3.7	1.3	.8	4.0	6.5	.26	.10	.06	-	98.48
11-452	Tqf	68.9	16.1	2.3	.6	.7	4.7	6.3	.26	.10	.06	-	99.94
23-84	Sb	66.4	16.8	6.5	1.8	2.9	.6	3.6	.83	.26	.34	4.1	97.23
23-133	Sb	54.2	22.2	14.8	2.4	.6	.7	3.4	.90	.27	.33	-	96.35
23-192	Sb	52.8	21.9	14.6	2.3	.5	.6	3.6	.78	.16	2.7	-	94.18
23-301	Sp	56.1	22.5	12.2	2.0	.7	.7	4.1	.86	.15	.71	-	97.26
23-360	Sp	60.8	20.0	10.5	2.0	.7	.4	3.8	.85	.22	.73	.4	97.41
23-383	G	52.1	14.5	12.6	7.7	8.9	2.5	.1	1.14	.04	.33	-	88.94
23-396	G	51.8	14.6	13.3	7.1	8.8	3.0	-	1.22	.06	.14	.2	89.99
23-410	G	52.0	15.2	13.5	7.3	5.7	4.4	-	1.49	.17	.16	-	94.85
23-455	Hwt	63.4	17.6	4.9	5.7	1.6	3.8	2.4	.42	.18	.13	-	96.11
23-464	Hwt	57.2	16.4	8.4	14.4	.3	2.6	.1	.42	.07	.20	-	95.12
23-477	Hwt	50.2	19.6	9.3	15.8	.8	2.6	.9	.46	.08	.21	-	92.58
23-529	Hwt	67.5	13.5	8.0	5.2	1.6	.2	3.0	.77	.24	.12	1.0	97.51
23-548	Hwt	65.4	15.6	9.3	4.7	.1	.1	3.4	1.12	.04	.18	1.8	96.87
23-555	Hwt	85.1	8.9	1.1	.8	.8	.1	2.5	.52	.18	.08	1.2	93.69
23-574	Hwt	58.7	17.2	11.6	6.1	1.2	.2	3.2	1.50	.10	.34	.2	95.27
23-585	Hwt	56.1	16.4	14.0	7.8	1.5	.4	2.2	1.25	.07	.49	1.5	94.46
23-592	Hwt	53.9	18.2	5.7	4.4	10.5	.4	4.5	1.68	.13	.52	1.3	91.88
23-597	Hwt	65.0	18.4	5.8	2.8	.9	.2	5.3	1.44	.04	.21	1.8	96.26
23-709	Fwb	68.8	17.0	6.7	2.4	.7	.1	4.1	.11	.02	.09	4.6	98.35
23-739	Fwb	76.6	11.7	6.3	1.8	.6	.2	2.7	.08	.02	.07	2.8	100.45
23-781	Fwb	60.7	20.0	10.9	3.9	-	.1	4.1	.13	.03	.09	3.5	96.86
23-844	Fwb	69.1	14.5	9.3	3.6	.4	.1	2.8	.09	.02	.09	9.9	97.81
23-886	Fwb	66.6	15.1	11.4	3.4	.2	.2	2.9	.10	.03	.08	-	98.12
28-74	Sp	56.4	23.4	10.5	1.8	.4	1.2	4.4	.91	.21	.90	-	98.88
28-113	Sp	57.9	23.3	9.8	1.5	.3	.8	4.9	.92	.19	.47	-	98.95
28-170	Sp	59.3	21.9	10.2	1.5	.3	.7	4.6	.88	.16	.30	-	99.71
28-224	Sp	57.8	23.8	9.6	1.8	.2	1.1	4.3	1.03	.14	.25	-	98.49

APPENDIX A (cont)

Sample #	Rock Type	SiO2 %	Al2O3 %	Fe2O3 %	MgO %	CaO %	Na2O %	K2O %	TiO2 %	P2O5 %	MnO %	FeS2 %	Total %
28-288	Sp	55.6	23.9	11.0	1.8	.7	.5	5.0	.90	.14	.45	-	98.46
28-336	Sp	56.7	20.9	12.7	2.3	1.2	.5	3.6	.93	.37	.86	-	98.10
28-386	G	50.1	15.7	12.6	7.6	9.1	3.4	.1	1.07	.05	.20	-	90.09
28-427	G	49.3	15.4	11.9	10.7	8.6	2.8	.1	.97	-	.20	-	93.26
28-442	Hwt	48.7	19.7	11.0	16.1	1.1	2.6	-	.48	.09	.21	-	92.69
28-470	Hwt	70.0	12.5	4.7	7.8	.7	4.0	-	.10	.03	.12	-	98.31
28-506	Hwt	77.8	12.4	2.1	2.4	.2	2.4	2.5	.11	.02	.06	-	100.31
28-528	Hwt	67.9	13.2	8.3	4.7	1.3	1.8	2.2	.26	.22	.11	-	101.06
28-536	Hwt	58.5	21.1	7.0	4.5	1.2	1.7	4.6	1.20	.12	.09	-	98.50
28-568	Hwt	52.4	15.0	13.5	14.1	2.7	.7	.1	1.22	.12	.18	.4	93.84
28-600	Hwt	47.2	25.3	15.8	3.8	.7	.2	5.2	1.50	.20	.15	15.5	93.60
28-612	Hwt	61.6	18.1	9.8	1.8	2.0	.2	4.5	1.59	.15	.13	.1	98.24
28-693	Fwb	63.8	21.7	4.3	3.4	.2	.6	5.6	.19	.04	.07	2.3	97.62
28-703	Fwb	76.1	12.9	3.0	3.2	1.3	.2	3.1	.08	.02	.07	1.3	100.31
28-732	Fwb	70.0	17.1	2.4	5.5	.3	.5	4.1	.11	.02	.07	-	98.92
28-748	Fwb	69.8	18.6	4.7	1.0	.1	.1	5.4	.12	.04	.04	8.1	100.38
28-768	Fwb	77.0	10.8	9.0	.9	-	-	2.1	.07	.02	.08	3.2	100.85
28-789	Fwb	77.1	11.0	8.7	.8	-	-	2.4	.07	.02	.07	7.4	101.20
28-807	Fwb	75.6	14.1	5.1	1.1	-	.1	3.8	.09	.03	.08	1.9	99.94
28-818	Fwb	78.8	11.3	6.3	.4	-	-	3.1	.07	.02	.05	11.7	102.83
28-847	Fwb	77.8	10.8	5.2	1.5	1.8	.1	2.6	.07	.02	.17	.4	100.87
28-863	Fwb	66.9	12.4	14.8	5.0	.1	-	.8	.09	.03	.14	1.7	95.64

APPENDIX B

COMPARISON OF PRESSED POWDER AND FUSED BEAD MAJOR ELEMENT ANALYSES

Sample #	Sample Type	Rock Type	SiO_2 %	Al_2O_3 %	Fe_2O_3 %	MgO %	CaO %	Na_2O %	K_2O %	TiO_2 %	P_2O_5 %	MnO %
23-192	Powder	Sb	52.8	21.9	14.6	2.3	.5	.6	3.6	.78	.16	2.77?
	Bead	Sb	52.1	21.2	15.3	3.1	.5	*	3.1	.84	.17	3.25?
28-427	Powder	G	49.3	15.4	11.9	10.7	8.6	2.8	.1	.97	-	.20
	Bead	G	47.2	16.1	11.7	9.5	10.7	*	.2	1.34	.12	.28
2-306	Powder	Fwb	78.0	11.6	2.0	2.9	1.0	3.5	.9	.07	.02	.07
	Bead	Fwb	76.8	12.5	1.8	3.1	1.1	*	.9	.10	.05	.14
11-311	Powder	Tqf	66.6	17.6	2.8	.7	.8	6.2	5.0	.22	.09	.06
	Bead	Tqf	65.1	18.5	2.8	1.0	.8	*	5.1	.29	.08	.12

? Values are beyond the range of the standards.
* Not analayzed
- Not detected

APPENDIX C

PETROCHEMICAL DATA - TRACE ELEMENTS

In Parts Per MilLION

Sample #	Rock Type	Ba ppm	Cu ppm	Zn ppm	Rb ppm	Sr ppm
1-28	Hwt	130	40	220	130	60
1-35	Hwt	420	40	140	190	150
1-37	Hwt	420	30	100	180	60
1-50	Hwt	440	30	270	40	90
1-69	Hwt	-	30	280	-	190
1-81	Hwt	-	90	290	-	80
1-119	Hwt	-	40	160	-	30
1-160	Fwb	1320	-	90	70	150
1-222	Fwb	1200	30	110	150	60
1-246	Fwb	480	20	100	60	90
1-265	Fwb	660	10	90	120	140
1-291	Fwb	230	10	100	30	170
2-20	Hwt	160	90	400	90	140
2-31	Hwt	160	50	210	100	210
2-50	Hwt	160	40	230	110	150
2-68	Hwt	140	70	380	90	140
2-86	Hwt	170	70	320	90	190
2-105	Hwt	290	50	190	130	130
2-118	Hwt	350	40	160	110	120
2-125	Hwt	670	660	1180	120	-
2-141	Hwt	640	20	100	50	140
2-154	Hwt	-	30	110	-	160
2-163	Hwt	-	20	40	-	150
2-176	Hwt	-	70	170	-	240
2-187	G	-	30	150	-	290
2-198	G	-	40	130	-	540

APPENDIX C (cont)

Sample #	Rock Type	Ba ppm	Cu ppm	Zn ppm	Rb ppm	Sr ppm
2-204	G	-	50	230	-	250
2-258	Fwb	940	20	100	60	260
2-271	Fwb	2770	10	90	240	80
2-83	Fwb	1020	30	160	80	60
2-292	Fwb	530	-	70	30	80
2-306	Fwb	260	-	120	-	120
2-326	Fwb	160	-	120	-	110
2-329	Fwb	690	-	50	100	190
2-336	Fwb	530	-	50	60	120
2-360	Fwb	360	-	140	50	70
2-378	Fwb	470	-	90	90	170
8-285	Hwt	570	20	270	80	190
8-308	Fwb	1580	50	930	160	30
9-192	G	-	670	1590	-	140
9-235	G	-	70	150	-	350
9-250	G	-	150	230	-	80
11-31	Hwt	370	-	140	60	70
11-36	Hwt	510	-	120	70	140
11-72	Hwt	970	30	910	110	20
11-85	Hwt	220	10	290	20	170
11-107	Hwt	460	10	350	90	20
11-122	Hwt	320	30	4070	50	50
11-136	Hwt	-	70	490	-	40
11-154	Hwt	330	160	300	20	160
11-165	G	110	20	740	-	160
11-195	Fwb	1320	40	270	120	40
11-206	Fwb	1010	20	250	90	-
11-219	Fwb	280	30	330	30	70
11-261	Fwb	-	40	340	-	70
11-270	Fwb	770	-	630	140	-

APPENDIX C (cont)

Sample #	Rock Type	Ba ppm	Cu ppm	Zn ppm	Rb ppm	Sr ppm
11-302	Tqf	600	20	70	20	100
11-311	Tqf	770	10	50	50	100
11-338	Tqf	260	-	20	30	630
11-361	Tqf	420	10	90	160	100
11-383	Tqf	440	20	90	100	120
11-452	Tqf	430	10	40	80	90
23-84	Sb	370	40	90	120	60
23-133	Sb	500	30	100	110	40
23-192	Sb	400	50	110	130	80
23-301	Sp	430	80	130	190	100
23-360	Sp	350	80	120	140	50
23-383	G	-	70	100	-	120
23-396	G	-	80	80	-	150
23-410	G	-	40	90	-	320
23-455	Hwt	380	90	170	60	80
23-464	Hwt	-	-	140	-	-
23-477	Hwt	120	10	120	-	-
23-529	Hwt	500	20	80	70	-
23-548	Hwt	1660	40	180	80	-
23-555	Hwt	17980	60	630	60	600
23-574	Hwt	1860	30	140	50	-
23-585	Hwt	1470	40	220	40	10
23-592	Hwt	3390	60	170	120	110
23-597	Hwt	7350	440	170	140	10
23-709	Fwb	400	20	160	120	-
23-739	Fwb	290	120	580	70	-
23-781	Fwb	470	50	150	90	-
23-844	Fwb	270	40	340	80	-

APPENDIX C (cont)

Sample #	Rock Type	Ba ppm	Cu ppm	Zn ppm	Rb ppm	Sr ppm
28-74	Sp	630	70	110	210	160
28-113	Sp	650	30	100	230	100
28-170	Sp	640	60	130	230	100
28-224	Sp	510	40	130	200	150
28-288	Sp	480	20	110	200	60
28-336	Sp	390	50	40	130	60
28-386	G	-	80	80	-	100
28-427	G	-	80	80	-	350
28-442	Hwt	-	40	140	-	110
28-470	Hwt	-	40	100	-	70
28-506	Hwt	260	10	80	50	30
28-528	Hwt	150	-	250	30	30
28-536	Hwt	310	80	200	90	30
28-568	Hwt	-	40	350	-	20
28-600	Hwt	-	650	720	90	20
28-612	Hwt	2830	80	320	140	40
28-693	Fwb	3640	60	810	210	40
28-703	Fwb	1140	20	200	90	20
28-732	Fwb	1230	-	110	110	-
28-748	Fwb	1740	-	100	110	-
28-768	Fwb	250	120	3990	30	-
28-789	Fwb	260	50	180	60	-
28-807	Fwb	470	40	3020	120	-
28-818	Fwb	340	50	230	60	-
28-847	Fwb	270	50	70	70	-
28-863	Fwb	80	-	90	-	-

APPENDIX D

ELECTRON MICROPROBE DATA

In Weight Percent

Sample #	Mineral	S %	Fe %	Cu %	As %	Pb %	Zn %	Sb %	Ag %	Total %*
34-842	Galena	11.5	-	-	-	88.5	-	-	-	101.7
34-842	Chalcopyrite	34.6	31.1	34.3	-	-	-	-	-	103.9
34-842	Tetrahedrite	29.2	4.8	43.3	18.4	-	-	3.6	.8	101.5
34-842	Tetrahedrite	29.7	4.5	43.3	18.0	-	-	3.3	1.3	98.1
34-846	Pyrite	51.8	46.9	-	1.3	-	-	-	-	106.1
34-846	Pyrite	52.7	47.3	-	-	-	-	-	-	104.0
34-846	Galena	11.5	-	-	-	88.5	-	-	-	102.7
34-846	Galena	11.6	-	-	-	88.4	-	-	-	102.6
34-846	Galena	11.7	-	-	-	88.3	-	-	-	101.6
34-846	Chalcopyrite	34.6	30.8	34.5	-	-	-	-	.1	102.9
34-846	Tetrahedrite	29.1	5.1	42.3	18.8	-	-	3.2	1.6	101.3
34-846	Tetrahedrite	29.0	4.8	43.1	18.5	-	-	3.2	1.4	101.2
34-846	Tennantite	27.1	4.9	39.8	10.9	-	-	14.1	3.3	101.2
34-846	Arsenopyrite	25.8	30.9	-	43.3	-	-	-	-	103.0
34-846	Sphalerite	32.5	1.3	-	-	-	66.2	-	-	107.1
34-846	Sphalerite	31.6	1.1	-	-	-	67.3	-	-	101.1

* Analyses shown have been normalized to total 100%

\- Not detected

PLATES

(in facing pocket)

I. GEOLOGIC MAP - MOUNT CHASE PROSPECT

II. GEOLOGIC CROSS SECTIONS - MOUNT CHASE PROSPECT

PLEASE RETURN PLATES TO THE POCKET.
COPIES OF THESE PLATES ARE AVAILABLE
AT A NOMINAL CHARGE IN THE DEPARTMENTAL
OFFICE.