A METALLOGENIC STUDY OF THE ANTIGONISH AREA, NOVA SCOTIA,WITH SPECIAL REFERENCE TO THE COPPER OCCURRENCES OF THE OHIO-SYLVAN GLEN BELT

by

Paul Daniel Bourque

Submitted in partial fulfillment of the requirements
for the degree of Master of Science at Dalhousie
University, Halifax, Nova Scotia, Septembe 1980.

DALHOUSIE UNIVERSITY

Date February 9, 1981

AUTHOR Paul Daniel Bourque

TITLE A METALLOGENIC STUDY OF THE ANTIGONISH AREA, NOVA SCOTIA, WITH SPECIAL REFERENCE TO THE COPPER OCCURRENCES OF THE OHIO-SYLVAN GLEN BELT

DEPARTMENT OR SCHOOL Geology

DEGREE M.Sc. CONVOCATION Spring YEAR 1981

Permission is herewith granted to Dalhousie University to circulate and to have copied for non-commercial purposes, at its discretion, the above title upon the request of individuals or institutions.

Signature of Author

THE AUTHOR RESERVES OTHER PUBLICATION RIGHTS, AND NEITHER THE THESIS NOR EXTENSIVE EXTRACTS FROM IT MAY BE PRINTED OR OTHERWISE REPRODUCED WITHOUT THE AUTHOR'S WRITTEN PERMISSION.

ABSTRACT

Significant mineralization in the Antigonish Area is, to date, found only in the Carboniferous sediments of the basinal areas within the region. The Antigonish Highlands, made up of volcanic and sedimentary rocks of the Browns Mountain Group, show little indication of any substantial mineralization other than Cambro-Ordovician ironstones.

Several mineral groups, defining metallogenic areas are delineated. Each group comprises several mineral occurrences in similar lithological environments. With the exception of Cambro-Ordovician and Silurian ironstones, a minor Cambro-Ordovician contact metamorphic copper-zinc showing and a sedimentary copper deposit in Devonian rocks, all significant mineral groups are confined to Carboniferous lithologies.

Other mineral groups include galena in calcite cavities in Upper Windsor carbonate mounds; red bed type copper occurrences in Canso Group fluvial sediments and Kupferschiefer type mineralization along the Horton-Windsor contact.

Ore textures within the copperbelt of the Horton-Windsor contact suggest that pyrite formed contemporaneously with the sediments through the production of H_2S by bacterial action. Ore textures further indicate that the pyrite was subsequently replaced by chalcopyrite, which was in turn replaced by increasingly copper rich sulfides. Comparisons of this deposit with similar deposits, suggests a model involving dewatering of oxidized Horton sediments by compaction and expulsion of copper bearing water. Copper sulfides are precipitated upon contact with pyrite in a reducing environment.

ACKNOWLEDGEMENTS

I would like to thank the Nova Scotia Department of Mines for funding of field work and laboratory expenses for this thesis. I am indebted to Mr. Stan MacEachern and Mr. John MacLeod of Esso Minerals Canada for use of Esso data; to Dr. Marcos Zentilli, my supervisor, whose advice was invaluable, and to Dr. Warren Irvine for stimulating discussions. Thanks to Mr. Pat Hannon of Esso Minerals for much time and care devoted in examination of this thesis.

Thanks also to the Izaak Walton Killam Trust for generous financial assistance during my residence at Dalhousie

My sincerest appreciation and gratitude to Dr. Damian Nance for his help and consultation not only with this thesis but with many problems throughout the past years. I am deeply indebted to Damian.

Finally I would express my heartfelt thanks to Robin, my wife, for her support over the years this thesis was being prepared, and her work in typing the manuscript.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF MAPS

LIST OF FIGURES

LIST OF PLATES

CHAPTER I

INTRODUCTION

I GENERAL STATEMENT

The Antigonish Highlands has been the site of active mineral exploration since the turn of the century. However, to date, no ore bodies have been located, although several prospects with good potential are known.

This thesis is based on field work done as a contribution to the Antigonish Highlands Project, a metallogenic study devised by the Nova Scotia Department of Mines under the coordination of Dr. A.K. Chatterjee. Preliminary results of the project have been published (Bourque 1979). The present report integrates field and laboratory studies and attempts to provide a better understanding of the metallogeny of the Antigonish Highlands.

II LOCATION

The map area (Fig. I-1) is located in northern mainland Nova Scotia, and is covered by five National Topographic System map sheets (1:50,000 scale). The Malignant Cove, Merigomish and Lochaber map areas in Antigonish and Pictou Counties, lie between Latitudes 45°22'30" and 46°00'00" North

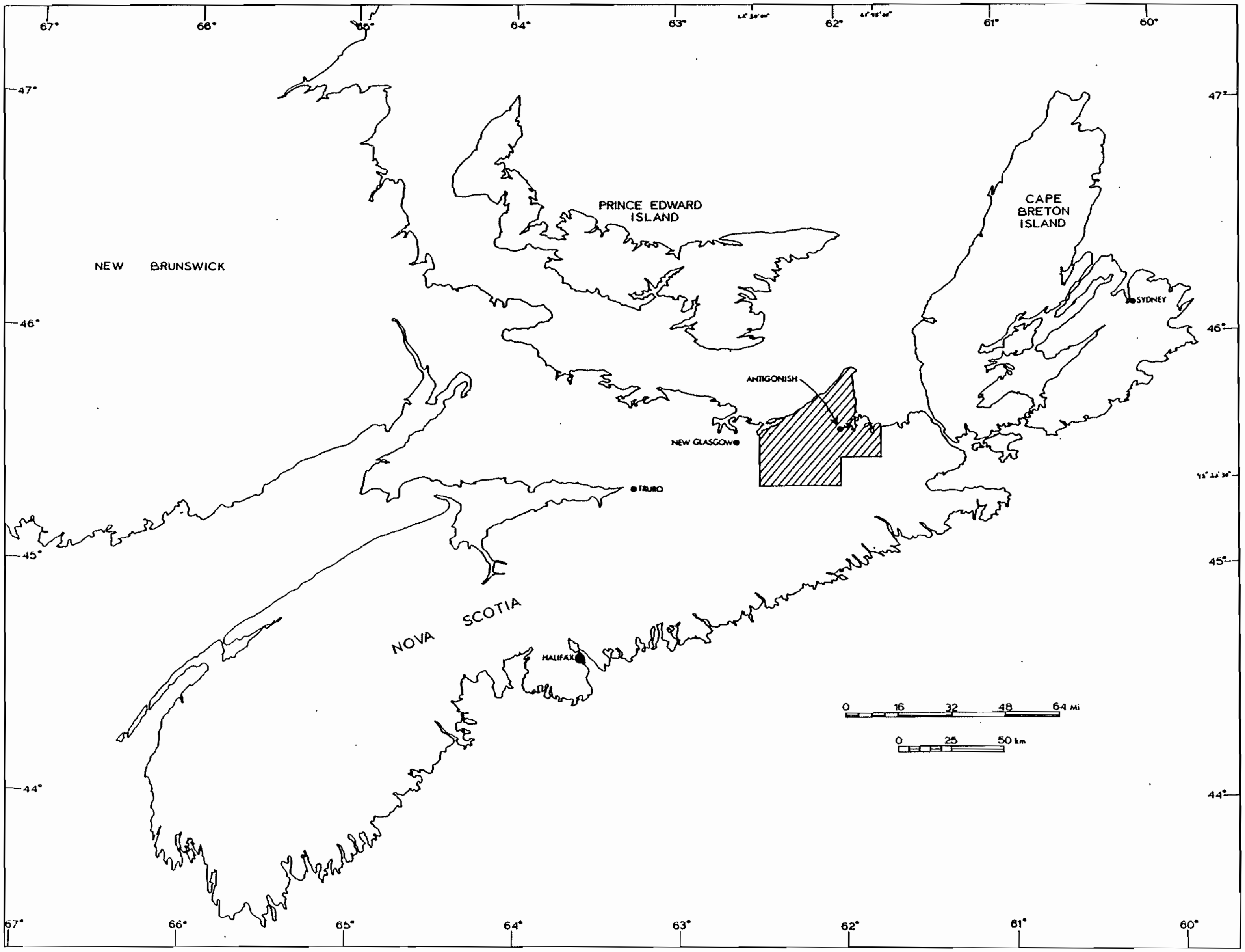


Figure 1-1 LOCATION OF MAP AREA - ANTIGONISH HIGHLANDS, NOVA SCOTIA

and Longitute 62°00'00" and 62°30'00" West. The Antigonish and Cape George map areas in Antigonish County, lie between Latitudes 45°30'00" and 45°00'00" North and Longitude 61°45'00" and 62°00'00" West. The total map area amounts to approximately 800 sq. mi. (2,000 sq. km).

Access to most areas of the Highlands is excellent. Highways, secondary (gravel) roads and logging roads provide ready access to nearly all general locations while coastline, paths, trails and streams cover most other areas.

The largest population centre, Antigonish (population 5,000) lies in the eastern region of the Highlands (Fig. 1). The region is thickly covered by coniferous forest (predominantly) but there is abundant farmland along certain valleys.

III PREVIOUS WORK

The Antigonish Highlands and Basin have been the subject of geological investigations since the early 1800's. Jackson and Alger (1928, 1929) first described the rocks of the area. Early geological work was followed by Gesner (1836, 1845), Dawson (1843, 1845, 1847, 1850, 1855, 1860, 1863, 1874, 1880, 1881, 1891) and Honeyman (1859, 1860, 1864, 1866, 1870a,b,c, 1873, 1874, 1876, 1878, 1886a,b, 1890). Brief accounts of the geology of these early workers in the Arisaig Area may be found in Boucot et al (1974) and McLean (1924).

Fletcher (1887) mapped the area and compiled an extensive geological report with accompanying maps at a scale of 1" = 1 mile. His report describes the rock types and most important localities in the study area. His work correlates reasonably well with more recent investigations.

Later geological work in the area was done by Ami (1892, 1900, 1901) who catalogued the Silurian fossils at Arisaig and described the Devonian Knoydart Formation. The paleontology of the Arisaig region was further studied by Twenhofel (1909) who classified the fossils for recognition in the field and also made a detailed subdivision of the stratigraphic succession.

Williams (1914) did extensive work in the Arisaig area with emphasis on the iron beds within the Cambro-Ordovician Browns Mountain Group (Occurrence No. 37). Williams' very detailed report of the area discusses the sedimentary stratigraphy, the igneous rocks, the geological structures, the economic mineralization and a geologic history of the area. The report also provides a fairly detailed summary of all previous work done and several summary maps accompany the report.

The most complete succession of Silurian fossils in the Appalachians was systematically catalogued at Arisaig by McLean (1924) in a very extensive study.

Bell (1926, 1927, 1929, 1940, 1944, 1958, 1960) studied the Carboniferous series of the Maritime Provinces including paleontological studies.

Sage (1954) compiled a comprehensive report on the stratigraphy of the Carboniferous Windsor Group. This report describes and subdivides the complex Windsor lithologies. Sage's terminology, although modified somewhat, is still in common use. Maehl (1960, 1961), as Sage, mapped his respective area during a field school conducted by the Massachusetts Institute of Technology (MIT). The culmination of the work done at this field school was compiled and interpreted by Boucot et al (1974). This is probably the most comprehensive study of the Arisaig lithologies and structures available.

Benson (1970, 1974) mapped by far the largest area of the Antigonish-Pictou Highlands and Basin since Fletcher's work in 1887. The work was carried out as a regional mapping project on a scale of 1:50,000, under the Geological Survey of Canada and included lithological descriptions and stratigraphic interpretations of the Cambro-Ordovician, Silurian, Devonian and Carboniferous units present in the map area (Map 1). This report has been used as a base map for most geological and exploratory work underway in the area.

Wright (1975) compiled all available data concerning the iron occurrences in the area, especially the previously mined iron beds near Arisaig.

Murray (1975) catalogued the limestone and dolomite occurrences in the area. His paper includes locations, lithological descriptions and chemical analysis.

Current work by the Nova Scotia Department of Mines (1976a, 1977a, 1978a, 1979) continually updates the geological knowledge of the area. Programs include the Carboniferous Basin study (Boehner 1978a,b,c; Boehner and Giles 1976; Giles 1977, 1978; Giles and Keppie 1978) the Antigonish Highlands structural study (Keppie 1978; Keppie, Giles and Boehner 1978; Murphy and Keppie 1979) and the Antigonish Metallogenesis study (Bourque 1979). Moore and Ryan (1976) catalogued the invertebrate fauna of the Windsor Group in the Maritimes. Drilling by the Nova Scotia Department of Mines (1959, 1962, 1964, 1967, 1970, 1971, 1974, 1975, 1976, 1977b, 1978b) has increased the subsurface data of the Antigonish area. Keppie (1976) interpreted structural lineaments from Plan Position Indicator (P.P.I.) Radar Imagery for all of Nova Scotia and pointed to complex linear features for Antigonish, most of which are interpreted as faults.

Mineral exploration has been active in the study area for about one hundred years. Fletcher (1887) reports many of the known mineral occurrences in Antigonish including several of the Ohio-Sylvan Glen copper occurrences, especially described in this thesis. Messervey (1929a,b) compiled data on copper, lead and zinc occurrences in Nova Scotia. Wright (1966) compiled an extensive report of all known mineral occurrences in the Province of Nova Scotia. This work provides useful details of location, description of occurrences and map references for the Antigonish Highlands. Bishop and Wright (1974) compiled available data on manganese in Nova Scotia, of which some occurrences are known in the area.

Mineral exploration companies have provided a wealth of geological, geochemical, geophysical and subsurface data in the Antigonish Highlands and Basin. Woodman (1909) investigated the area of Arisaig where sedimentary iron formation was thought to occur, but failed to find any iron beds of ore grade (Occurrence No. 36). Chambers (1920) assayed several iron samples from the Arisaig district. The Arisaig Iron Company prospected the areas in 1910, but no ore was taken out. Small amounts of ore were recovered just prior to 1900. Wright (1975) and Williams (1914) contain brief histories of the Arisaig iron district. No further work on the area is recorded until 1961 when diamond drilling was done by the Nova Scotia Department of Mines. After the drilling program, the area was abandoned.

Goudge (1939) explored Merigomish Island to assess coal potential, but found that the coal seams present were nonmarketable at that time. West (1944) mapped Merigomish Island for the Island Development Co. to assess oil potential. No oil showings were found. Further petroleum exploration was continued by Whitehead (1944) for the Pictou Petroleum Co. Whitehead outlined areas of potential and further study in the Antigonish Harbour area. MacNeil (1946) furthered Whitehead's work by geological mapping in this area.

Goudge (1944) assessed the potential of limestone for quarrying at Hillcrest. In 1940, Goudge reported "manganese nodules" to 18 feet depth in Georgeville (Occurrence No. 4).

Maritime Exploration Ltd. (1946) found much barite float in the Browns Mountain Area (Occurrence No. 28).

Ironlake Exploration Co. Ltd. drilled two holes in 1949, which intersected siderite beds at Telford, Pictou County (Occurrence No. 38).

MacNeil (1947, 1952) continued mapping the Antigonish Harbour area for oil and gas potential. MacNeil (1948) assessed the oil and gas potential of the Big Marsh Anticline for The Pictou Petroleum Co. Petroleum exploration in the Antigonish Harbour area continued in 1952 with a seismic survey done by Seismograph Service Corp. for the Nova Scotia Department of Trade and Industry. The magnetic and gravity survey outlined possible environments for oil and gas. MacNeil (1954) in assessing this area for Imperial Oil Ltd., could not extend the work of Sage (1952) any further. However, MacNeil (1956), on examining oil and gas seepages in the Antigonish Harbour area for Eastern Northern Explorations Ltd. proposed that source, reservoir and trap rocks are all available for petroleum accumulation in this area. These same recommendations were given to Eastern Petroleums Ltd. by MacNeil in 1964. Detailed geology of the Antigonish Harbour area was done in 1959 by MacNeil for the Lura Corp. Ltd. Diamond drill core by Nova Scotia Department of Mines and Lura Corp. Ltd. was available to MacNeil for this study. This report includes quite comprehensive descriptions of Windsor lithologies. In it MacNeil considered a conglomerate unit mapped as part of upper Horton by Benson (1974), as lower Windsor in age. The Nova Scotia Department of Trade and Industry (1952) sponsored a gravity and magnetic survey conducted by Seismograph Service Corp., of South Side, Antigonish Harbour. The Nova Scotia Research Foundation (1958) increased the knowledge of the Antigonish Harbour area with a magnetic, gravity and limited seismic interpretation. MacNeil (1952) described a salt unit found in drill core in the Antigonish Harbour area.

Bridger (1953) explored the Georgeville coast and found only small, disseminated sulfide (pyrite, sphalerite, chalcopyrite, galena, phyrrotite) occurrences (Occurrence No. 12). Bridger also indicated that he found no evidence of an ore body in the intrusive diorite. However the diorite was quarried by Maritime Rock Products Co. (1960). The British Newfoundland Corp. (1954) conducted geophysical surveys over the Georgeville coast and concluded that the sparse mineralization was related to fault zones in the area. Cheriton (1960) attributed geochemical annomalies to metals distributed in the Browns Mountain sediments. The presence of magnetic annomalies with no electromagnetic conduction was interpreted by Cheriton as a possible phyrrhotite-nickel ore body on the diorite-sediment contact.

Eastern-Northern Explorations (1955) found disseminated sphalerite in the Georgeville argillites.

Geochemical and geophysical surveys conducted over this area by New Jersey Zinc Exploration Co. (Canada) Ltd. (1967, 1969, 1970) indicated a broad zone distribution in the argillite (hornfels) unit. Diamond drilling showed sphalerite distributed throughout the argillites and concentrated along fractures. Chalcopyrite is confined to shear zones. Johnson (1976) also showed a widespread zinc anomaly with geochemical techniques. Noranda Exploration Co. (1977) drilled geophysical anomalies on the Georgeville coast and concluded that no economic grade of ore occurs in the area.

Transterre Explorations Ltd. (1966) indicated that no major geophysical responses were present in the Malignant Cove area after boulders high in Cu-Pb-Zn-Ag were reported. However, slight geochemical anomalies were found in the Doctor's Brook area.

Eastern-Northern Explorations (1955) found significant enough copper mineralization at Blue Mountain (Occurrence No. 23) to recommend an exploration program in the area. Nowlan (1958) conducted an airborne electromagnetic survey (Canadian Aero Service Ltd. and Aerophysics of Canada Ltd.) of the area for Eastern-Northern Explorations. A.C.A. Howe International Ltd. (1967) based on a geochemical survey, recommended future detailed exploration of the Blue Mountain area.

Eastern-Northern Explorations (1955) also examined, geologically and geophysically, Copper Lake and College Grant (Occurrence No. 14). Heathridge Mines Ltd. (1966)

examined the College Grant area and Northern Minerals Ltd. (1966) diamond drilled the prospect. No extensive extraction of ore is reported from this area. However, Great Horn Mining Syndicate (1972) proved reserves of 2.29 million tons of 0.33% (average) copper in the Lochaber Lake area. The ore body was to be mined but no excavations were undertaken.

CERA reported a thick barite vein in the Lower Windsor limestone at Big Marsh (Occurrence No. 29). McCulloch (1972) concluded that the vein occupied a fault zone.

Imperial Oil Ltd. (Ward 1974b) conducted geological, and geochemical studies in the Pomquet area. Kenting Earth Sciences Ltd. flew an extensive magnetic survey over the Antigonish Basin for Imperial Oil Ltd. Small showings of galena in limestone and dolomite were found (Occurrence No. 3). Imperial Oil Ltd. (1974) then drilled significantly mineralized areas and found only minor lead in organic carbonate mounds. Eight holes totalling nearly 3,000 feet were drilled. Imperial Oil Ltd. also conducted exploration programs in the Pitches Farm Area (Ward 1975a) (Occurrence No. 20) and Stewart Lake area (Ward 1975b, 1976). No significant mineralization was determined in either case.

Ohio - Sylvan Glen Area

The Ohio - Sylvan Glen area (Map 3) has been of interest to mining companies since copper was reported in the area by Fletcher (1887).

Numerous pits, adits and shafts were sunk in the area about this time. On one property (MacLean Showing - Occurrence No. 18) workers extracted and transported limited amounts of ore to Sherbrook for smelting and/or transport (R. MacLean, pers. comm.). The first documented survey of the area for copper is an assessment of the property by Keating (1951) for A.J. Sears of Antigonish, N.S. Keating assayed 0.93% copper over 9.4 feet at the MacLean showing and recommended that further investigations were warranted. MacNeil (1959) geologically mapped the Ohio area assessing the petroleum potential for MacInnis Brothers of Detroit, Michigan. Knapp (1959) also mapped the area for potential petroleum environments. A gravity survey of the area was conducted by the Nova Scotia Research Foundation in 1952. Profiles across the Antigonish Basin were formulated from this survey. MacIntyre Porcupine Mines Ltd. (1960) geologically mapped and conducted stream geochemistry of the James River - Marshy Hope area (Occurrence No. 15). Kenco Explorations (Canada) Ltd. (1966) drilled six holes in the Ohio - Sylvan Glen area and found widespread copper mineralization in the basal Windsor rocks. Hudgins (1971) drilled three holes in the basin, east of the Ohio river. None of the holes intersected the mineralized basal Windsor. However, this drilling indicated thick silt and evaporite sequences deeper in the structural basin. Johnson (1972) found significant copper mineralization in outcrop around Sylvan Glen, for Cerro Mining Co. of Canada Ltd. Amax Exploration (1974) compiled gravity data of the Antigonish Basin outlining the basin topography and proposed that extensive salt exists in the area.

Imperial Oil Ltd. drilled five holes after geological and geochemical investigations of Sylvan Glen (Ward 1974a; Johnson 1973). Drill core revealed widespread non-economic copper mineralization in basal Windsor lithologies.

Quebec Uranium (1974) drilled seven holes in the James River area. Only one hole (JR-6, Appendix III) intersected the copper zone. Other holes show a great thickness of silt, evaporites and salt (JR-3) deeper in the structural basin. Amax Exploration Inc. (1974) intersected a thick salt unit in drill holes spotted at James River. The Lower Windsor was not reached and copper mineralization was not found.

Imperial Oil Ltd. conducted extensive exploration surveys over the Ohio region (Ward 1974c,d, 1975c) and outlined areas of significant mineralization. Diamond drilling of these areas indicated widespread copper in the basal Windsor rocks in the Ohio region (Burton 1974). However, the copper is of sub-economic grade. Drilling of a gravity low in Addington Forks by Imperial Oil Ltd. (Ward 1975d) encountered only thick sequences of silt and evaporites. This indicated that either the hole missed a salt unit or the Windsor sediments are very thick in this area. The Ohio properties are presently held by Imperial Oil Ltd. and Maritime Exploration Ltd. and exploration is ongoing.

IV PURPOSE AND SCOPE

The immediate purpose of the project was to provide geological information on all known mineral occurrences in the Antigonish Highlands and adjacent Antigonish Basin. The data provide an assessment and update of files on all occurrences (Bourque 1979a and b). It also provides information for the Nova Scotia Metallogenic Map in preparation by the Nova Scotia Department of Mines.

The study also outlines several groups of mineral occurrences and attempts to classify them in a tectonic-metallogenic framework.

The major mineral group is treated in detail and a possible ore genesis is outlined. This section is the main concern of the thesis.

V METHODS USED

Geological mapping by the author was carried out from May 1978 to September 1978, inclusive. Nova Scotia Department of Mines (NSDM) Mineral Assessment Files were used to locate approximately 60 known mineral occurrences in the map area. Field mapping was compiled on maps that indicate roads and streams prepared from air photographs by the Department of Lands and Forests (Scale: 4" = 1 mile) and on air photographs of approximately the same scale. Final edition of the data was compiled on five 1:50,000 N.T.S. maps, using a legend similar to that to be used in the new Metallogenic Map in preparation by Dr. A.K. Chatterjee of the Nova Scotia Department of Mines (Maps 1 and 2).

Each mineral occurrence was investigated separately. Where necessary, mapping of the rocks in the immediate area of the occurrence(s) was carried out. However, the map area was too large to attempt geological mapping at a regional scale.

Laboratory investigation included study of 156 thin sections of lithologies throughout the map area, 160 polished thin sections and approximately 50 sections used for fluid inclusion studies. Several fluid inclusion heating runs were done for one group of occurrences. Microprobe analysis was used for identification of some minerals. Limited whole rock analyses of the Browns Mountain volcanics were carried out in one region and metallic element analysis outlined geochemical trends of one group of occurrences. Rock analyses were carried out in the Geochemical Laboratory at the Nova Scotia Technical College.

VI ORGANIZATION

After the Introduction, Chapter II is a discussion of the regional geology of the map area. Descriptions of all major rock units are summarized from Benson (1974).

A synthesis of field work investigations is presented in Chapter III. This summary presents several groups of mineral environments, each made up of several mineral occurrences. An accompanying map displays this data. A summary of each mineral occurrence in map and table form is also included in this chapter. This section outlines the regional mineral distribution of the map area.

In Chapter IV, iron deposits near Arisaig are compared chemically and geologically to other iron deposits.

A detailed petrographic study of the ore minerals of the Ohio - Sylvan Glen Region, which forms the most significant mineral group, is presented in Chapter V. The possible genetic history of the deposit is discussed in some detail.

Finally, Chapter VI attempts to correlate the mineral groups of the Antigonish map area with the regional tectonic-metallogenic framework.

The reports of field investigations are found in Appendix I. They are treated occurrence by occurrence and are modified after Bourque (1979a,b).

Appendix II includes detailed descriptions of nearly all thin and polished sections studied and/or referenced in this thesis.

Appendix III includes stratigraphic columns compiled from drill core logs. The cores were logged by various exploration companies. The columns were used to set the stratigraphic framework of Chapter V.

Appendix IV includes chemical analyses used in this thesis.

CHAPTER II

REGIONAL GEOLOGY

I GENERAL GEOLOGY

All geological information in this section is summarized from Benson (1974). New nomenclature and formation names (eg. Geological Map of Nova Scotia, 1979) have not yet been formally described and accepted (Code of Stratigraphic Nomenclature) and will not be discussed here.

The Antigonish Highlands are underlain by rocks of the Paleozoic (Precambrian?) geosynclinal belt, which extends from Newfoundland to southeastern United States. The Highlands consist of folded and faulted Cambro-Ordovician (now considered to be Precambrian, Keppie, 1979b) volcanic and sedimentary rocks of the Browns Mountain Group (Benson 1974, Boucot 1974) further subdivided into their units characterized by the predominance of acidic volcanics, sediments and basic volcanics (Benson 1974).

To the northwest of the map area, less disturbed Silurian and Devonian sedimentary rocks, mainly of the Arisaig Group, unconformably overlie the Browns Mountain Group. These rocks provide one of the most complete sequences

PALEOZOIC	Ordovician	The Beechill Cove is in unconformable contact with the Browns Mountain Group: The Arisaig Group and the Knoydart Formation are in fault contact with the Browns Mountain Group		
				Brownish grey, medium-grained hornblende granite; pale red leucogranite
		Granite is in intrusive contact with the Browns Mountain Group		
			Malignant Cove 350+	Greyish red pebble - to boulder - conglomerate and wacke
		The Malignant Cove is in unconformable contact with the Browns Mountain Group		
				Dark greenish grey to black diorite, hornblende diorite, and gabbro to diorite
		The diorite is in intrusive contact with the Baxter Brook and Brierly Brook formations		
				Light grey to pale red, medium grained hornblende syenodiorite and granodiorite
		The syenodiorite and granodiorite are in intrusive contact with the Keppoch Formation and the granodiorite possibly intrudes the Brierly Brook Formation		
		Browns Mountain	Little Hollow 850 -	Greyish red and dark grey siltstone and quartzite and minor ferruginous wacke
			Brierly Brook 5,800 ±	Dark purplish grey and greenish grey leucoandesite porphyry, lapilli crystal tuff, hornblende and amygdaloidal andesite. Medium greenish grey and light grey with minor reddish grey laminated tuffaceous siltstone, shale, and argillite. Purplish and dark grey agglomerate and breccia, lithic tuff and greywacke.
			Baxter Brook 2,600±	Medium greenish grey, fine-grained quartz-feldspar crystal tuff, shale, and silty shale.
	Cambrian		Keppoch	Light grey to brownish grey and pale red, massive and porphyritic leucodacite to rhyolite and minor breccia and tuff. Medium grey quartzite, light brown metasiltstone, and minor black phyllite.

Fig. II-1 Table of Formations (after Benson 1974).

ERA	America	PERIOD OR EPOCH	Europe	GROUP	FORMATION THICKNESS (feet)	LITHOLOGY
Cenozoic		Recent			0-10	Stream alluvium (sand, silt and gravel), and beach sand
		Pleis-tocene			0-60	Glacial deposits; sand and gravel
				Unconformable contact		
PALEOZOIC	Pennsylvanian	Upper Carbon-iferous	Westphalian	Pictou	1,400+	Light grey, medium to coarse grained arenite and wacke and minor conglomerate
				Cumber-land	New Glasgow Conglomer-ate 650	Medium greyish red pebble to cobble-conglomerate and interbedded medium to coarse grained wacke
				The New Glasgow Conglomerate unconformably overlies the pre-Carboniferous.		
			Namurian	Canso	Lismore (north - west of Antigonish Highlands) 6,950	Greyish red and greenish grey wacke, siltstone, and conglomerate; greyish red and light grey mudstone, siltstone, and minor calcareous shale
					(Antigonish basin) 120	Medium grey, fine-grained wacke, siltstone, and silty shale with calcareous layers minor greyish red siltstone
	Mississippian	Lower Carbon-iferous	Visean	Windsor	(northwest of Antigon-ish High-lands) 200	Medium grey argillaceous and oolitic limestone and minor calcareous shale, and medium grey-red mudstone and siltstone
					(Antigon-ish basin 1,000 - 2,600	Light grey and greyish red mudstone and siltstone, medium grey calcareous shale and argillaceous lime-stone, minor gypsum, and anhydrite and red conglomerate
				The Windsor Group disconformably overlies the Horton Group, and the Canso and Windsor unconformably over-lie the pre-Carboniferous		
			Tournaisian	Horton	(near mouth of McArras Brook) 200	Greyish red, fine-grained micaceous wacke and silt-stone, cobble-conglomerate and amygdaloidal basalt
					Rights River (Antigon-ish basin) 5,500±	Greyish red boulder- to pebble- conglomerate and micaceous wacke. Grey mudstone and argillaceous limestone near base of section
PALEOZOIC		Devonian		The Horton Group unconformably overlies the pre-Carboniferous		
						Dark green, fine-to medium grained diabase
				The diabase is in intrusive contact with all older rocks except the Arisaig Group and Knoydart Formation		
						Moderate red, medium-to coarse grained granite
				The granite is in intrusive contact with the Baxter Brook and Brierly Brook formations		
			Gedinnian		Knoydart 900 +	Greyish red mudstone, siltstone, and fine-grained wacke; green-ish grey and greyish purple shale and argillite
		Silurian	Pridoli	Arisaig	Stonehouse 1,375	Bluish grey, calcareous and non-calcareous wacke and siltstone, greenish grey mudstone, shale, and minor siltstone.
					32 Moydart 350	Red calcareous mudstone Greenish grey mudstone, wacke, and siltstone, minor fragmental limestone
			Ludlow		McAdam 560	Grey mudstone, wacke, shale, calcareous wacke, arenaceous limestone and dark grey wacke with septarian and phosphatic nodules
			Wenlock		French River 175+	Bluish grey, fine-grained wacke and mudstone
					Ross Brook 1,200 - 1,500	Dark grey mudstone and shale overlain by bluish grey, inter-bedded mudstone and wacke; minor calcareous beds and tuff laminae; basal black shale
			Llandovery		Beechhill Cove 300	Greenish and bluish grey well-bedded wacke and siltstone; minor shale and massive wacke
					Dunn Point Volcanics 300 +	Red rhyolite and tuff, and dark green amygdaloidal andesite and volcanic breccia

of Silurian fossils in the world (Boucot 1974).

The relatively undisturbed Carboniferous rocks to the east of the map area, consist of marine and non-marine sedimentary rocks that were deposited in a subsiding basin. In this basin, the coarse Horton Group sediments unconformably overlie the Browns Mountain Group and are conformably to unconformably overlain by Windsor Group marine lithologies.

The Antigonish Highlands are bounded on the north by the Hollow fault and on the south by the Chedabucto fault, which are the major structural features of the region.

II LITHOLOGICAL DESCRIPTIONS

Lithological descriptions and subdivisions used are those of Benson (1974), which encompass the entire area of the Antigonish Highlands. For recent reinterpretations of rock stratigraphic units along the Georgeville coast (Northumberland Strait) see Murphy et al (1979). For purposes of simplification, rock units of Benson (1974) will be used throughout this text.

A) Browns Mountain Group

The Browns Mountain Group is a pre-Silurian, probably

Cambro-Ordovician sequence of volcanic and meta-sedimentary rocks. An approximate thickness of 15,000 feet is interpreted from several incomplete sequences (Benson 1974). Recently the unit has been reinterpreted as being Precambrian in age (Murphy et al 1979).

The sequence of 1) lower acid volcanics with minor sediments; 2) sediments and pyroclastics; 3) basic volcanics, pyroclastics and minor sediments; and 4) uppermost siltstones - quartzites, is found in other areas of the Appalachians including southeastern Cape Breton, the Cobequid Mountains and the Avalon Platform of Newfoundland.

Keppoch Formation: This formation makes up the lowermost unit of the Browns Mountain Group and thus consists of the oldest rocks in the Antigonish Highlands. Lithologies include light grey to brownish grey and pale red, massive and porphyritic leucodacite to rhyolite and minor breccia and tuff, light brown metasiltstones, medium grey quartzite, and minor black phyllite.

This formation outcrops mainly in the southern section of the Antigonish Highlands.

Specular hematite and quartz are common in fractures throughout the unit.

The Keppoch Formation is most likely part of a eugeosynclinal sequence.

Baxter Brook Formation: Rocks of this formation are exposed throughout the Antigonish Highlands. Lithologies include faintly laminated, tuffaceous, fine-grained, medium greenish grey and light grey, massive siltstone, shale and argillite. Minor interbedded, medium greenish grey, fine-grained greywacke, fine-grained quartz-feldspar crystal tuff, shale and silty shale are also present.

Quartz veins commonly fill fracture zones in the rocks.

The sedimentary rocks of the Keppoch Formation were most likely derived mainly from the siliceous volcanics of the Keppoch Formation and more acid intrusives. The interbedded volcanics were probably formed by volcanism related to the Keppoch and Brierly Brook Formations.

Brierly Brook Formation: This unit is exposed throughout the Antigonish Highlands. Lithologies include massive, dark purplish grey and greenish grey leucoandesite porphyry, lappilli crystal tuff, amygadaloidal andesite, and hornblende andesite, as well as less common purplish and dark greenish grey andesite agglomerate and breccia, lithic tuff, and greywacke. Minor dark grey dacite and greenish grey, laminated argillite occur locally. Specular hematite is commonly found on fractures in the basic volcanics.

The Brierly Brook Formation was formed in a eugeosynclinal sequence during a time of intense volcanic activity (Lower to Middle Ordovician).

Little Hollow Formation: The Little Hollow Formation makes up the youngest unit of the Browns Mountain Group. The sequence is made up of greyish red and light to dark grey siltstone, fine-grained wacke and quartzite, and minor, greyish purple, ferruginous wacke. The iron ore of the Arisaig Iron District (Doctors Brook), is found in this unit.

Origin of the Little Hollow Formation is likely erosion of a regolith developed in the older Browns Mountain Group rocks (Lower to Middle Ordovician).

Most units of the Browns Mountain Group have gradational, conformable contacts with overlying and underlying units. Subdivisions are arbitrarily based on lithology.

B) Malignant Cove Formation

This unit is in unconformable contact with rocks of the Browns Mountain Group. A tenuous age of Middle to Late

Ordovician is proposed for the formation. Rock types include greyish red, silicified pebble-conglomerate, grading into boulder-conglomerate.

Deposition of the formation may be related to possible uplift and erosion resulting in a small outwash deposit of terrestial origin.

C) Dunn Point Volcanics

This unit unconformably overlies the Browns Mountain rocks. The age of the volcanics is taken to be uppermost Ordovician. Lithologies include red rhyolite and tuff underlain by dark green amygdaloidal andesite and volcanic breccia.

The volcanics were deposited subaerially, probably on the rocks of the Browns Mountain Group.

D) Arisaig Group

The Arisaig Group is found by the Hollow fault near Kenzieville where the sediments form the Kenzieville trough. The sediments are folded into a syncline and offset about 20 miles by the right lateral Hollow Fault. The remainder of the displaced section is found along the Northumberland coast near Arisaig.

Lithologies of each formation of the Arisaig Group, which are predominently red and grey siltstones and wackes, may be found on the stratigraphic column (Fig. II-1). The Iron Ore bed of Arisaig Brook is found interbedded in sediments of the McAdam Formation.

The environment of deposition of the Arisaig Group sediments is interpreted as minor channel deposits overlain by thick sequences of deltaic shallow marine sediments derived from a nearby source, probably the Browns Mountain Group rocks.

E) Stonehouse Formation

The predominently bluish grey calcareous and non-calcareous wacke and siltstone is interpreted as a normal shallow marine deposit, similar to the Arisaig Group.

F) Knoydart Formation

The Knoydart Formation consists of greyish red mudstone, siltstone and fine grained wacke deposited in a nonmarine, deltaic environment which emerged from the marine Stonehouse Formation. The similarity of the Knoydart Formation to the Arisaig Group suggests a similar source area.

The limestone intersected in an area interpreted as

Knoydart Formation, is assumed to be Windsor limestone.

G) Horton Group

The rocks of the Horton Group lie unconformably on Lower Devonian and older rocks of the Antigonish Highlands. The Horton Group comprises the basal sediments of the Antigonish Basin. The Basin abuts the Antigonish Highlands on the east. The Rights River Formation of the Horton Group, is made up of poorly sorted, angular to subangular pebble- to boulder-conglomerate containing interbedded, medium- to coarse-grained wacke. Some areas also include interlayered dark green and red, amygdaloidal basalt. This formation is interpreted as an alluvial fan deposited in a relatively restricted valley.

H) Windsor Group

The Windsor Group forms a predominently transgressive sequence over Horton lithologies, and onlaps unconformably on older rocks. The generally transgressive episode was interrupted several times by cyclic fluctuation resulting in intercalated sequences of limestone, siltstone, mudstone, calcareous shale, gypsum and anhydrate.

The environments of deposition are interpreted as 1) open marine carbonate platform; 2) oolitic and algal bank; and 3) restricted shallow marine (lagoonal). The Antigonish Highlands probably remained a positive arch, possibly a half graben structure forming the boundary of the Antigonish Basin and restricting Windsor seas to the eastern part of present day Antigonish County.

The age of the Windsor Group is taken to be Lower Carboniferous.

I) Canso Group

The Canso sediments lie conformably above the Windsor Group rocks. Lithologies include medium grey fine-grained wacke, siltstone and silty shale with calcareous layers and minor greyish red siltstone found northwest of the Antigonish Highlands. To the east of the Highlands (Antigonish Basin) Canso rocks include greyish red and greenish greywacke, siltstone and conglomerate; greyish red and light grey mudstone, siltstone and minor red conglomerate. The former sediments were deposited in a transgressive fluvial sequence derived from the Antigonish Highlands and the latter (Antigonish Basin) are interpreted as a lacustrine environment.

J) Cumberland Group

This group, in the map area, is made up entirely of the New Glasgow Conglomerate, consisting of a poorly sorted, medium greyish red, poorly stratified and indurated pebble- to cobble-conglomerate with interbedded medium- to coarse-grained wacke with minor carbonaceous remains. These deposits are local conglomerate deposits probably resulting from vertical movements of the Browns Mountain Block.

K) Pictou Group

This group of rocks includes interbedded dusky red sandstone, grey arenite, dusky red shale and mudstone and minor grey shales of fluvial origin derived from older Carboniferous rocks to the south.

L) Intrusive Rocks

The Antigonish Highlands are intruded by syenodiorite, granodiorite, diorite, granite and diabase. See stratigraphic column (Fig. II-1) for details. All intrusive rocks are pre-Lower Carboniferous.

III STRUCTURAL GEOLOGY

The Antigonish Highlands forms a horst bounded by the Hollow fault on the northwest and the Chedabucto fault on the south (Fig. II-2). Main movements along these faults are believed to have been post-Lower Carboniferous and

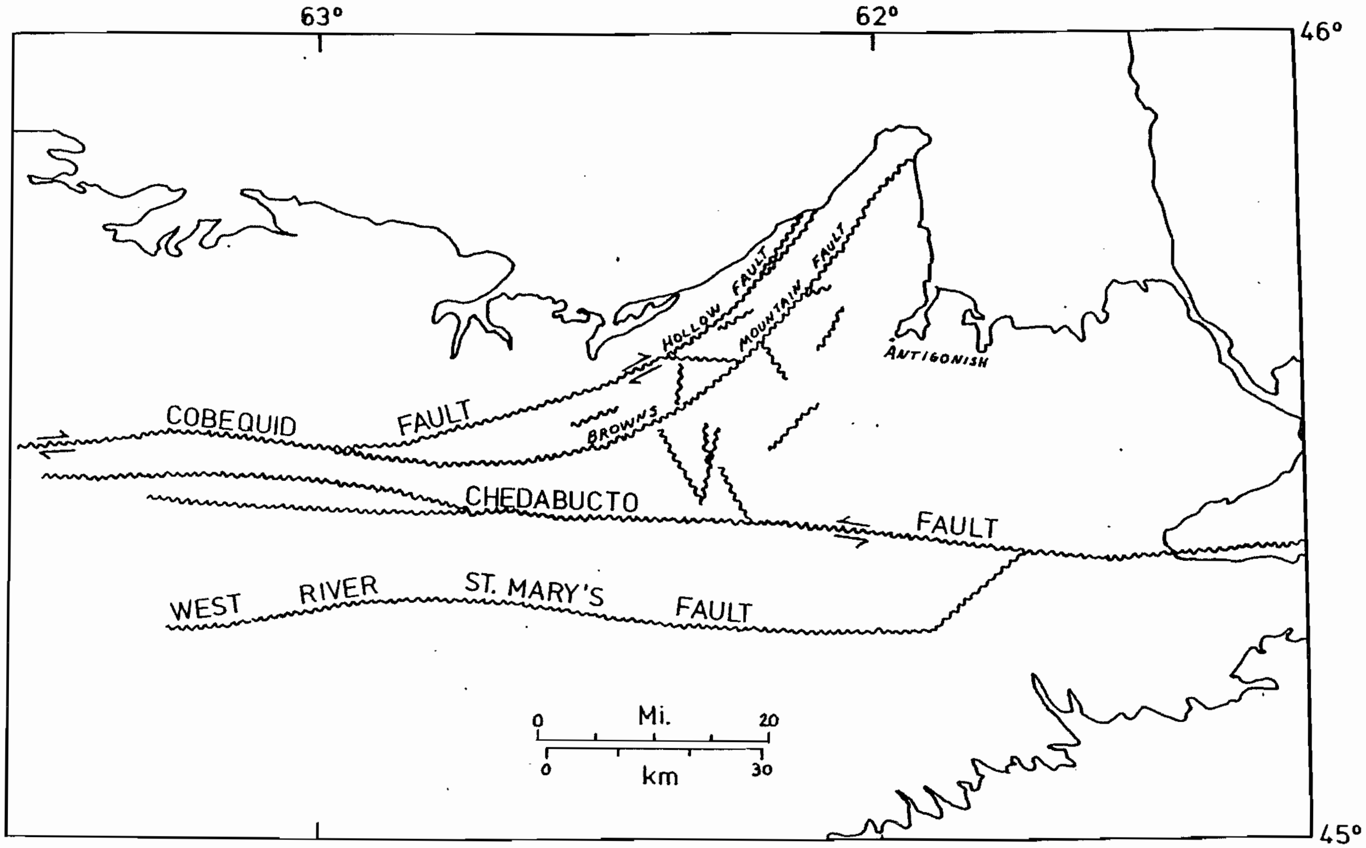


Figure II-2 Major faults in northern mainland Nova Scotia (after Benson 1974).

pre-uppermost Carboniferous. Subsequent Upper Carboniferous-pre-Cretaceous movement occurred along the Chedabucto fault.

No strike-slip component of the Browns Mountain fault is recorded.

These three major faults are considered one fault system.

All pre-Upper Carboniferous rocks are folded to various degrees. Fold identification in the Browns Mountain Group is precluded by the absence of top indicators. The Arisaig Group is folded into a syncline plunging to the southwest, overturned toward the Hollow Fault. This folding was probably related to the mid-Devonian Acadian Orogeny since the overlying Carboniferous rocks are unaffected by these folds. The Carboniferous contains only broad open folds.

IV TECTONIC HISTORY

Although outdated and newly modified (see Chapter VI) Benson's tectonic history of the area is included since his theory is based on the most extensive field investigation in this area, and to establish a basis of discussion for Chapter VI. It is stressed that his is only one possible explanation of an area which is as yet very controversial.

The main tectonic elements of concern in the area are the Antigonish Highlands block and the surrounding Carboniferous strata. For a more regional study, see Bird and Dewey (1970), Dewey (1969), Schenk (1971) and Williams (1979).

The low grade metamorphic rocks of the Antigonish Highlands formed at the site of part of a magmatic arc system during the Cambrian (Precambrian?) and Ordovician. This orogeny (Taconic) has been stipulated as shortening of the continental margin before continental collision (Bird and Dewey 1970). This episode was followed by Silurian and Devonian sedimentation originating from the earlier formed Browns Mountain Group. The Devonian period also contributed minor granitic intrusions into the Antigonish Highlands. During the middle to late Devonian Acadian Orogeny, most of the Appalachian rocks were metamorphosed, faulted and folded possibly in response to the collision of the African and North American plates (Benson 1974). By late Devonian the Highlands block had been elevated to positive land areas. Intermittent vertical movement of the Highlands block along the boundary faults and/or changes in sea level provided areas for basinal sedimentation during the Carboniferous. Late movement along the Hollow fault occurred during the Late Carboniferous. The final stage, broad open folding in the Carboniferous sediments is referred to as the Maritime Disturbance.

CHAPTER III

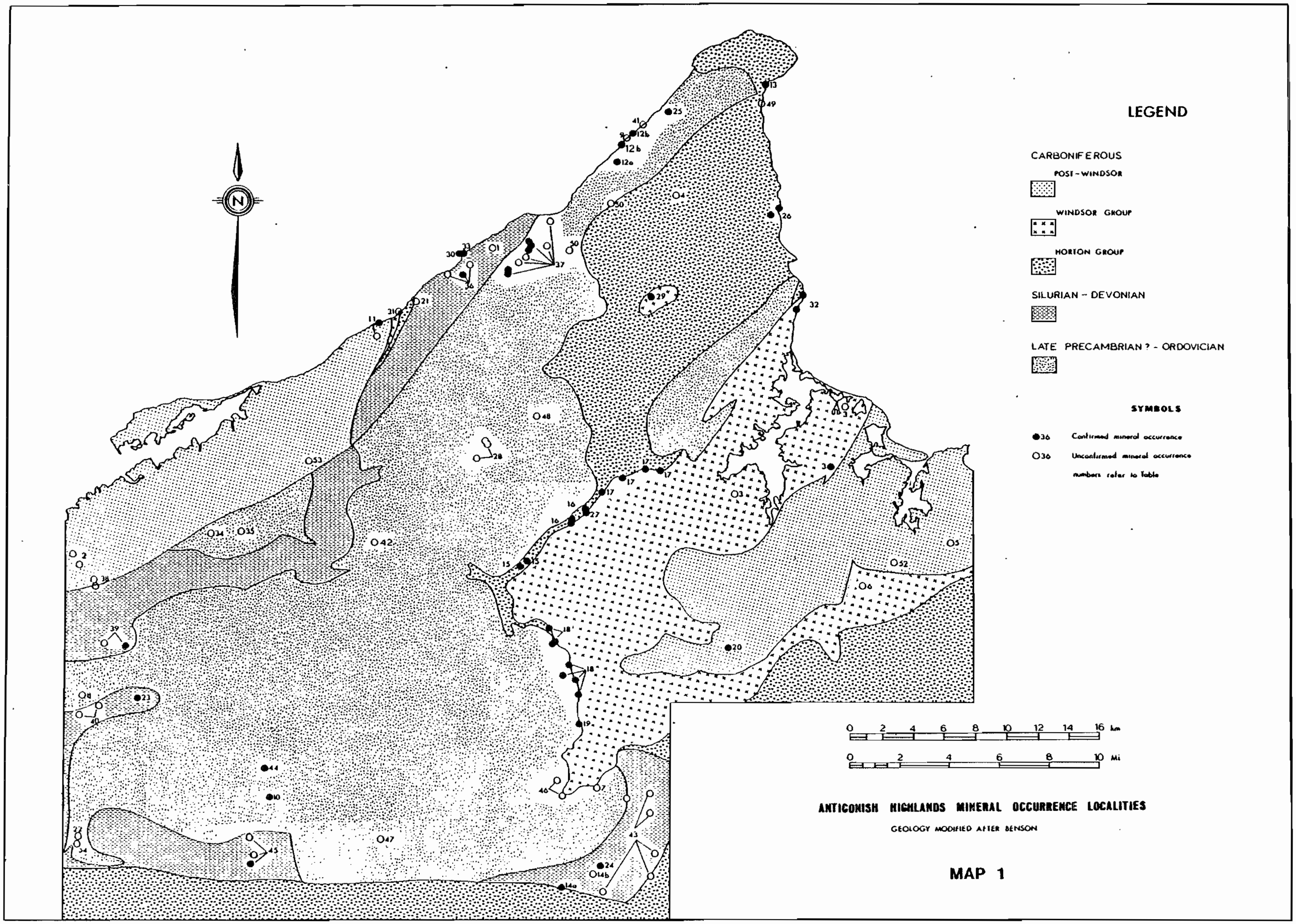
REGIONAL MINERALIZATION STUDY

A summary report of locations and geology of individual mineral occurrences are presented in Appendix I. Table 1 provides a summary of mineral occurrences of the Antigonish Highlands. Individual mineral occurrence locations are represented on Map 1.

Most mineral occurrences studied are at present of no economic significance. However, several groups of mineral occurrences were defined, some of potentially economic significance. These mineral groups, each consisting of several mineral occurrences, are outlined on Map 2.

Boundaries enclosing mineral groups are approximate and do not necessarily define a metallogenic province. The boundaries are based on mineral occurrence extent and lithology within which the mineralization is contained.

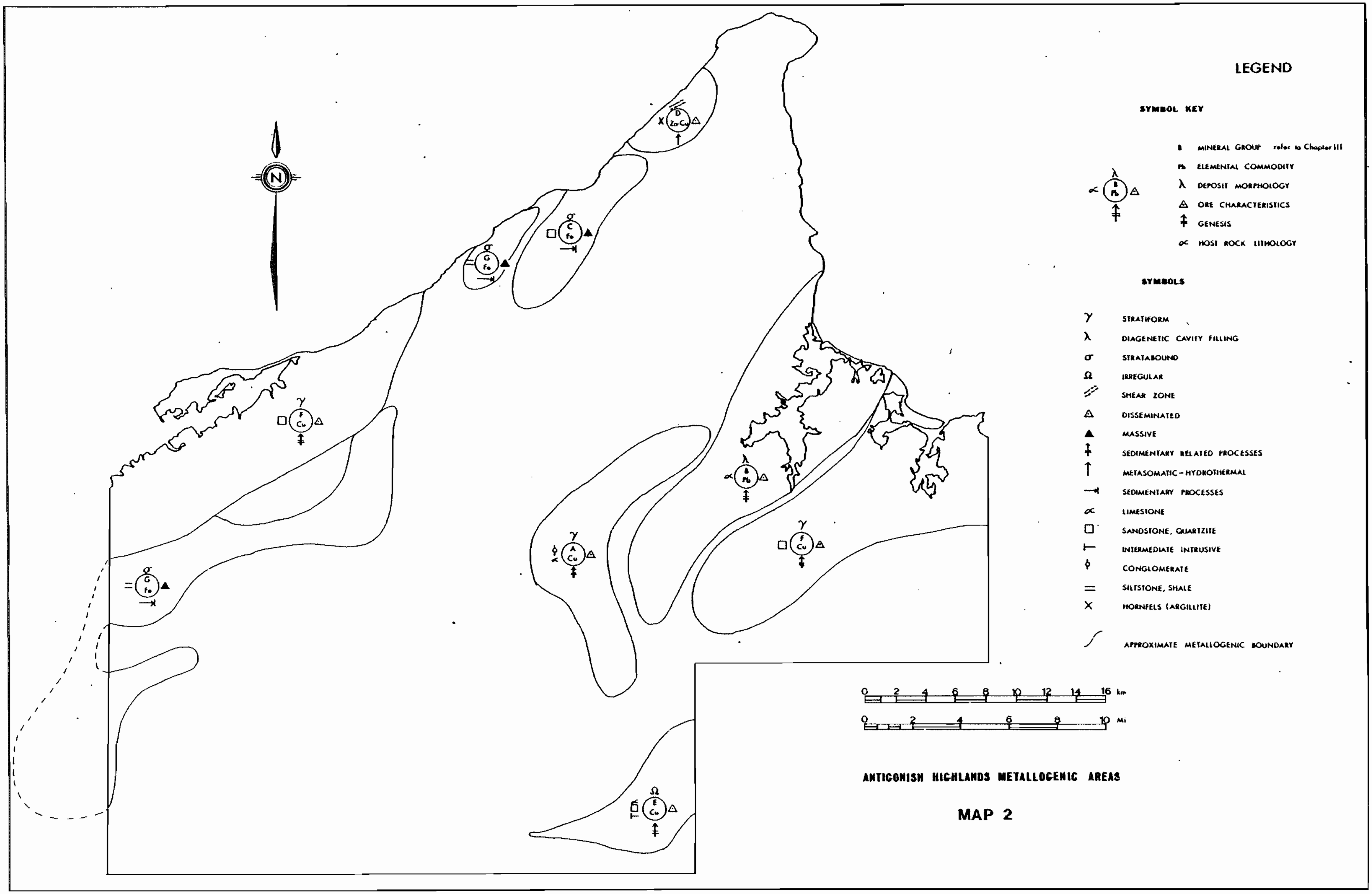
Group A consists of copper occurrences forming a belt approximately 15 miles long. It is by far the most significant (geologically and economically) mineralization encountered in this study and is treated in detail in Chapter V.



ANTIGONISH HIGHLANDS MINERAL OCCURRENCE LOCALITIES

GEOLOGY MODIFIED AFTER BENSON

MAP 1



ANTICONISH HIGHLANDS METALLOGENIC AREAS

MAP 2

Group B is comprised of several occurrences of galena in Upper Windsor carbonates. (see Occurrence No. 32 and 3, Appendix I). Two additional galena occurrences in this area are reported in drill core (see Map 1). Unfortunately rocks of the area selected for polished sections contained no mineralization. However, the galena mineralization appears to be associated with calcite cavity fillings in brownish grey dolomite. This suggests a process similar to those involved with Mississippi Valley Type Deposits may have been operative in this locality. A much more detailed study of the area must be undertaken to assess this potential.

Group C is made up of at least two iron-rich beds (see Occurrence No. 37, Appendix I). This group of iron occurrences is treated in more detail in Chapter IV.

Group D is a relatively continuous occurrence of sphalerite disseminated in hornfels argillites of Cambro-Ordovician age. Chalcopyrite is also found in the argillites, associated with shear zones. Faulting in this section is widespread, and may account for at least part of the mineralization. High contents of sphalerite and galena in some parts of the diorite which intrudes the argillite may also account for the mineralization.

The processes of intrusion, faulting and mineralization may be related, in that faulting resulted from intrusion and subsequent mineralizing fluids percolated from the intrusion via shear zones into the argillite. A detailed investigation of these aspects should be undertaken in order to determine their relationship. (see Occurrence No. 12, Appendix I).

Group E includes several copper occurrences in Lower to Middle Devonian sediments and intrusives. (see Occurence Nos. 14 and 24, Appendix I). Fletcher (1886) related the mineralization to the dioritic intrusions. However, at least some of the copper (Occurrence No. 24) appears to be related to sedimentary processes. A detailed study of these areas is necessary in order to substantiate this. This group also contains the abandoned iron-copper mine at Copper Lake. The mineralization is similar to College Grant (Occurrence No. 14) and is also hosted by Devonian lithologies (Fletcher 1886). Although Benson (1961) in a preliminary report, considers the sediments Horton in age, they lithologically resemble the Devonian sediments of the area.

These mineral occurrences may be accounted for by compaction and dewatering of sediments resulting in migration and precipitation of copper bearing fluids. See Occurrence Nos. 14 and 24 for more details.

This area shows potential as a copper bearing zone (Map 2).

The mineral occurrences making up Group F consist of copper in Upper Carboniferous (Canso Group) fluvial sediments (Occurrences Nos. 11 and 20). Two copper occurrences other than the two examined (Nos. 11 and 20) are reported by Fletcher (1886) in these lithologies. The Canso Group covers an extensive portion of the area (Map 1). This same type of mineralization is reported elsewhere in northern Nova Scotia in the Upper Carboniferous Pictou Group (Dunsmore 1977, Papenfus 1931). Dunsmore (1977) proposes that in this area, this style of mineralization be designated as the Pugwash-Tatamagouche type. The copper mineralization is confined to green, organic layers of sediments within a predominently red sequence of fluvial sandstone. Dunsmore (1977) proposes that the mineralization is derived from connate brines in lower evaporite units. The metals, which are concentrated in solution by evaporation are expelled in solution during compaction and dewatering of the evaporites. Precipitation of copper and uranium occurs when the organic rich reducing environment is encountered by the ascending solutions. Although very little information concerning uranium content is available, its presence in other occurrences of this type would indicate its presence in the map area also.

In this way, although the environments differ somewhat, the Pugwash-Tatamagouche type of mineralization is very similar to the Ohio - Sylvan Glen copper deposit discussed in Chapter V. The mechanisms of these types of mineralization will be examined in more detail in Chapter V.

The vast extent of Upper Carboniferous fluvial sediments and associated mineral occurrences in Northern Nova Scotia, affords great potential for a "Colorado Plateau" type deposit in this area.

Group G is made up of several iron beds in rocks of Silurian age (Occurrence Nos. 36, 38, 39 and 40, Appendix I). Many of the beds have been mined on a small scale in the past. Only one iron occurrence (No. 36) may be observed in the map area, although others are present just west and south of the map area, in Pictou County (see Wright 1975, Fletcher 1886).

The iron is undoubtly of sedimentary origin and is usually confined to shallow marine sediments (Brown 1974) belonging to the Arisaig Group. These iron beds are treated in more detail in Chapter IV.

Summary of Mineral Occurrences
Table 1

Deposition No. & Name - Commodity	Mineral Association Ore - Gangue	Host Rock and Age	Morphology	Ore Characteristics	Ore Genesis	Mineral Grouping*
1. Arisaig - Pb	galena, sphalerite, chalcopyrite, pyrite		following fractures	disseminated		
2. Telford - Pb, Zn	galena, sphalerite, pyrite - carbonaceous matter	greywacke - Canso Group	stratiform			
3. Antigonish Harbour - Pb	galena - host	dolomite - Upper Windsor Group	cavity filling	disseminated	diagenetic calcite cavity fillings	B
4. Georgeville, Heffernan - Mn	bog iron and manganese					
5. Afton - Mn	manganese nodules					
6. Pomquet River - Mn	manganese nodules					

7. Hillcrest - Mn	pyrolusite float					
8. Greenvale - Au	chalcopyrite, (gold?) - quartz	greywacke - Browns Mountain Group, Brierly Brook Formation	multiple veins parallel to foliation	disseminated	hydrothermal	
9. Georgeville - U, Be	uranium, thorium - host	alaskite - Cambrian	following fractures?	disseminated	pegmatitic?	
10. Moose River - Cu	chalcopyrite, malachite, specularite - calcite	crystal tuff - Browns Mountain Group, Brierly Brook Formation	large veins occupying a shear zone	disseminated	hydrothermal	
11. Knoydart Point - Cu	malachite - host	carbonaceous layers in sandstones - Canso Group	stratiform	disseminated	replacement by compaction and dewatering	F
12. Georgeville - Cu, Zn	(A) sphalerite, galena, pyrite, pyrrhotite - host	(A) diorite - Cambro-Ordovician		(A) disseminated	(A) contact metasomatic	
	(B) chalcopyrite, sphalerite - calcite	(B) argillite (hornfels) - Browns Mountain Group - Baxter Brook Formation	(B) veins occupying shear zones	(B) disseminated	(B) hydrothermal	D

13. Ballantynes Cove - Cu	chalcopyrite, malachite - host	greywacke - Horton Group	stratiform?	disseminated		
14. College Grant - Cu	chalcopyrite, malachite, hematite, specularite, siderite - host, quartz, calcite	diorite, quartzite Lower Devonian	veins and stratiform	disseminated	replacement by compaction and dewatering	E
15. James River 16. Brierly Brook 17. Sylvan Glen - Cu	bornite, chalcocite, chalcopyrite, malachite, covellite, azurite - host, calcite	conglomerate, limestone - Lower Windsor contact	stratiform	disseminated	replacement by compaction and dewatering	A
18. St. Joseph - Ohio Copper Region - Cu	chalcopyrite, sphalerite, bornite, malachite - host, calcite	breccia, limestone - basal Windsor Group	stratiform	disseminated	replacement by compaction and dewatering	A
19. Cross Roads Ohio - Cu	chalcopyrite, sphalerite, malachite - calcite, host	lapilli tuff - Browns Mountain Group, Brierly Brook Formation	'veins' occupying a shear zone	disseminated	replacement by compaction and dewatering	A
20. Pitchers Farm - Cu	chalcopyrite - host	quartzite, sandstone - Canso Group	stratiform	disseminated	replacement by compaction and dewatering	F

21. McArras Brook - Cu	malachite	siltstone - Knoydart Formation	stratiform?	disseminated?	replacement by compaction and dewatering?	F
22. Sunnybrae - Cu	chalcopyrite - host	diorite, argillite - Browns Mountain Group, Brierly Brook Formation				
23. Blue Mountain - Cu	chalcopyrite, pyrite - quartz, ankerite, chlorite	argillite - Arisaig Group	veins parallel to foliation	disseminated	hydrothermal	
24. Lochaber - Cu	chalcopyrite, pyrite, bornite, fluorite - host, calcite	argillaceous limestone - Knoydart Formation	stratiform	disseminated	replacement by compaction and dewatering	E
25. Cape George - Cu	pyrite, chalcopyrite, sphalerite - host	argillite (hornfels) - Browns Mountain Group, Baxter Brook Formation	following fractures in shear zone	disseminated	hydrothermal?	D
26. Lakevale - Ba	barite - calcite	limestone - Lower Windsor Group	multiple veins	massive	hydrothermal?	
27. Brierly Brook - Ba	barite, malachite - calcite	limestone - Lower Windsor Group	multiple veins	massive	hydrothermal?	

28. Browns Mountain - Ba, Fe	barite					
29. Big Marsh - Ba	barite - host	limestone - Lower Windsor	vein	massive	hydrothermal?	
30. Arisaig Point - Ba	barite, agalmatolite - host	rhyolite - Dunn Point Volcanics	veins	massive	hydrothermal?	
31. McArras Brook - Ba	barite - calcite, pyrite, chalcopyrite	shale - Lower Windsor	stratabound	massive		
32. McIsaac Point - Ba	barite - calcite, marcasite	limestone - Lower Windsor	multiple veins	massive	hydrothermal?	
33. Arisaig - Agalmatolite	agalmatolite - barite, chert	rhyolite - Dunn Point Volcanics	multiple veins and lenses	massive	hydrothermal?	
34. Piedmont - Mn						
35. Piedmont - Fe	hematite - detrital quartz	sandstone - Browns Mountain Group, Baxter Brook Formation	stratabound?	massive	sedimentary	C?

36. Arisaig Brook - Fe	hematite - detrital quartz	siltstone - Arisaig Group	stratabound	massive, forms cement	sedimentary	G
37. Arisaig Iron District - Fe	hematite - detrital quartz	quartzite, greywacke - Browns Mountain Group	stratabound	massive, forms cement	sedimentary,	C
38. Telford - Fe	siderite - ?	conglomerate - Arisaig Group?	stratabound?	massive		
39. Meiklefield - Fe	hematite - ?			massive		
40. Wentworth Grant - Fe	hematite - ?	slate - Arisaig Group?	stratabound?	massive	sedimentary?	G
41. Georgeville - Fe	pyrite - host	argillite (hornfels) - Browns Mountain Group, Baxter Brook Formation	possibly following fractures	disseminated	hydrothermal?	
42. Barneys River Station - Fe						
43. Lochaber Lake - Fe	specularite - quartz	slate - Knoydart Formation	multiple veins	disseminated		

44. Moose River - Fe	specularite, pyrite, pyrrhotite - host	rhyodacite, diorite - Browns Mountain Group, Keppoch Formation	fracture fillings	massive in fractures
45. Beaver Lake - Fe	specularite, pyrrhotite, hematite - host	diorite, granodiorite - Lower Ordovician	fracture filling	disseminated
46. Ireland (Hillcrest) - Fe				
47. Campbell Brook - Fe	specularite - ?	- Browns Mountain Group	fracture fillings	disseminated
48. Silver Mine - PB	galena, silver? - quartz?	quartzite? - Browns Mountain Group?		

CHAPTER IV

ARISAIG IRON GROUP

I ARISAIG BROOK IRON OCCURRENCES

The Arisaig Brook Iron Occurrence (No. 36, Appendix I) is located along the MacDonald Road, 670 m south of Hwy. 245 in Arisaig (Map 1).

This previously mined deposit consists of two adits on either side of the MacDonald Road, approximately 10 m up the hill. These adits have been driven about 8 m into the north wall and 2 m into the south wall.

A one metre thick bed of massive, oolitic hematite rests conformably between nearly vertical beds of medium grey, micaceous, slatey siltstones of Silurian age. The ironstone consists of about 55-75% hematite and 25-45% fine grained siliceous clasts. The hematite consists of two or three concentrically lined lenses filling voids between quartz clasts (Plate IV-1 e, f).

Very sharp contacts exist between the ironstone and the host siltstones. An abundance of fossils on the bottom 2 cm of the iron bed probably marks the drastic chemical change in environment which occurred at that time.

One set of crystalline quartz veins cut the hematite bed.

II ARISAIG IRON DISTRICT, IRON OCCURRENCES

See Occurrence No. 37, Appendix I for location Coordinates.

Location (1) is found 1.8 km south of Hwy. 245, along the New Road at Doctors Brook.

Location (2) is found 8 m east of New Road, 1.9 km south of Hwy. 245, at Doctors Brook. This was a production pit.

Location (3) is situated on the side of a steep hill, 330 m west of the bridge on the New Road, 2.3 km south of Hwy. 245. Several old test and production pits exist here.

Locations (4) and (5) may be reached by way of a new logging road, 1.5 km west of the New Road. The locations are found approximately 100 m east and 170 m south respectively, of the present end of the logging road, which is 1 km south of Hwy. 245. Location (4) is the site of the largest production pit. It stretces northeast for about 25 m and is 3 m deep and 2 m wide. It is believed this iron band continues northeast for at least another 330 m, where another pit (no coordinates) of comparable size lies. Williams (1914) defined a 4 km lateral extent of this iron band.

Unless otherwise noted, the following descriptions apply generally to all locations.

Some iron ore extraction occurred on a small scale just previous to 1900 (Williams 1914). Numerous old pits, both test and production, stretch northeasterly for nearly 3.2 km, approximately 1 km inland, between Arisaig and Doctors Brook.

These occurrences are found within Cambro-Ordovician Browns Mountain sedimentary rocks and are not to be confused with the Silurian Arisaig iron occurrences (Williams 1914, Wright 1975).

Some iron is also found in the adjacent Browns Mountain basic volcanics (location 1) where it occurs as specular hematite up to 1 cm thick in fracture surfaces, associated with calcite. Slickenslides occur on some surfaces of the specularite fracture fillings. Pyrrhotite, in quantities of about 15%, is disseminated in the basic volcanics which are situated adjacent (170 m north) to the ironstones found in the Browns Mountain Group sediments.

Plate IV-1

a Cherty bands (grey) aligned parallel and detrital clasts (grey, rounded) constituting iron beds of the Arisaig Iron District. Transmitted.

b Possible cross bedding in cherty bands (centre). Arisaig Iron District. Transmitted light.

Plate IV-1

c Typical clast (grey) - iron oxide (black) ratio. Transmitted light. Arisaig Iron District.

d Reflected light of Plate IV-1c. Specular hematite is white. Arisaig Iron District.

Plate IV-1

e Typical clast (white) - iron oxide (black) ratio. Clasts more rounded than those of the Arisaig Iron District (Plate IV-1c).

f Reflected light of Plate IV-1e. Specular hematite is white, hematite (dark grey) and quartz clasts (light grey).

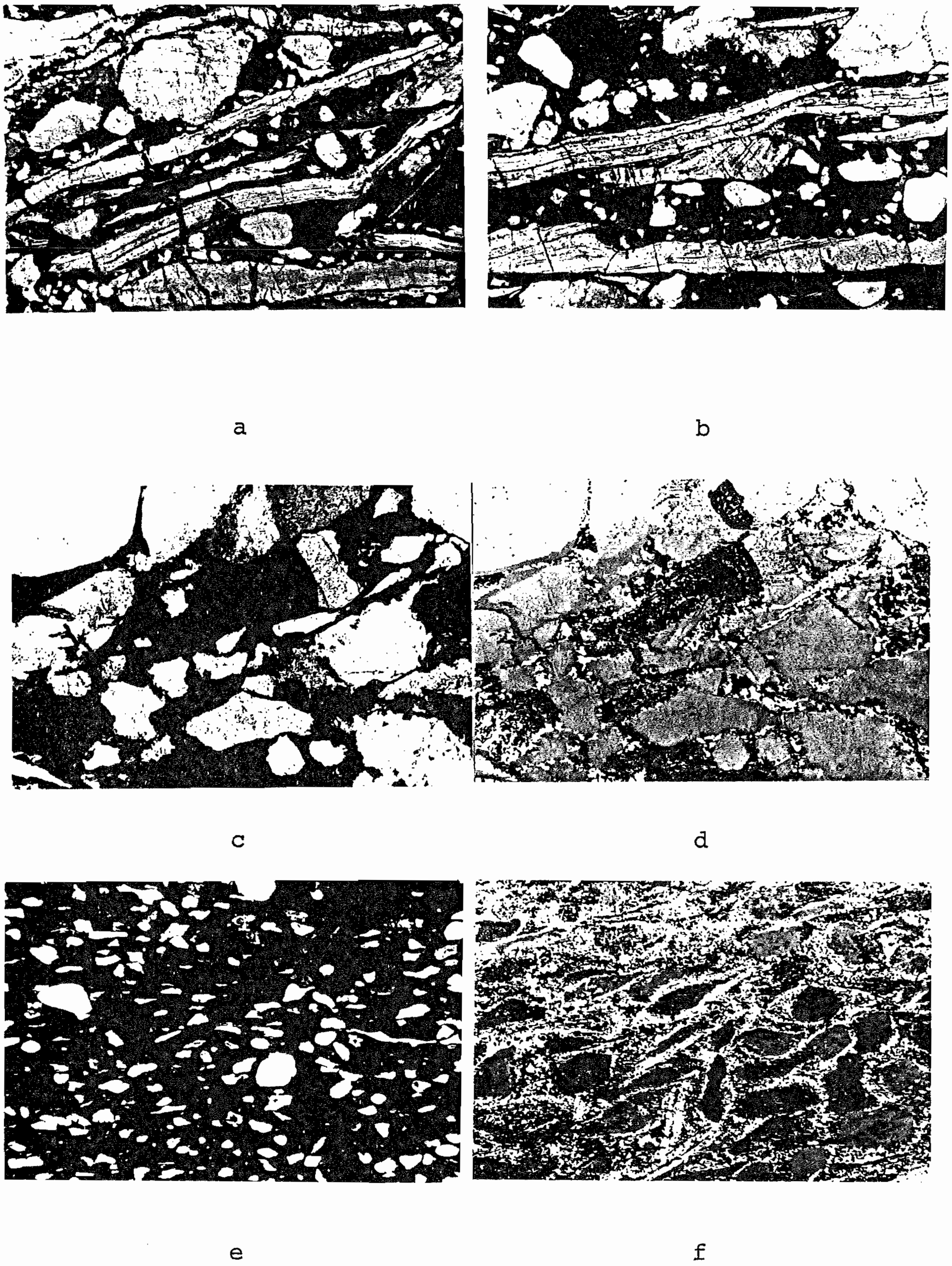


Plate IV-1 Arisaig Iron Area

Scale unless otherwise
indicated

The ironstones consist of nearly vertical, concordant, hematite beds from 5 to 8 feet thick, with different amounts of detrital quartz. The hematite forms the matrix of the ironstones, in proportions of about 20% to 50%. The quartz clasts which form from 50% to 80% of the ironstones, range from fine to coarse-grained and are subangular to subrounded with a nearly vertical preferred orientation.

Micro-laminated cherty beds, 1 mm thick, with intact primary sedimentary features are found fragmented in the ironstones (Plate IV-1 a, b).

Fairly sharp contacts with wall rocks are evident, indicating a probable sedimentary origin. Wall rocks consist of light grey, fine to medium-grained, subangular to subrounded quartzites with minor pyrite, and medium grey, fine-grained, micaceous slaty greywacke.

One pit (location 5) contains a very fine grained red sediment with a relatively low hematite content of about 15% to 20%. This ironstone lies conformably between a nearly vertical pinkish-red fossiliferous Ordovician (?) limestone, and a medium grey siltstone. Thus more than one unit of ironstone exists in the area.

In most trenches, the quartzite appears to form the footwall and the slaty greywacke the hanging wall. However, folding in this region is complex and this sequence is not conclusive.

III SUMMARY AND DISCUSSION

From the previous description it is concluded that the iron beds of Arisaig may be compared with the Lorraine or "Clinton" type ironstone deposits found in the Silurian sediments of the eastern United States. Other deposits occur in Ordovician sediments of Newfoundland and Nova Scotia, such as at Torbrook, Nova Scotia.

Ironstone deposits commonly occur in and interbedded with near-shore shallow marine limestones, siltstones, shales, sandstones and conglomerates. Hematite replaced fossils are common. The iron beds may extend laterally for miles and thicknesses may attain tens of feet. The deposits usually occur as groups of beds confined to relatively small stratigraphic intervals (Stanton 1972).

The oxide ores consist principally of hematite and/or limonite commonly found as oolites or pellets. Oolites form around detrital material in most cases.

Chemical analysis show trends which are distinctly indicative of ironstone deposits. Table 2 compiles average values for Arisaig iron analysis by Wright (1966) and those of this study. Average values of ironstones and iron formations are compiled from Stanton (1972). Lorraine type ores are typically high in P_2O_5 as are both the ironstones of Arisaig Brook and especially the Arisaig Iron District. Al_2O_3 is also quite high in ironstones and usually is found in amounts between 2% and 10%. Ironstones of Arisaig all fall in or very near this range. The high silica content of the Arisaig ironstones does not indicate chamositic type ironstones, as characteristically low Fe_2O_3 contents of these ores precludes this. CaO content of the Arisaig ironstones is relatively high as are ironstones, generally. High SiO_2 content of some samples analysed in this study reflect the abundance of detrital quartz in the Cambro-Ordovician ironstones. Although most ironstones average low SiO_2 contents, high SiO_2 analysis are known for other ironstones. An inverse relationship between SiO_2 and total Fe also reflects the relative iron/detrital quartz contents of the Arisaig ironstones. Silica and iron contents are not indicative of type of iron deposit. Thus, chemically and geologically, both Arisaig iron occurrences very closely resemble ironstone-type iron deposits.

Most ironstones are probably derived from continental erosion, submarine volcanic hot springs carrying iron salts and/or upwelling currents containing iron salts from deeper areas of the ocean floor (Stanton 1972). One problem with continental erosion is deriving large quantities of iron

	Average Hematite Ironstones (Stanton 1972)	Average Arisaig Brook Iron Occurrence (Wright 1966)	Arisaig Brook Iron Occurrence (This study)*	Arisaig Iron District (Wright 1966)	Arisaig Iron District (This study)*	Arisaig Iron District (This study)*	Average Hematite Iron Formation (Stanton 1972)
SiO_2	13.94^x	15.10	11.31	18.15	44.76	44.20	41.90^x
Al_2O_3	3.37^x	7.72	6.52	6.10	2.21	11.97	1.37
FeO	5.93	44.03	8.70	46.35	2.10	0.60	1.37^x
Fe_2O_3	49.99^x		75.72		32.56	31.35	53.94^x
CaO	9.29	11.70	1.81	1.86	11.09	3.05	0.64^x
P_2O_5	1.32^x	0.57	0.80	0.83	7.57	1.98	0.14
CO_2	9.52	---	0.35	---	0.17	0.21	1.50
S	0.12	0.02	0.012	0.008	0.032	0.006	0.01^x

IRONSTONE CHEMICAL ANALYSIS
TABLE 2

* Analysis by Nova Scotia Technical College

^{x} Average value with relatively narrow range with relatively little detritus. However, the Arisaig ironstones are made up of up to 80% detrital material. Continental erosion is thus the most likely source of the Arisaig ironstones, although other sources are not precluded by the high detrital quartz content.

Similar iron beds are found in Ordovician and Silurian sediments about 20 miles southwest of the Arisaig iron beds, in Pictou County (see Occurrence Nos. 35, 38 & 39 and Wright 1975). Chemical analyses reported by Wright (1975) are similar to those of the Arisaig ironstones. The Pictou County ironstones, largely out of the map area, in conjunction with those of Arisaig would form, approximately, a 40 km long belt of ferrugenous, Ordovician and Silurian sediments (Map 2).

Continuity between the two groups of occurrences is unknown and further work on the relationship is warranted.

Other major groups of iron occurrences in mainland Nova Scotia include those of the Londonderry Iron Area located on the south flank of the Cobequid Mountains in Colchester County. Wright (1975) concludes that the primary siderite and ankerite veins are derived from a plutonic source. Chemical analysis of the ores (Wright 1975) are similar to those of carbonate ironstones (Stanton 1972). Proximity to and alignment along the Chedabucto fault

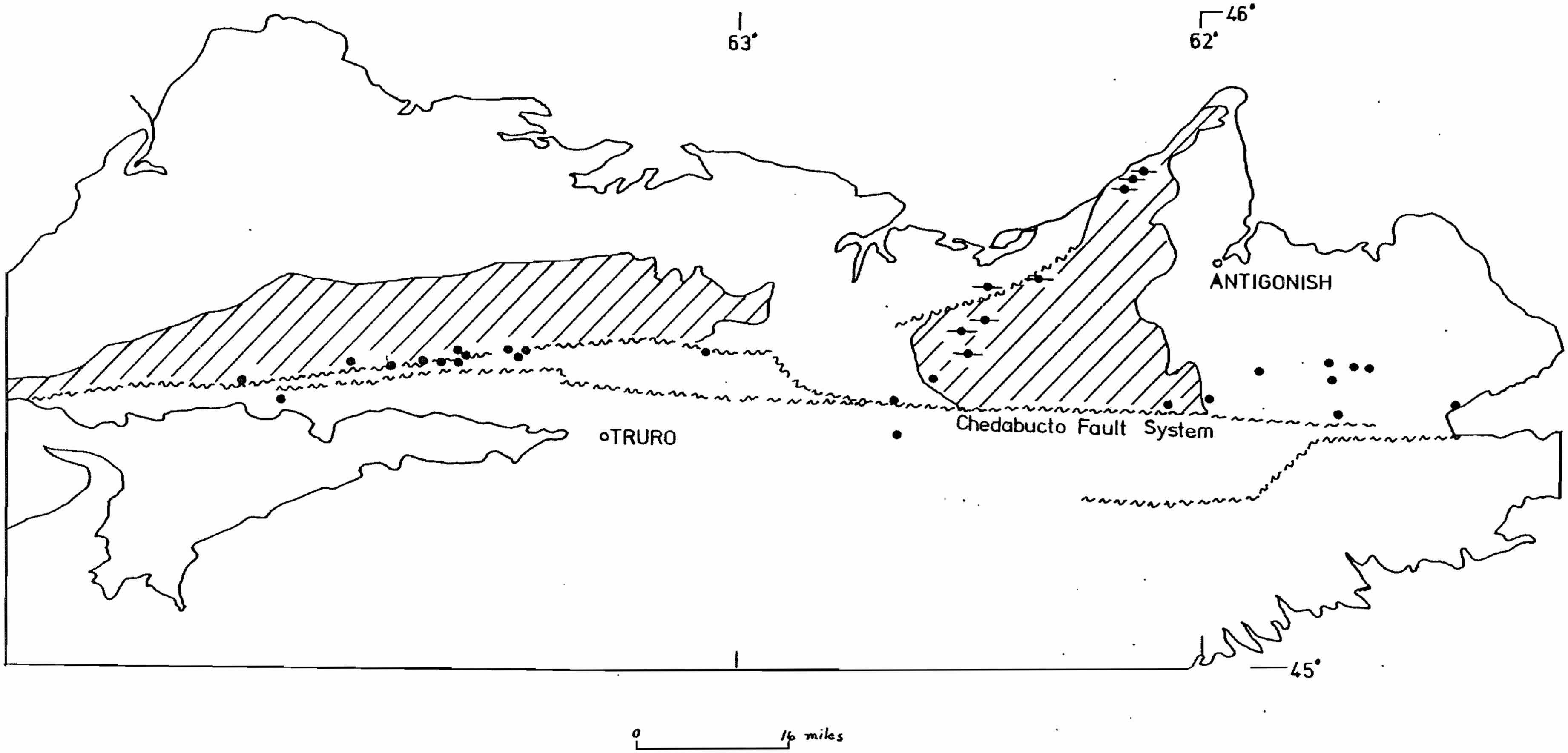


Figure IV-1 Map illustrating two probable classes of iron deposits in northern mainland Nova Scotia. Iron occurrences modified after Wright, 1975.

Symbols:
- ● iron occurrence fault related
- -●- iron occurrence related to sedimentary accumulation
- ☐ CARBONIFEROUS
- ▨ PRE-CARBONIFEROUS

system would certainly indicate a possible fault involvement in the iron mineralization (Fig. IV-2). Several additional vein iron occurrences are located along or near the Chedabucto fault in Pictou, Antigonish and Guysborough Counties (Wright 1975). The Pictou County occurrences consist of siderite veins with similar chemical analysis to carbonate ironstones. The Guysborough and Antigonish iron occurrences are predominently specular hematite veins.

Thus, two general classes of iron deposits occur in northern mainland Nova Scotia: 1) Sedimentary ironstone beds (oolitic hematite) accumulated in Ordovician and Silurian sediments in the Antigonish and Pictou Highlands. 2) Hydrothermal and/or magmatic related iron veins (siderite, ankerite and specular hematite) formed in spatial proximity to the extensive Chedabucto fault system.

A geological-geochemical program of these iron areas would provide the necessary information to further delineate and classify the deposits.

CHAPTER V

OHIO - SYLVAN GLEN COPPERBELT

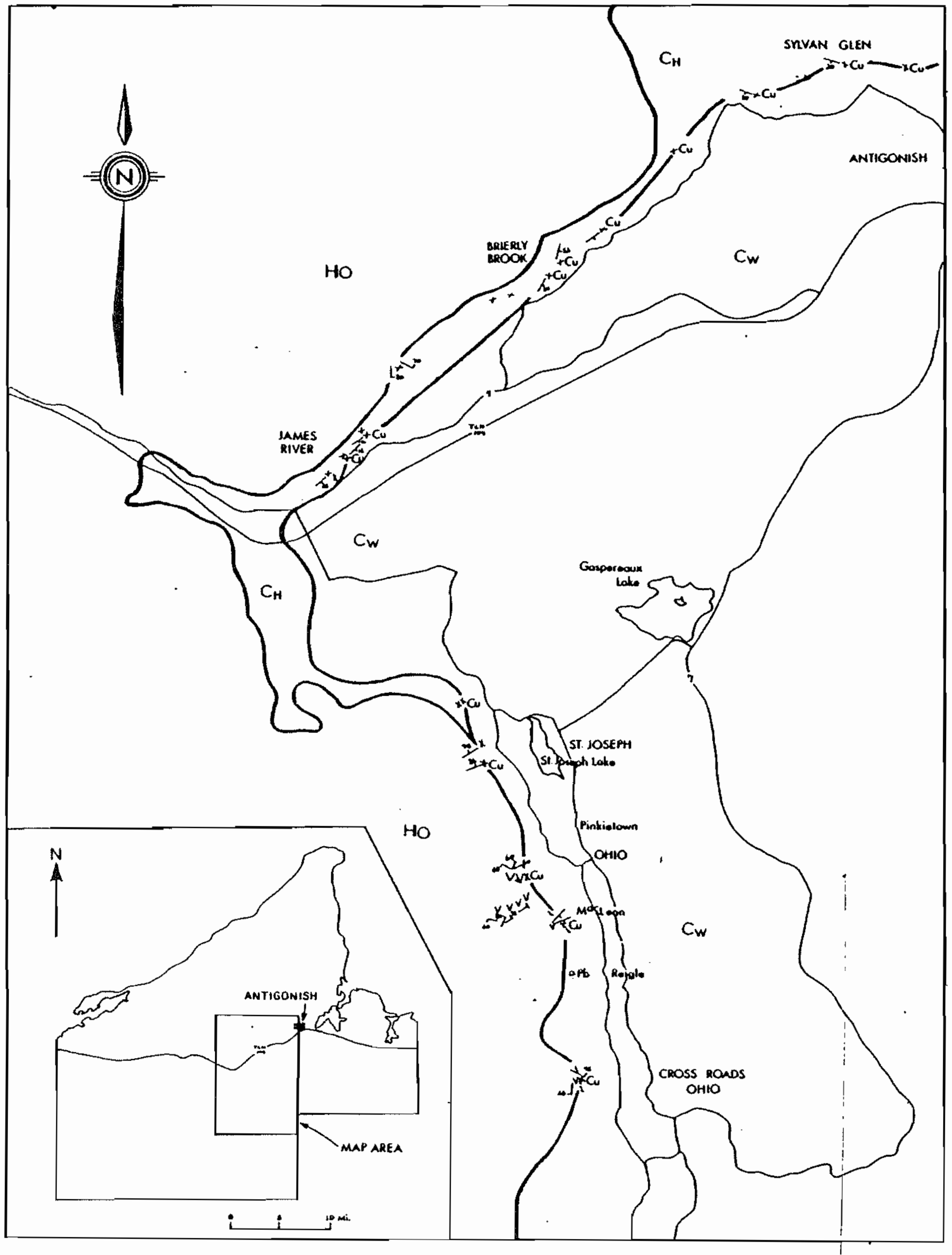
I INTRODUCTION

Geological descriptions of the mineral occurrences involved in this chapter are found as Occurrence Numbers 15, 16, 17, 18 and 19, Appendix I. These mineral occurrences are designated as Group A (Chapter III) and form the most significant and important mineralization in the map area.

The following chapter outlines a detailed study of the ore minerals found in the Ohio - Sylvan Glen Copper Belt. An interpretation of ore genesis is subsequently made on textural evidence. Experimental work to support conclusions is subsequently proposed. An experimental project of this nature is beyond the scope of the present work.

Descriptive ore petrology is summarized area by area for use in future work. (Individual polished slide descriptions are found in Appendix II-D) Areas and locations are plotted on Map 3.

This work represents the first reported ore microscopy of the copper belt. Representative samples of all units in



LEGEND

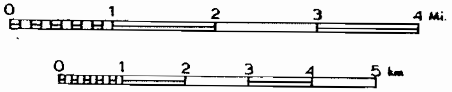
CARBONIFEROUS

Cw	WINDSOR GROUP
CH	HORTON GROUP

LATE PRECAMBRIAN ? - ORDOVICIAN

HO

X	ROCK OUTCROP
V	VOLCANIC ROCK OUTCROP
	GEOLOGICAL BOUNDARY
	BEDDING
Γ T	JOINT (inclined, vertical)
	FAULT
o	FLOAT
	ROAD
Cu	MINERAL OCCURRENCE



OHIO-SYLVAN GLEN AREA
GEOLOGY AND MINERAL OCCURRENCES

MAP 3

outcrop for each area were used for the study.

Textural terms used in this section have no genetic significance unless otherwise noted.

Due to the variability of composition and optical properties of chalcocite and digenite (Ramdohr 1969, Wolf 1976, Brett 1962) the two minerals are differentiated only where optical differences allow for positive identification.

A program of microprobe identification of sphalerite was undertaken due to the nearly ubiquitous distribution of detrital rutile and anatase. These minerals are almost optically identical (Ramdohr 1969) in reflected light. The sphalerite usually occurs as finely disseminated grains and is thus physically similar in appearance to the small titanium grains. The microprobe program provides fairly good parameters on sphalerite distribution.

II STRATIGRAPHY

A) Description

Introduction

Descriptions of the basement, conglomerate, breccia and the laminated Macumber limestone are taken from field and microscope work done by the author. The overlying units of carbonate, evaporites and red beds are described from drill core logs and are added for purposes of completeness and comparison with other deposits.

Some ambiguity exists as to the age of the breccia unit in the Southern section (St. Joseph, Ohio) of the map area. Benson (1974) maps the unit as Windsor. However, as Boehner (1978, pers. comm.) points out, the line between Horton and Windsor is arbitrarily based on lithology, the Windsor beginning at the base of the lowermost carbonate unit. Many problems of Windsor correlation exist in the Carboniferous Basins of Nova Scotia (Boehner 1978, Giles 1978, Giles and Keppie 1978, Keppie et al 1978). For arguments of mineralization the two may be considered equivalent lithologies. Both are made up of basement fragments and carbonate cement and both have the same relationship to units above and below.

1- General Geology

The area of interest in this chapter is concerned with the arcuate contact between the Cambro-Orodovician Browns Mountain Group and the Carboniferous Horton and Windsor Groups. The contact extends from Sylvan Glen in the North-eastern section to James River in the Western section and to Cross Roads, Ohio in the Southern section. Detailed stratigraphy will be denoted by these sections (see Map 3).

In the Southern section, the basement is formed by the Keppoch, Baxter Brook and Brierly Brook Formations of the Browns Mountain Group, (see Regional Geology Ch. I) while in the Western and Northern sections the Baxter Brook and Brierly Brook Formations alone form the basement (Benson 1974).

Lowermost in the structural basin and lying unconformably above the basement is a thin (20 ft., Boehner 1975) layer of conglomerate belonging to the Horton Group of the Lower Carboniferous. It extends from Sylvan Glen to south of James River Station. Benson (1974) does not show the Horton Group around a Basement knoll west of St. Joseph. However, field mapping by the author and Boehner (1979) indicates an extension of the Horton Group around this knoll to St. Joseph, where it pinches out.

From St. Joseph to Cross Roads Ohio, a basal Windsor (?) breccia unconformably overlies the basement. Whether this is an Upper Horton equivalent or a basal Windsor lithology is not known. However, with respect to mineralization this is unimportant since the Horton-Windsor contact is an arbitrary boundary in this area. MacNeil (1959) considers the conglomerate a Lower Windsor lithology, while Benson

(1974) maps the unit as Upper Horton.

Conformably above the conglomerate breccia, is a sharp contact with undoubted Windsor lithologies. A predominently transgressive sequence of carbonates and evaporites with overlying transgressive-regressive cycles of intercalated evaporites and siltstones occupies the Antigonish Basin to the ridge of Browns Mountain rocks which outlines the basin. The total thickness of the Windsor in this area is approximately 1,500 to 2,100 feet (500 to 700 m) (Benson 1974).

The Lower Carboniferous strata strike generally parallel to the Browns Mountain - Carboniferous contact, and dip gently (15° - 20°) basinward (Map 3). These lithologies have been relatively undisturbed. Detailed mapping of the area, presently being undertaken by Boehner (1978a), indicates that the structure and stratigraphic succession is as yet unknown. The Ohio River, which forms a prominent linear feature, may follow a fault line. This proposed fault could account for a large section of the Lower Windsor apparently absent from the succession in this area (Boehner, pers. comm.)

2- Lithological Descriptions

a) Basement Unit

Thin section studies of the Browns Mountain volcanics that comprise the basement come mainly from the MacLean, Ohio Iron and Cross Roads Ohio mineral occurrences (Appendix I).

The basement is made up predominantly of a greenish-grey to pinkish coloured lithic to crystal lappilli tuff. The tuff consists of approximately 40-50%, subangular to subrounded, 2 to 20 mm fragments of porphyritic acid (rhyodacite to latite composition) volcanics with indistinct boundaries. The fragments are aphanitic with feldspar phenocrysts (<1-2 mm) altered beyond identification in most cases. Matrix of the fragments show a pilotaxitic texture composed of microlites of chlorite and feldspar. The matrix of the tuff is aphanitic (<0.01 mm) and comprises 50-60% of the rock. Relict feldspar crystals (1-2 mm) with rare lamelli, constitutes up to 10% of the tuff matrix. The remainder of the matrix is made up of silicious (feldspar and quartz) microlites with tiny chlorite and sericite grains (10%) forming indistinct bands around crystals and fragments.

The tuff contains up to 10% opaque material, made up predominantly of small hematite grains distributed mainly in discontinuous 0.25 mm stringers which form a fabric around crystals and fragments.

Other volcanics, away from the Browns Mountain - Carboniferous contact, comprise porphyritic rhyodacites, quartz trachite-latites and andesites. For descriptions of these lithologies see individual slide descriptions Nos. 7334, 7336 and 7337, respectively in Appendix II-A. No metasediments of the Browns Mountain Group are present in this area.

b) Breccia Unit

The breccia is a poorly sorted, compact, scree deposit with angular to subangular, pebble to cobble sized volcanic fragments in a carbonate matrix. The proportions of fragments to carbonate decreases gradually towards the top of the breccia unit. The fragments consist predominantly of tuff and the more acid members of the Browns Mountain volcanics described above. The fragments range in size from about 1 to 8 cm. The carbonate matrix may consist of up to about 40% sand and silt-sized detrital material. Some carbonate is found as crystalline calcite (up to 1 mm). However, most occurs as a lime mud filling voids between the fragments.

No oxidized, red equivalent of the green-grey, reduced breccia was encountered in outcrop although a lower red section was reported in DDH OH-1 (see Appendix III). All other drill holes in the Southern section show only the green-grey breccia unit. Since the green-grey coloration is attributable to reducing conditions at the onset of sudden Windsor transgression (see Section II-C, this chapter) the breccia unit must have been almost entirely permiable to the Windsor sea.

c) Conglomerate Unit

The conglomerate is found in the Western and Northeastern sections of the area. It is poorly sorted. well lithified to poorly consolidated (crumbly in some cases), fairly well rounded, pebble to cobble conglomerate. The fragments consist largely of Browns Mountain volcanics and meta-sediments (described in Appendix II-A), but also contain minor granitic pebbles. The matrix consists of sand and silt sized detrital material (mainly quartz and feldspar) with carbonate mud which constitutes up to 50% of the matrix.

The conglomerate unit grades upwards from a red (oxidized) loosely consolidated conglomerate with minor carbonate in the matrix to a green-grey, fairly well consolidated conglomerate with considerable carbonate in the matrix. Generally, the red sub-unit shows larger cobble-size fragments. In areas where the contact is exposed, the transition from red to green conglomerate is either gradational over a few centimeters or knife sharp (eg Cape Blue).

In one area (James River) the conglomerate contains 5 cm interbedded units of fine to medium grained, grey carbonaceous sandstone. It is probably conformable to the conglomerate.

At several locations, a fine grained, light grey, limy sandstone made up of subangular quartz clasts (approximately 50%) marks a 4 cm transition into the overlying Windsor limestone. Rutile (1%) and minor sphene comprise other detrital clasts found in the sandstones as well as in the matrix of the conglomerate.

d) Limestone Unit

In most areas studied, the limestone is a medium grey, finely laminated, algal, pelletoidal micrite. Laminations in this Macumber limestone have been ascribed to algal origins (Schenk 1967). Up to 10% subangular to subrounded, sand and silt sized quartz clasts are found throughout the lime mud. The pellets are predominantly lens shaped and vary from 0.1 mm to 1 mm. Some of the larger pellets show concentric bands of light and dark material about lime mud. The laminations (<1 mm thick) are parallel, usually 1 to 4 mm apart, and consist of fine strands of dark greyish-brown semi-transparent (probably organic) material. Mineralization is often associated with the laminations.

Some of the limestone is sub-crystalline with grains of calcium carbonate up to 0.03 mm across.

No skeletal remains were observed in any of the basal laminated limestones. However, scattered skeletal material (probably brachiopods) and rare detrital quartz grains were encountered in boulders of non-laminated, basal Windsor limestone.

The limestone found at the MacLean occurrence (Appendix I) is a non-laminated, medium grey, massive micrite, with minor detrital quartz clasts and abundant calcite-filled cavities. Although it appears to be in fault contact with the lower breccia unit, Boehner (pers. comm.) considers this carbonate a Macumber equivalent. No skeletal material is present in this limestone.

Descriptions of the limestone which overlies the lower laminated sub-unit come from drill core descriptions, (MacLeod 1978, Burton 1974) since these lithologies do not outcrop in the map area. Generally the laminated limestone is conformably overlain by interbedded medium and dark grey to brownish grey, skeletal and algal pelmicrite. Skeletal debris consists primarily of brachiopods, (which increase in abundance up the section) and minor gastropods and ostracods. Minor amounts of coral or bryozoa were encountered in one section (OH-9A). Some highly leached dolomite is found higher in the sections.

e) Evaporite - Red Bed Sequence

Evaporites and red beds do not outcrop in the map area but have been reported in drill core (Johnston 1973, 1974, Black 1978, Anderle 1974, Grace 1966). A brief description of the sequence will serve to complete the stratigraphic succession.

Conformably overlying the carbonate sequence is a thick (approximately 200-260 m) unit of blue-grey, massive anhydrite with gypsum-anhydrite veinlets throughout. Minor interbedded layers of thin silty limestone and siltstone are frequent in the unit.

Salt was encountered in two drill holes (JR-3 and H1), apparently above the anhydrite unit (Boehner 1978a). The thickness and extent of the salt may be found in Boehner (1978b).

Conformably overlying the evaporites is a thick (150-350 m) sequence of intercalated green and red siltstone, anhydrite and gypsum, with minor shale and sandstone. Much of this succession is brecciated. The evaporites form the cement and veinlets in the silty material. Massive anhydrite forms occasional interbeds within this unit.

Conformably above and gradational from the intercalated unit is a sequence of green and red siltstone, shale and mudstone with minor gypsum stringers. This unit generally marks the top of the known stratigraphic succession. However, in one drill hole (AN-3) the unit is overlain by more intercalated siltstones and evaporites. This indicates a modification of a predominantly regressive environment, in the southernmost section of the map area.

B) Distribution

1- Introduction

The distribution of the described lithologies is given from field mapping of the Basement - Carboniferous contact and from 30 drill holes (locations Fig. V-1). The drilling was carried out by various mining companies during exploration for base metals and salt and for stratigraphic information (see Appendix III).

Simplified profiles showing cross sections of two representative areas of the structural basin are shown in Figs. V-2 and V-3. These profiles have been compiled and

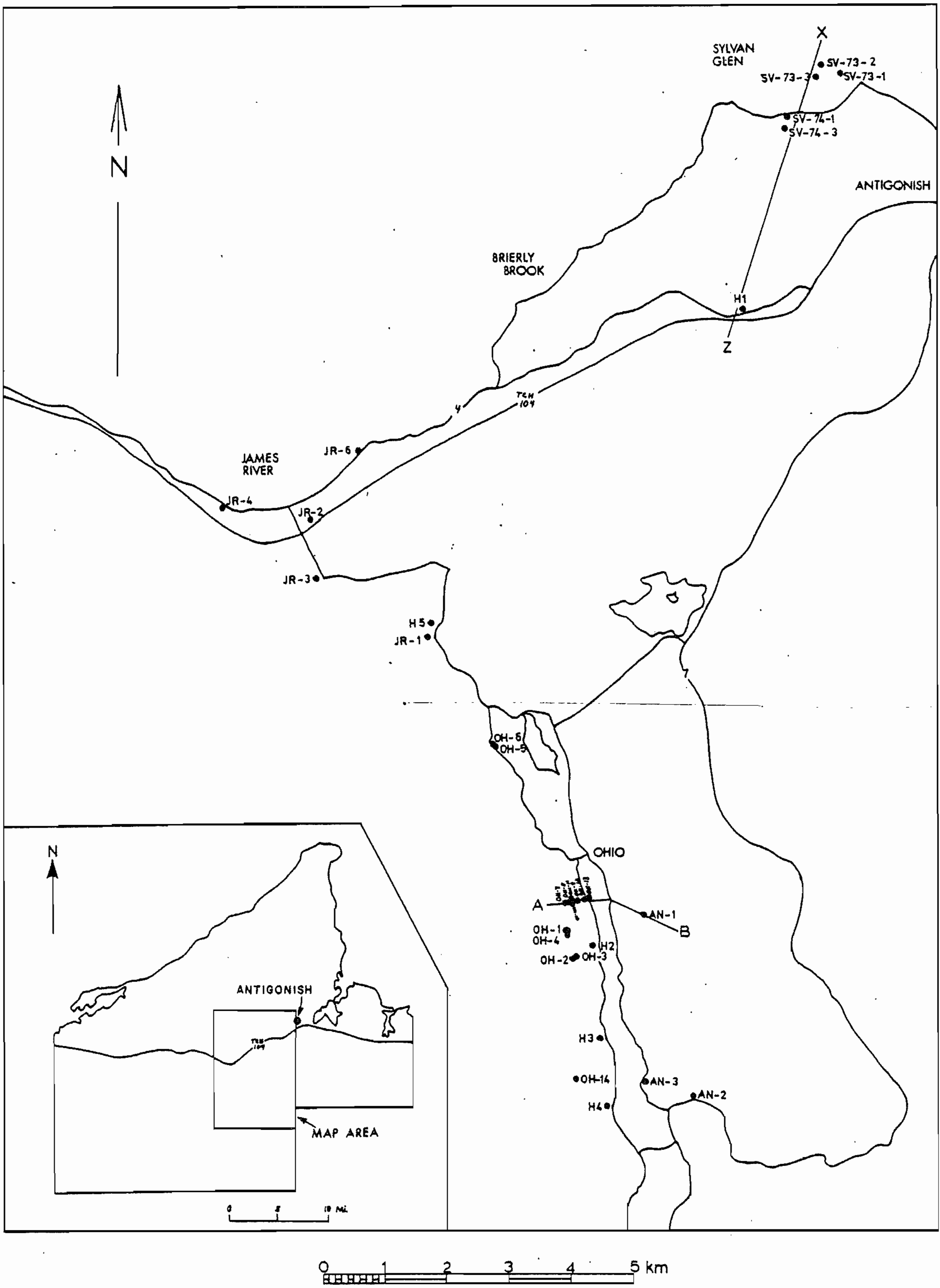


Figure V-1 Location of diamond drill holes and cross sections in the Ohio-Sylvan Glen Area.

simplified from drill logs (summarized graphically in Appendix III) in order to show the structural and stratigraphic relationships within the map area on the periphery of the structural basin. A very generalized model of the sedimentation history will be proposed in section III. Detailed models of sedimentation and sedimentary environments are beyond the scope of this thesis. The specific environments and processes operating in this area are controversial (Schenk 1967, 1969, Boehner 1978a, Boehner & Giles 1976, Kirkham 1978) with opposing views ranging from deep water to supratidal (sabkha lagoonal) deposition of the same units.

2- Surficial Distribution

The Cambro-Ordovician basement forms an arc-like ridge about the perimeter of the Carboniferous Basin (Map 3). The ridge is formed by rolling hills commonly reaching an elevation of 800 ft. The elevation of the basement-basin contact averages about 250 ft. Giles (1976) describes the Browns Mountain Group as forming a half-graben.

In the Southwestern section of the area from James River to Cross Roads Ohio, the ridge strikes approximately NNW, while in the Northeastern section from James River to Sylvan Glen the ridge strikes NE-SW. The ridge section within the map area has a total length of about 15 miles (24 km).

The basal Windsor breccia probably rests unconformably on basement in the South section of the area. On the west side of the Ohio River, from about 1 mile south of Ohio to St. Joseph, it forms a scree deposit along the ridge at approximately 250 feet elevation. It appears to be only a few feet thick in outcrop.

The Upper Horton conglomerate rests unconformably over the basement in the Northeast and Western sections of the area. It is found west of, and parallel to the road, between Sylvan Glen and James River (Map 3). It is also found just north of the northerly limit of the basal breccia at St. Joseph. It is postulated that the Horton follows the basement ridge in this area, and pinches out just north of St. Joseph (Map 3). The thickness of the conglomerate is also only a few feet.

The Lower Windsor carbonates rest conformably (to ?unconformably) on the Lower Breccia and the Upper Horton conglomerate and follow the same trend as the basement - breccia-conglomerate units. The carbonates may be found from Sylvan Glen to Cross Roads Ohio.

The Upper Windsor was not studied. However, its distribution will be discussed in the following section. Recent data concerning surfical mapping of the Upper Windsor may be found in Murray (1975), Boehner (1979), Benson (1974)

Figure V-2 Section X-Z, compiled from drill logs in the Sylvan Glen Area.

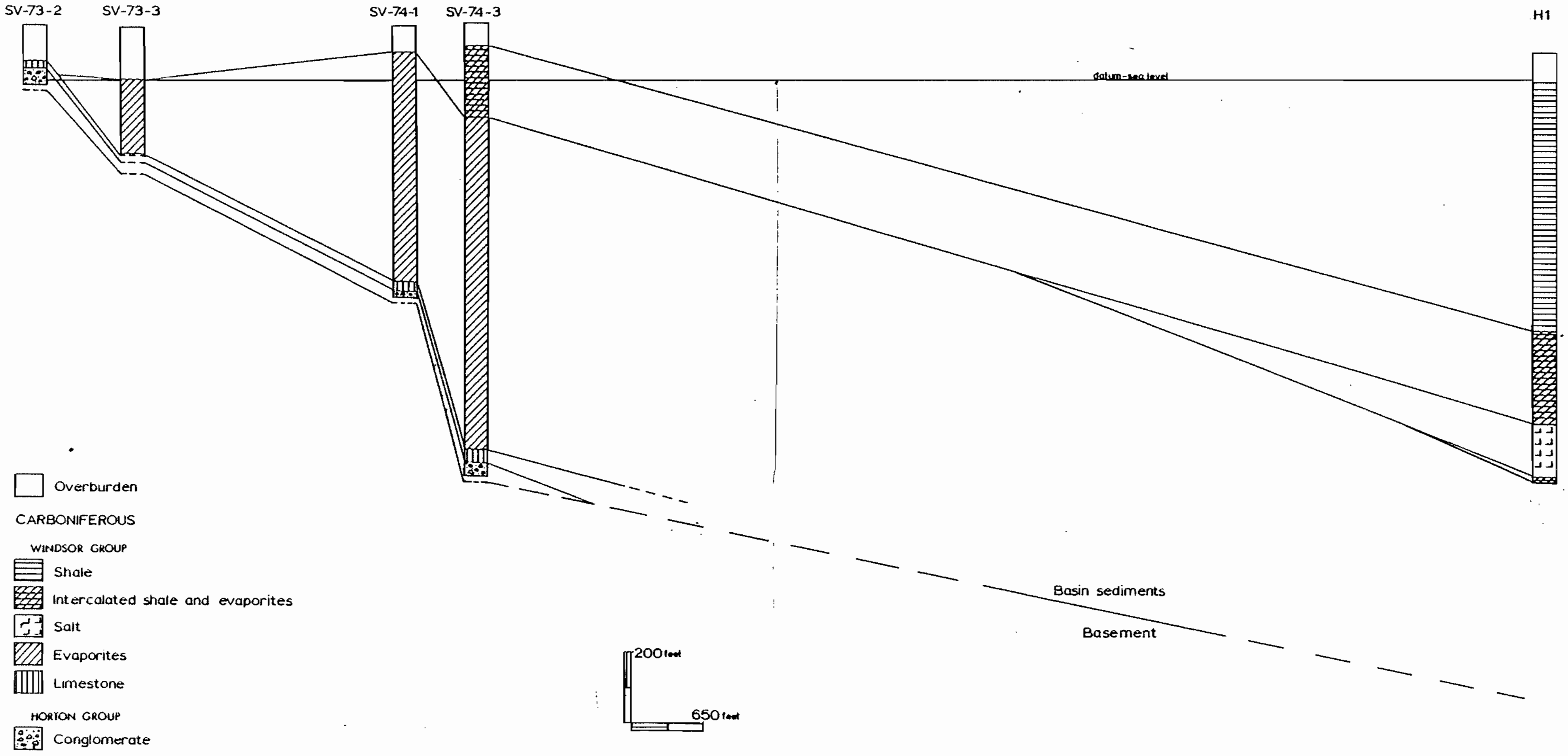
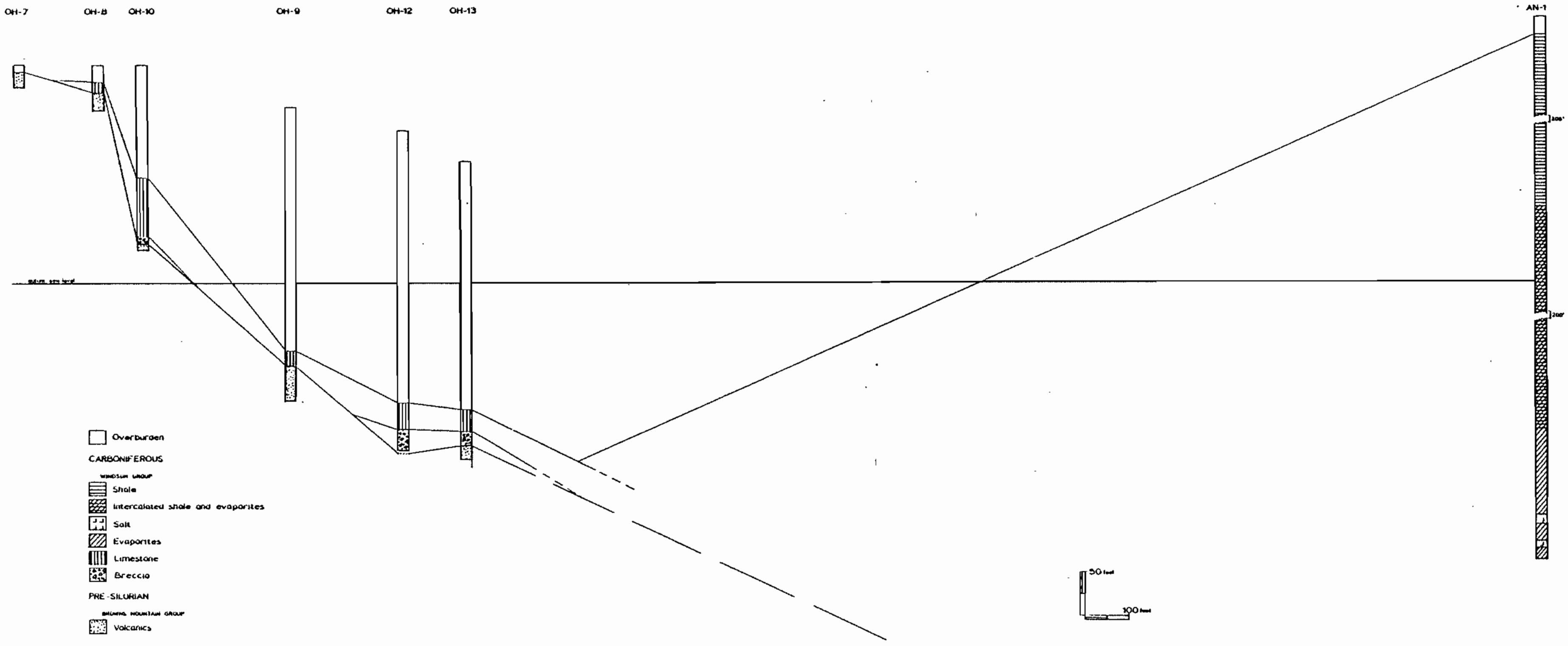

SV-73-2
SV-73-3
SV-74-1
SV-74-3
H1
datum-sea level
Basin sediments
Basement
200 feet
650 feet
Overburden
CARBONIFEROUS
WINDSOR GROUP
Shale
Intercalated shale and evaporites
Salt
Evaporites
Limestone
HORTON GROUP
Conglomerate

Figure V-3 Section A-B, compiled from drill logs in the Ohio Area.


OH-7
OH-8
OH-10
OH-9
OH-12
OH-13
AN-1
200'
200'
datum sea level
Overburden
CARBONIFEROUS
WINDSOR GROUP
Shale
Intercalated shale and evaporites
Salt
Evaporites
Limestone
Breccia
PRE-SILURIAN
BROWNS MOUNTAIN GROUP
Volcanics
50 feet
100 feet

and Sage (1954).

3- Distribution of Units from Drill Core Data

Locations of the diamond drill holes and cross sections are found on Fig. V-1 (see Appendix III for drill log compilation columns). From the drill core data, Boehner (1978) and Giles & Ryan (1975), it is possible to assemble a generalized stratigraphic column for the area (Fig. V-4).

a) Basement

(i) Southern Section

Good basement control was obtained in the Southwestern section of the map area. The drill core data are supported by the Nova Scotia Research Foundation Gravity Survey (1974).

The data show that the basement forms a series of terraces inclined towards the east (Fig. V-3). An initial slope of approximately 5° from present topography increases to 50° eastward towards the basin. This slope grades off to approximately 20° for about 700 feet before levelling off to at least horizontal if not a small negative (upwards towards the basin) slope. This 'negative' slope may indicate a basement high approximately 2,500 feet east of OH-7. Basement was not encountered in drilling nearly one mile

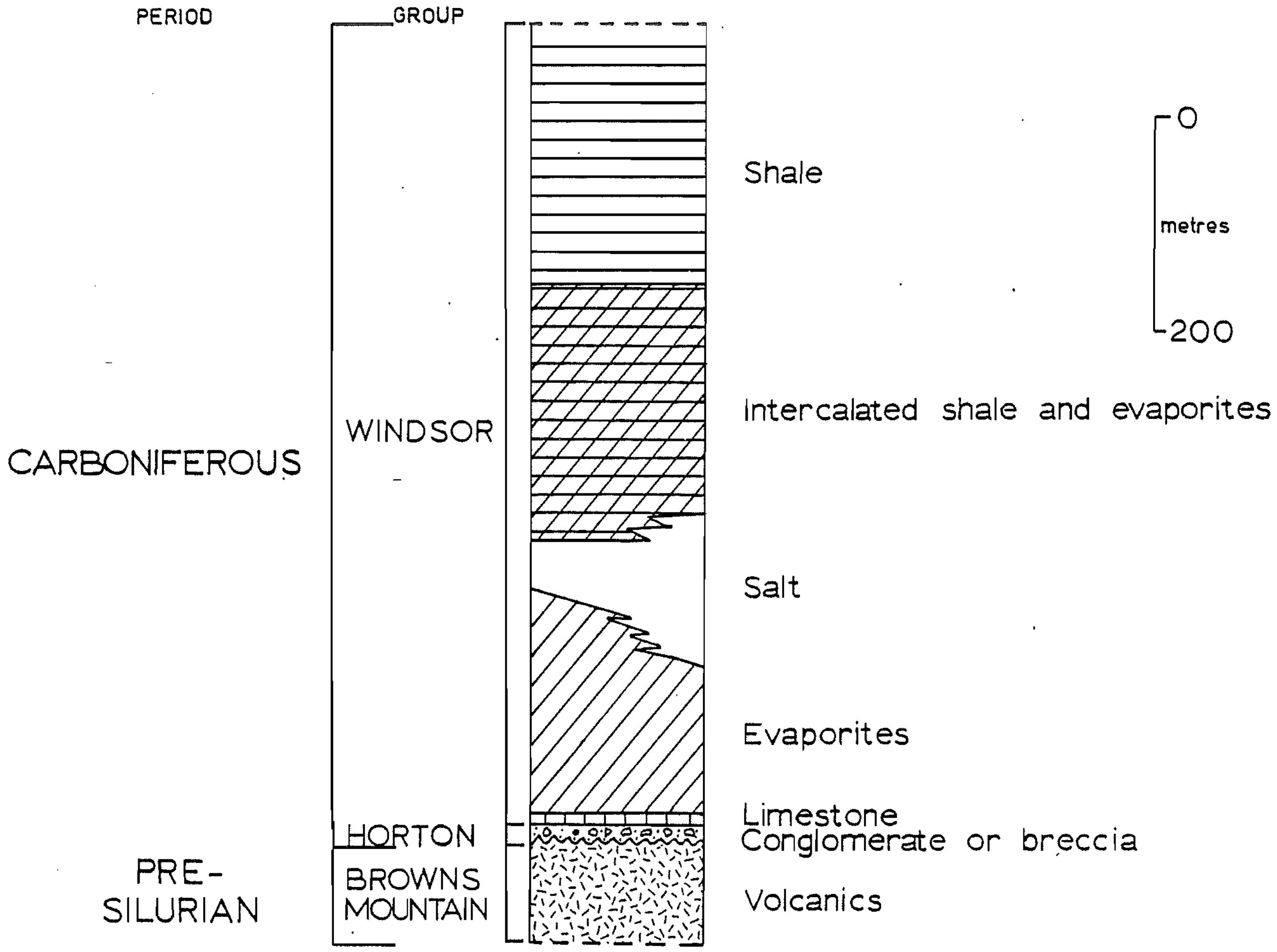


Figure V-4 Simplified stratigraphic column of the Ohio-Sylvan Glen Region (modified after Boehner 1978a).

east of OH-7.

The profile (A-B) shown in Fig. V-3 supports the view that this basin formed against a series of fault blocks of Browns Mountain basement (Giles 1976). NW-SE gravity profiles across the basin support this view.

Westward of the drill holes, the basement outcrops and rises steeply to an elevation of about 800 feet.

The only lateral variation in the basement is a small rise about 1 km south of Ohio. Otherwise, the basement is generally horizontal at any given elevation in the area. The profile A-B (Fig. V-3) is typical of the basin profile in the Southern section.

North of Ohio, towards St. Joseph the basement slopes downward at an unknown angle. The Browns Mountain ridge changes from nearly N-S to nearly E-W, forming a sharp arc in the outline of the basin (see Map 3). Basement was not encountered in any drill holes in the Western section of the area. Thick sequences of Upper Windsor are found here, showing an invasion of the basin westward into the indented basement.

(ii) Western and Northern Section

Cross section X-Z (Fig. V-2) shows a similar terrace-like profile to that of the Southern section, although the steeper sides are not as acute. Slopes very from approximately 10° to 20°. Gravity profiles near section X-Z show a fault-block pattern. North of drill hole SV-73-2, Browns Mountain volcanics outcrop, rising to an elevation of about 500 feet.

Laterally the basement rises slightly from Sylvan Glen to James River.

b) Breccia Unit

The breccia unit is found (only in the Southern section) lying unconformably on basement. Its relative position is typified by profile A-B (Fig. V-3). The breccia collects as a scree deposit at the base of the steep sides of the basement terraces although no breccia is found where the basement walls are too steep (>20°) for the terrestial debris to collect. Only a thin lens of breccia is found in OH-10A where both terrace-step walls are steep, while a fairly thick breccia accumulation occurs in OH-12 and 13 where the basement levels off. The breccia pinches out against the steeper walls.

Lateral variation of the breccia parallels that of the basement, except that the breccia pinches out in the southerly part of the section near Cross Roads Ohio. The breccia also pinches out north of Ohio, somewhere in the vicinity of St. Joseph.

c) Conglomerate Unit

The conglomerate unit is found in the most northerly part of the Southern section, and in the Western and Northern sections. It unconformably overlies the basement. It appears to be more continuous than the scree breccia, as shown in profile X-Z (Fig. V-2). It pinches out south of drill hole SV-74-3, and north of SV-73-2 where it abuts against the Browns Mountain ridge. Laterally, the unit appears to be continuous, following the basement. It is unknown whether or not the unit is continuous in the Western section, following the basement arc from James River to St. Joseph, as no drill holes penetrated conglomerate. However, indications of Horton in this area (Benson 1974, Boehner 1979) and just north of St. Joseph (this study) indicate the unit is probably continuous from James River to St. Joseph.

Thus the conglomerate forms a fairly continuous lens-like accumulation, pinching out against the basement to the north and west and pinching out in the basin to the south and east of this section.

d) Carbonate Unit

(i) Southern Section

Although the carbonate may be subdivided, its distribution can be treated in terms of a single unit since all subdivisions are conformable and sequential.

The carbonate forms a somewhat thicker layer (3-16 m) than the breccia. The limestones lie apparently conformably (to possibly unconformably in some areas) on the breccia unit and in many cases, onlap directly onto basement, where the breccia unit has not accumulated. It pinches out against the Browns Mountain ridge in the west. Its easterly extent is not known as drill holes have not penetrated it in the structural basin (see Fig. V-3).

The carbonate pinches out approximately 3 km south of Ohio. No carbonate is found in the vicinity of Cross Roads Ohio.

(ii) Western and Northern Sections

The carbonate in this area shows a fairly constant thickness of 7 m and occurs uniformly over the perimeter of the basin. It abuts against the outcropping Browns Mountain Group and pinches out southerly and easterly towards the basin.

The carbonate also shows uniform lateral continuity.

No lower carbonate was reached in drill core in the western indentation of the basin.

e) Upper Windsor Units

The Upper Windsor evaporites and siltstones are found in deeper areas of the structural basin. The general succession is: 1) evaporites approximately 200 m; 2) intercalated silt and evaporites approximately 170 m; 3) siltstones and shales approximately 130 m.

In some drill holes the evaporites lie concordantly (Boehner 1979) on the lower carbonate unit (Fig. V-2). Most holes, however, do not penetrate deep enough for stratigraphic information below the evaporite unit. The thick sequences of Upper Windsor all pinch out on the western and northern perimeter of the basin and only outcrop east of the Horton-Windsor contact (see Figs. V-2 & 3). If these sequences had overlain the exposed carbonates as they probably did, they have since been eroded. They now form a wedge which pinches out approximately 1,000 m, basinward of the Browns Mountain - Carboniferous contact. One salt lens was reached in the Western and Northeastern sections below the silty-evaporitic unit. It pinches out to the northeast and south. The salt probably conformably overlies the evaporite unit (see DDH-H-1, Appendix III).

Drill holes deeper in the basin (H-6) show the same stratigraphic succession of Upper Windsor lithologies. The Upper Windsor appears to thicken in the western indentation of the Browns Mountain. This is due to the deeper (more westerly) penetration of the Windsor seas allowed by the westerly oriented arc of the Browns Mountain basement in this area.

C) General Model of Sedimentation

The shape of the structural basin is determined by the block-faulted Browns Mountain Group (Fig. V-3). Bottommost in the stratigraphic succession and lying unconformably above this basement is a terriginously derived, alluvial fan deposit (Benson 1974). It consists of poorly sorted conglomerates and sharpstone conglomerate and/or breccia, belonging to the Upper Horton or Lower Windsor Group. This unit was deposited on basement steps only where their steepness was not too great for accumulation.

Initial transgression of the Windsor sea was probably very rapid, completely inundating the Upper Horton (Kirkham 1978) as indicated by the extremely sharp contact between the conglomerate and the laminated basal Windsor limestone (A_1). Whether this laminated unit was unique in time and thus a chrono-stratigraphic unit as Kirkham (1978) postulates, or was repeated throughout transgressive episodes as Schenk (1975) proposes, is not important to the environment of metal deposition as this would be the same in both cases. Both workers are in agreement that the laminated basal Windsor limestone is a shallow water (i.e. within the photic zone) deposit, unlike other interpretations which would have the carbonate deposited in much deeper water. Recent discovery of algal stromatolites in the A_1 limestone (Macumber) near Gays River (Schenk 1979, pers. comm.) conclusively shows a shallow water origin for the unit in this area. If, as Kirkham (1978) contends, the A_1 is a very widespread, single, thin, algal unit; then, all A_1 limestones would have been deposited in a shallow water environment. Giles (1976, 1977) shows good correlation of several Windsor lithologies in all Carboniferous basins of Nova Scotia. Although no conclusive evidence is available concerning the dark laminations in the A_1 limestones of the Antigonish Basin, various interpretations include algal origins (Schenk 1967). Pellets or, more properly, peloids in the laminated limestone (in Antigonish) may be digested lime mud from mud eating organisms (Friedman and Sanders 1978) or possibly small fragments of re-worked algal material (Binney 1975) since some dark strands of the laminations surround and merge with the peloid strands. Although non-organic origins of the peloids is also possible (Friedman and Sanders 1978) the visual resemblance to organic peloids is much more striking. The dark strands in the laminations and peloids resemble the strands constituting small algal stromatolites.

Inundation of the 'Horton' conglomerates caused the upper part of the unit to become cemented by carbonate material. The upper conglomerate was probably unconsolidated to some extent and it is likely that the Windsor transgression occurred immediately after or during deposition of the conglomerate, before terrestial cementation processes could lithify the unit. Contemporaneous deposition of the sharpstone conglomerate with brief incursions of the ?Windsor sea is indicated in one area (see Appendix I, Ohio - MacLean Area) by the presence of small limestone units interbedded within the sharpstone unit. This would indicate an influx of marine waters prior to the postulated flooding of the basin by the Windsor sea (Kirkham 1978) and sudden deposition of carbonates on top of the conglomerate.

The green colouration of the upper conglomerate is probably due to reduction of iron in a reducing (low Eh) environment produced by the decay of organic material (algal?). Furthermore, since the lower part of the conglomerate contains little or no carbonate (this study and Binney 1975) and is red (oxidized) in colour, it was probably deposited and cemented before the onset of Windsor transgression.

Restriction of the basin, possibly be reefal development (Kirkham 1978) on basement highs postulated from magnetic data, caused the Windsor sea to become highly saline and to precipitate large quantities of sulfate and minor salt. Normal marine organisms (brachiopods and gastropods) found in the upper parts of the lower limestone could no longer survive. The high rate of evaporation which probably accompanied this process may have been associated with the eventual development of a sabkha environment, if the margins of the basin were very flat. However, Kirkham (1978) contends that the evaporites were deposited below sea level due to the enormously high salinity of the water. Schenk (pers. comm.) and others (see drill logs, Appendix III) believes at least some of the sulfate is a replacement of carbonate. The evaporites may have been related to an evaporite pan (Renfro 1974).

The evaporite unit marked the end of the rapid transgression of the Windsor sea and the close of the deposition of the lower carbonate. At this time, during a predominantly regressive period, cyclic fluctuations of the Windsor sea deposited thin carbonate beds among the red beds higher in the stratigraphic column. Shoreward of this environment, influxes of limited quantities of sea water coupled with continuous terrestial sedimentation onto a sabkha or lagoonal environment, deposited the thick sequence of intercalated silt, evaporites, sand and clay. The intercalated sequence contains interbedded silt and evaporites as well as networks of evaporite-filled fractures and/or nodules in the silt. This is a typical sabkha sequence (Renfro 1974, Friedman and Sanders 1978) and probably marks the evolution of an evaporite pan into a sabkha. If the A_1 limestone is indeed algal in this area, burial beneath the sulfate rich sediments provides an ideal environment for sulfate reducing bacteria and the production of hydrogen sulfide (Zajic 1969 in Renfro 1974).

Finally, a complete regression of the Windsor seas provided an environment for the deposition of thick sequences of red and grey, terrestrial silt and mud.

III MINERALIZATION

A) DETAILED MINERALOGICAL DESCRIPTION

1- Cross Roads Ohio Area

a) Lapilli Tuff Unit

Mineralization consists predominantly of chalcopyrite, with minor pyrite and traces of covellite. Fine to coarse grains of hematite and minor magnetite are disseminated throughout the tuff fragments (Plate V-1a).

Fine-grained, anhedral to subhedral chalcopyrite grains are disseminated in trace amounts throughout the tuff. Anhedral to subhedral, fine to medium grained pyrite grains in quantities of about 1%, are also disseminated throughout the tuff. In many cases, both chalcopyrite and pyrite appear to replace large phenocrysts.

The bulk of the chalcopyrite-pyrite mineralization occurs as (1 mm to 2 cm) discontinuous veinlets and blebs along fractures in the host rock and is also associated with large calcite veins (see Appendix I for geology of occurrence). The chalcopyrite - host boundary is irregular but fairly sharp with only a thin (0.03 mm) iron oxide layer forming around the chalcopyrite. These chalcopyrite grains, ranging from <0.5 cm to 2 cm +, are anhedral to subhedral and have extensively corroded grain boundaries. Thin iron oxide and/or covellite bands form around nearly all the chalcopyrite grains which form a brecciated (Schwartz 1951) texture (Plate V-1b). Secondary iron oxide banding is a common oxidation feature of iron containing sulfide (Ramdohr 1969).

Fractures (0.02-0.05 mm) infilled with rhythymic bands of iron oxide(s), and minor covellite and malachite, form an irregular network pattern throughout the chalcopyrite. No offsets along the intersection of fractures occur, indicating contemporaneous infilling of iron oxide (Park and MacDiarmid 1970) (Plate V-1c). Iron oxide also forms bands of large (0.1 mm) concentrically zoned blebs in chalcopyrite (Plate V-1b). Covellite often forms a thin layer adjacent to the chalcopyrite grains in the iron oxide fracture fillings. Malachite forms a radiating texture in open spaces, adjacent to the iron oxide bands in the chalcopyrite (Plate V-1e, f).

Traces of tiny (0.01-0.05 mm) anhedral blebs of galena with sharp boundaries are found in the chalcopyrite. The paragenesis of this assemblage cannot be ascertained with confidence.

Pyrite forms small to large (0.02-0.33 mm), euhedral to anhedral idiomorphs within the chalcopyrite and iron oxide layers. Euhedral crystals consist of cubes and pyritohedrons and are almost exclusively found within the

Plate V-1

a Hematite (white) disseminated throughout tuff (grey).

b Iron oxide with minor covellite bands filling fractures in chalcopyrite.

Plate V-1

c Network of iron oxide - covellite filled fractures (dark grey) in chalcopyrite (light grey). Absence of offsetting indicates contemporaneous fracture filling.

d Euhedral to subhedral pyrite (white) in chalcopyrite. Pyrite mainly corroded in iron oxide.

Plate V-1

e Malachite (dark grey) replacing open spaces in chalcopyrite (white) reflected light. Iron oxide (medium grey) borders chalcopyrite and malachite.

f Same Plate V-1e in transmitted light.

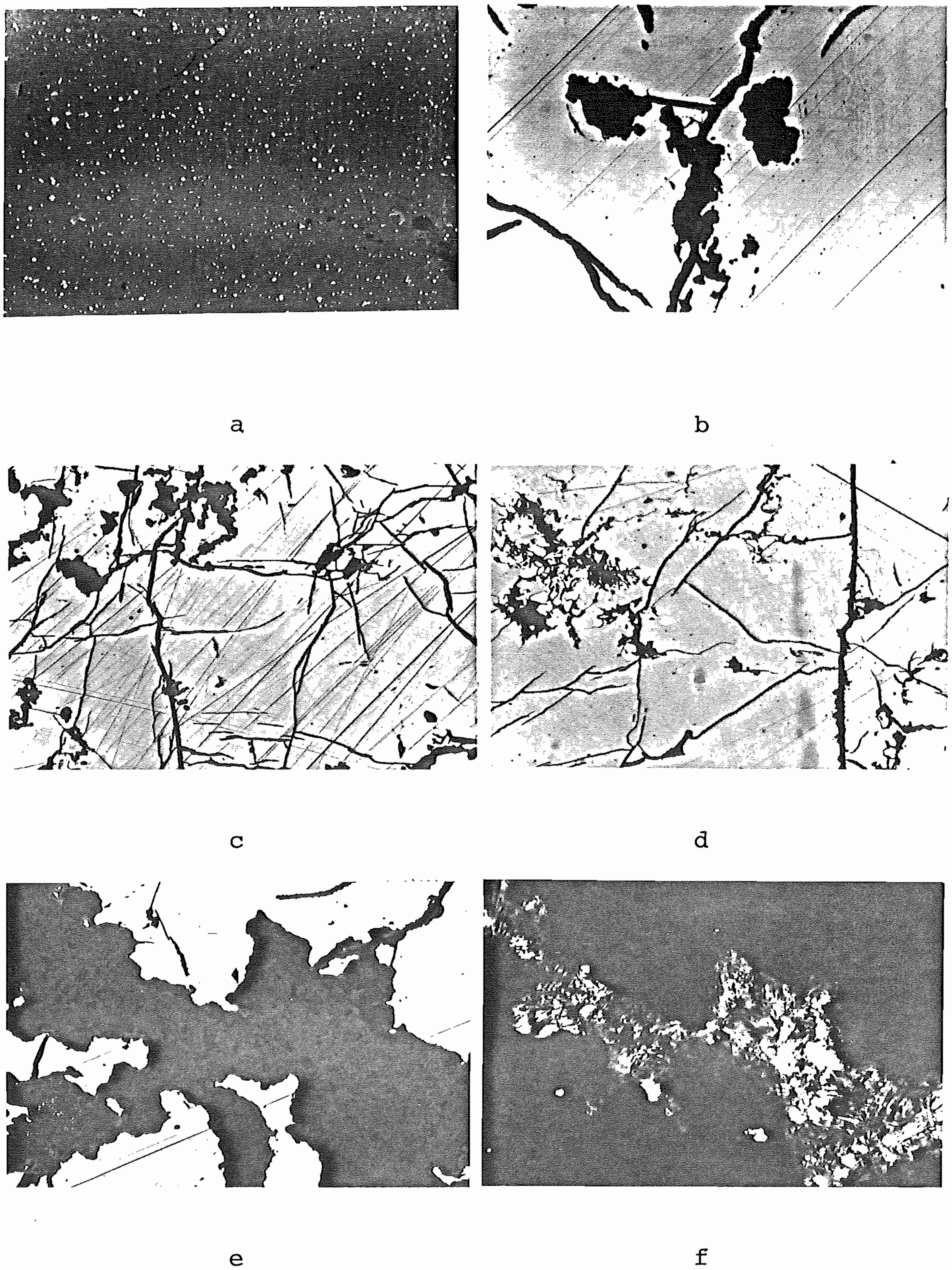


Plate V-1 Cross Roads Ohio Area

1mm

Scale unless otherwise
indicated

chalcopyrite. Grain boundaries are extremely sharp and no oxidation products are evident. Pyrite in iron oxide fillings is anhedral to subhedral with very corroded grain boundaries. Indivicual pyrite crystals imbedded within both hosts show sharp crystal faces within the chalcopyrite and corroded edges where they extend into an iron oxide layer (Plate V-2a).

Iron oxide-filled fractures commonly deflect and become displaced around pyrite crystals indicating that pyrite is pre-fracture filling (Plate V-2a).

Pyritohedrons are also found in gangue-filled open spaces in the chalcopyrite (Plate V-2b). In a very few cases chalcopyrite appears to replace pyrite (Plate V-2c, d). These relationships suggest an ambiguous paragenesis although some conclusions may be drawn from them.

Iron oxide fills fractures in both the pyrite and chalcopyrite. If the iron oxide infilling occurred soon after precipitation of chalcopyrite, it is unlikely that pyrite would be replacing chalcopyrite for it would then exist as euhedral crystals in the iron oxide as it does in the chalcopyrite. If, however, the iron oxide filled post-deformational fractures at a time after pyrite precipitation, then no conclusions of pyrite-chalcopyrite paragenesis could be surmized, and pyrite may conceivably have replaced the chalcopyrite.

Plate V-2

a Pyrite (light grey) idiomorphically developed in chalcopyrite (medium grey) and corroded in iron oxide areas (dark grey). Defelction of fracture around pyrite shows pyrite is pre-fracture filling.

b Pyritohedrons (white) in gangue filled open spaces (dark grey) in chalcopyrite (light grey).

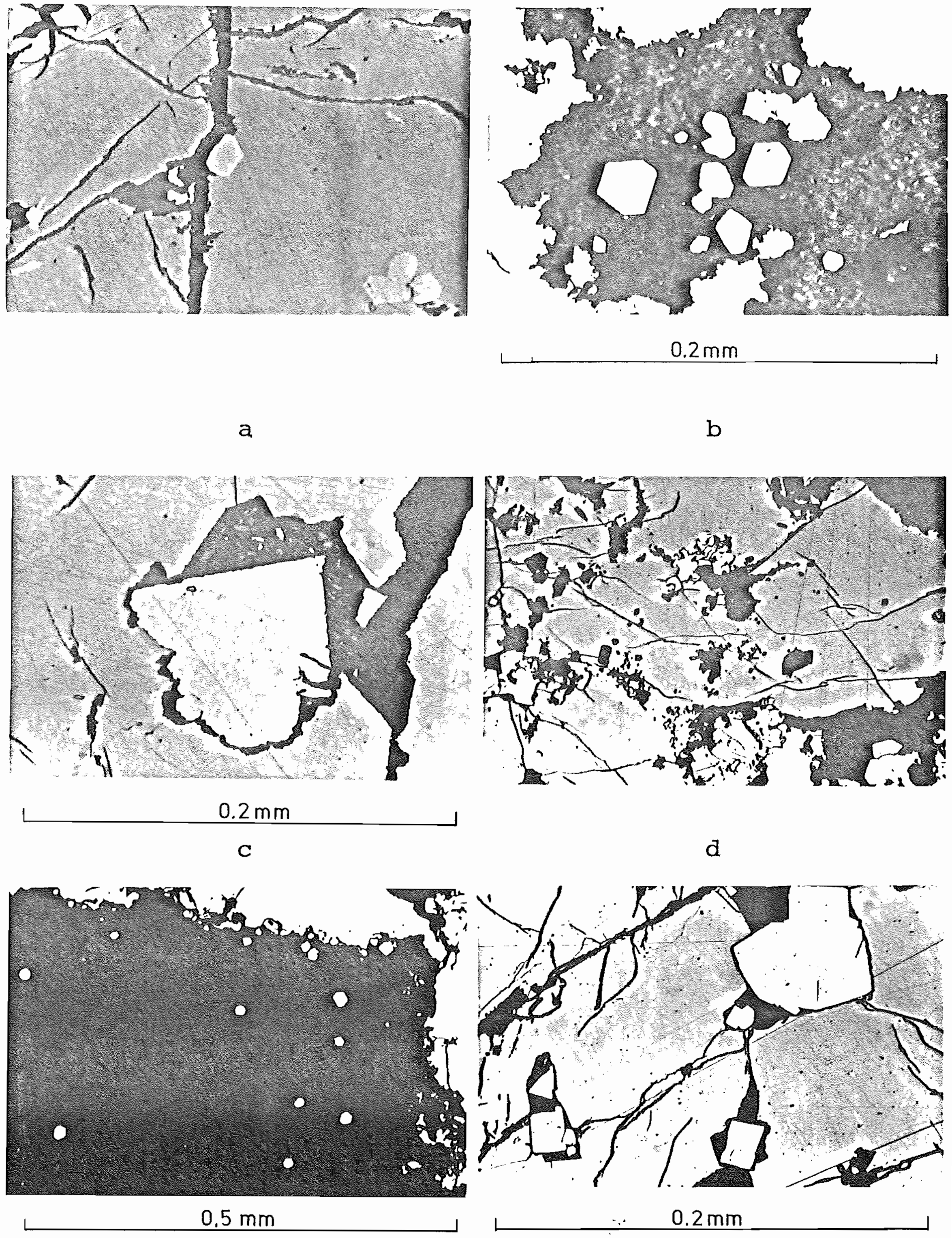
Plate V-2

c & d Replacement of pyrite (light grey) by chalcopyrite (medium grey). Pyrite in gangue (dark grey) is unreplaced. (Medium grey grains in gangue are silicon carbide grit).

Plate V-2

e Unreplaced pyritohedrons in gangue.

f Pyrite (light grey) corroded on chalcopyrite (darker grey) contact. Pyrite edges sharper in gangue.



a b

c d

e f

Plate V-2 Cross Roads Ohio Area

1 mm Scale unless otherwise indicated

Plate V-3

a Replacement of altered phenocryst by pyrite and hematite.

Plate V-3

b Partially replaced and brecciated, anisotropic, pyrite crystal.

Plate V-3

c Iron oxide (medium grey) pseudomorph after pyrite; in chalcopyrite (light grey).

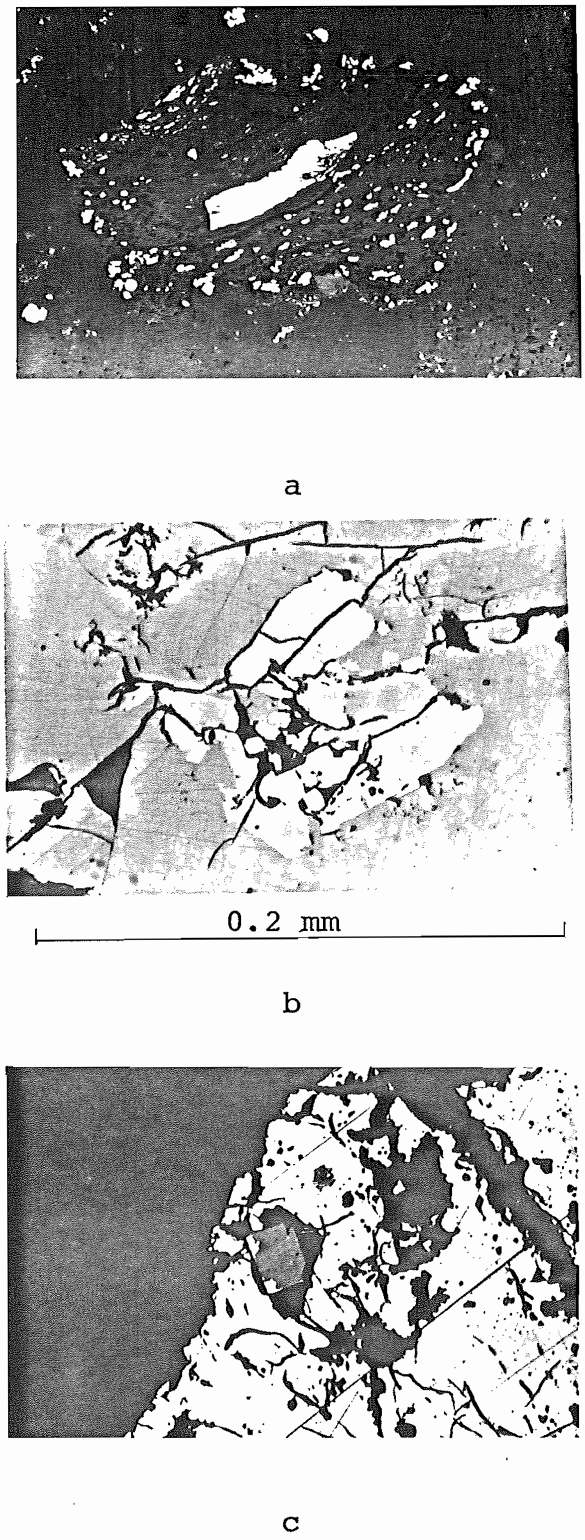


Plate V-3 Cross Roads Ohio Area

1mm Scale unless otherwise indicated

Furthermore, since pyrite will form idiomorphically in chalcopyrite, regardless of its age relationship (Ramdohr 1969), no conclusive paragenesis may be drawn from the above information. However, from the few examples of chalcopyrite replacing pyrite and the presence of much pyrite in the essentially chalcopyrite-free tuff, it can be seen that pyrite was available for replacement when the mineralizing fluids penetrated the host. Therefore, the pyrite was likely to have been replaced by chalcopyrite to some extent. Original replacement textures may have been masked by subsequent burial and remobilization of sulfides. Replacement of chalcopyrite by pyrite is less probable.

2- Ohio - MacLean Area

a) Breccia Unit (Lower)

Mineralization in this unit consists of chalcopyrite, pyrite, sphalerite and minor galena, covellite and malachite.

Euhedral to anhedral, 0.01-0.03 mm, grains of pyrite are disseminated in quantities up to 2% throughout the volcanic fragments. Traces of sphalerite are disseminated throughout the volcanic fragments.

The bulk of the mineralization is chalcopyrite (5-20%) with pyrite making up approximately five percent of the total assemblage. The large (2-10 mm) anhedral chalcopyrite grains fill voids between the volcanic fragments. No carbonate matrix is present in the slides studied although minor amounts may be present (see geology, Appendix I). The chalcopyrite-volcanic fragment boundaries are very irregular with an opaque layer forming a thin (0.02 mm) 'reaction rim' around the chalcopyrite (Plate V-4a). Irregular grain boundaries with a somewhat thicker (0.05-0.1 mm) opaque iron oxide rim extend into open areas.

An irregular network pattern of thin (<<0.01 mm) light grey, semi-transparent iron oxide and/or covellite-filled fractures occur extensively throughout the chalcopyrite. Covellite forms adjacent to the chalcopyrite. Minor malachite forms radiating grains in open spaces adjacent to iron oxide surrounding the chalcopyrite. Contemporaneous infilling of all iron oxide-filled fractures is indicated by the non-offsetting nature of intersecting fractures. These fractures do not extend into pyrite grains associated with the chalcopyrite, and often deflect around the pyrite (Plate V-4b).

Trace amounts of tiny (0.01-0.02 mm) anhedral blebs of galena and small (0.02-0.05 mm) anhedral to subhedral blebs of sphalerite, both with sharp boundaries are found displaying mutual boundary relationships in the chalcopyrite (Plate V-4c).

Pyrite forms euhdral to anhedral, 0.02-0.2 mm, grains associated mainly with chalcopyrite grain boundaries and gangue adjacent to chalcopyrite. Pyrite in the gangue is predominantly euhedral to subhedral. The bulk of the pyrite associated with chalcopyrite does not extend beyond the opaque iron oxide rim of the chalcopyrite (Plate V-4d). Very few pyrite grains are found in the interior of the chalcopyrite. A few pyrite grains found within the chalcopyrite show sharp subhedral grain boundaries. The pyrite found on grain boundaries is mainly anhedral and shows probable corrosion (replacement?) by the chalcopyrite and/or light-grey iron oxide rim (Plate V-4e, f).

A light-grey, banded, semi-transparent iron oxide rim is usually associated with the pyrite embedded in the chalcopyrite.

Pyrite embedded partially in chalcopyrite and partially outside the chalcopyrite grain boundary quite commonly shows intact crystal faces outside the chalcopyrite and corroded boundaries in the grey iron oxide bands surrounding the chalcopyrite (Plate V-4e). This same texture is found in pyrite embedded partially in chalcopyrite and partially in open spaces (Plate V-4f). These textures would appear to indicate pyrite replacement by chalcopyrite; the pyrite on the chalcopyrite grain boundaries representing only partially replaced crystals.

Plate V-4

a Highly irregular chalcopyrite (medium grey) - volcanic fragment (black) boundary. Partial replacement of pyrite (light grey) by chalcopyrite.

b Iron oxide filled fractures (dark grey) in chalcopyrite (medium grey) do not extend into pyrite (light grey).

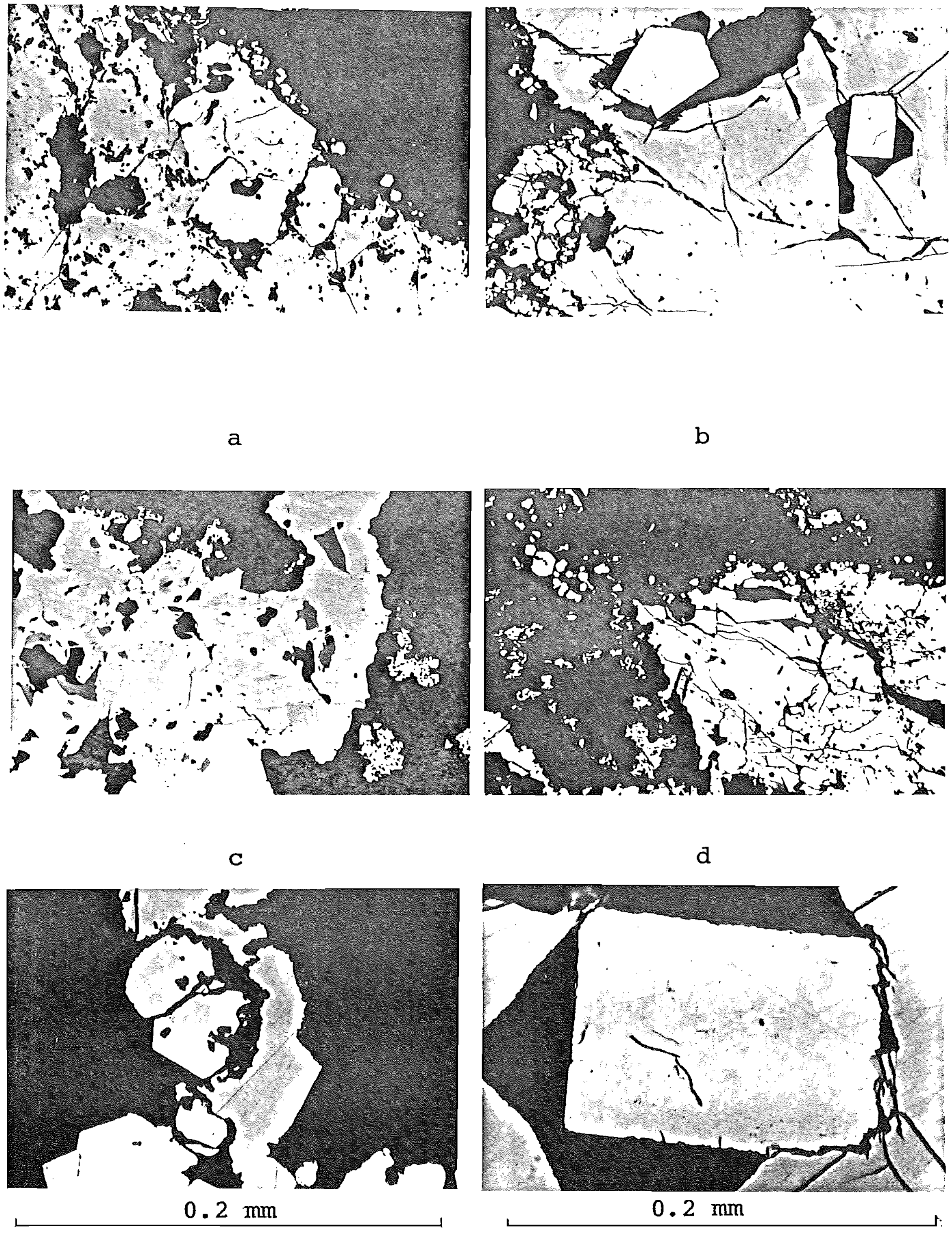
Plate V-4

c Sphalerite (medium grey) blebs within chalcopyrite (light grey). Gangue and oxidation products dark grey.

d Partially replaced pyrite (white) is found along the iron oxide rim of chalcopyrite (light grey). Pyrite euhedra are found in the gangue (black).

Plate V-4

e Pyrite (white) euhedra partially replaced by chalcopyrite
& (light grey).
f



e f

Plate V-4 Ohio - MacLean Area

1 mm Scale unless otherwise indicated

b) Breccia Unit (Upper)

The great bulk of the mineralization in this upper part of the unit consists of chalcopyrite (5-10%) with minor pyrite (1%), sphalerite (<1%), galena (<<1%), malachite and traces of covellite.

Anhedral pyrite grains are sparsely disseminated in some volcanic fragments. However, chalcopyrite, pyrite and sphalerite mineralization is contained almost wholly within the carbonate matrix (Plate V-5a, b), the granulated (mylonitized?) detrital volcanic material plus carbonate and in fractures in the fragments (Plate V-5c, d, e). In larger carbonate matrix areas, the mineralization tends to be found near the carbonate-fragment boundaries, while the interior of the carbonate contains very sparse mineralization (Plate V-5f, 6a).

Chalcopyrite constitutes approximately 90% of the sulfides. It occurs as anhedral, fine to coarse (0.01-2 mm+) grains. Grain boundaries are irregular, varying from sharp to highly corroded and display mutual boundary relationships (granule texture) with carbonate gangue material (Plate V-5b).

Grains are generally solid with little evidence of fracturing and/or iron oxide infilling. Chalcopyrite commonly shows growth about quartz grains or some of the

Plate V-5

a & b Typical chalcopyrite dissemination in matrix of breccia unit. (Ohio, MacLean Area). Lighter medium grey grains in 'b' are sphalerite.

Plate V-5

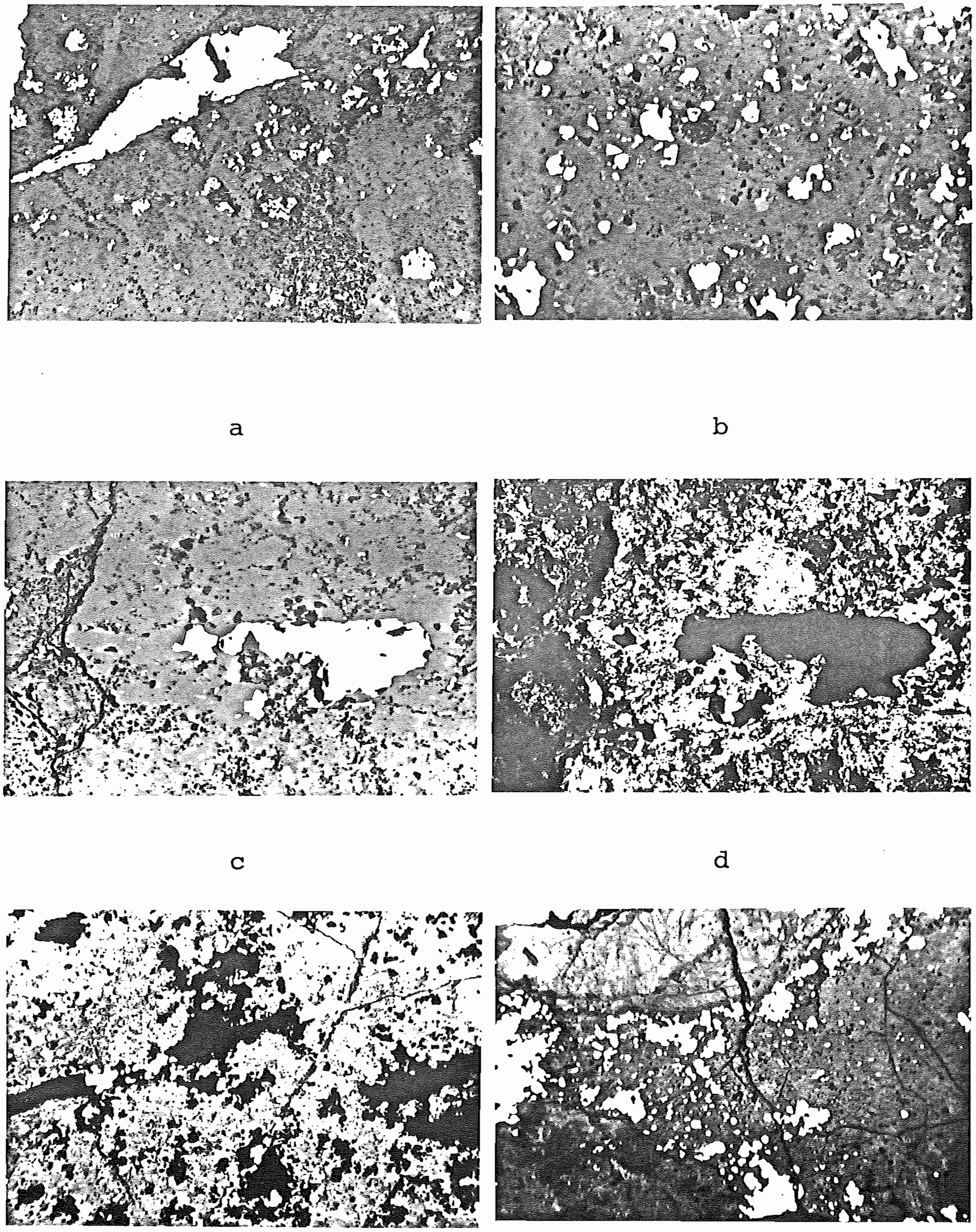
c Chalcopyrite (white) following fracture in volcanic fragment.

d Transmitted light of Plate V-5c. Healed fracture left of chalcopyrite (black).

Plate V-5

e Chalcopyrite (white) along fractures in volcanic fragments.

f Chalcopyrite (white) in carbonate, concentrated along fragment - (top and bottom left) matrix (middle and right) boundary.



a

b

c

d

e

f

Plate V-5 Ohio - MacLean Area

1 mm Scale unless otherwise indicated

Plate V-6

a Chalcopyrite (white) in carbonate (centre). Mineralization concentrates on matrix - fragment (left and right) boundary. Medium grey in fragment on right is hematite.

b Transmitted light shows fragments and calcite matrix.

Plate V-6

c Chalcopyrite (white) growth about a volcanic fragment.

d Oxidation products (medium grey) mainly iron oxide, rim chalcopyrite (white).

Plage V-6

e Brecciated pyrite (white) mass partially replaced by iron oxide (medium grey) network.

f Pyrite (white) crystals almost completely replaced by iron oxide (medium grey). Medium grey grains (bottom right) are detrital sphene or zircon.

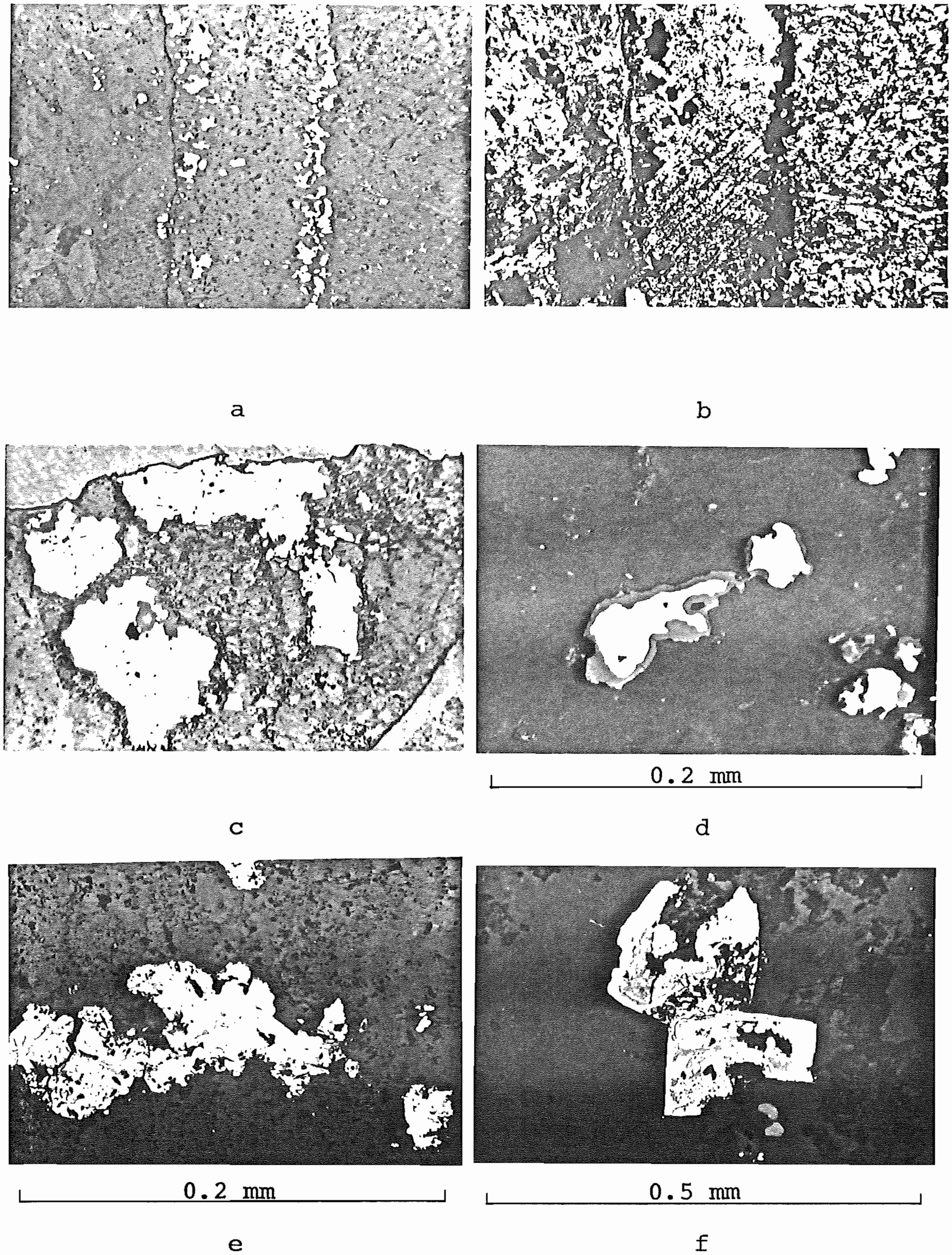


Plate V-6 Ohio - MacLean Area

1 mm Scale unless otherwise indicated

more impermeable volcanic fragments (Plate V-6c). The presence of chalcopyrite in volcanic fragments is associated with fracturing and/or alteration of the fragments. Chalcopyrite is often wholly or partially rimmed by variable widths of opaque oxidation products (Plate V-6d).

Pyrite makes up only about one percent of the total sulfide content. It occurs as subhedral to anhedral, 0.03-0.2 mm, grains and pseudo-cubes in some volcanic fragments and is also associated with chalcopyrite. Pyrite generally shows a brecciated texture within an iron oxide mass (Plate V-6e, f). Chalcopyrite commonly fills some of the large fractures in the pyrite regardless of whether the pyrite is discrete or found within larger chalcopyrite grains (Plate V-7c). Infilling of brecciated pyrite is a commonly encountered ore texture (Ramdohr 1969). Replacement of brecciated pyrite cubes, sometimes along crystallographic directions, is quite common (Plate V-7a, b, c). Thus, evidence of chalcopyrite replacement of pyrite is well defined.

Sphalerite, which has been identified by electron microprobe analysis, is very low in iron content (up to 1% Fe). Because of the abundance of rutile and/or anatase in volcanic fragments and as detrital material, identification of sphalerite was sometimes difficult. Fairly good parameters on sphalerite distribution have been delineated as a result of the microprobe program. Sphalerite occurs discretely as anhedral to subhedral, 0.01-0.05 mm grains associated with chalcopyrite rich areas. It displays mutual boundary texture as anhedral to subhedral, 0.02-0.1 mm, solid blebs contained wholly within the chalcopyrite (Plate V-5b). Adjacent growth of similar sized grains also displays mutual boundary relationships. Thus, no conclusions can be drawn on the paragenesis of this assemblage.

Minor amounts of galena (<<1%) are found mainly as discrete, subhedral to anhedral, 0.02-0.1 mm grains. Rare galena-sphalerite and galena-chalcopyrite mutual boundary intergrowths are found only in the carbonate matrix (Plate V-7d).

Traces of malachite are found in the opaque oxidation products surrounding chalcopyrite.

Confinement of sulfides to the carbonate rich matrix and their growth around volcanic fragments indicates contemporaneous precipitation with deposition, or possibly subsequent selective replacement of carbonate. The tendency of sulfides to collect near carbonate-fragment grain boundaries may indicate sulfide precipitation early in a carbonate deposition, or remobilization of sulfides to these areas during diagenesis. No conclusions beyond these can be drawn from the evidence found.

c) Summary

The resemblance of the mineralization and the host rock of the lower breccia unit with those of Cross Roads Ohio suggest a similar paragenesis. In one case the host is sheared into fragments; in the other, the host makes up fragments in a breccia scree. These similarities provide evidence that the Cross Roads Ohio area is indeed associated with the mineralization of the Lower Windsor, even though it is contained wholly within basement volcanics. This shows limited lateral continuity of mineralization in the Lower Windsor. Cross Roads Ohio may represent Lower Windsor mineralization in sheared basement rocks once covered by Lower Windsor lithologies.

The dissimilarity of the lower breccia unit with the upper breccia unit indicates a vertical change in mineralization in the Lower Windsor lithologies.

d) Interbreccia Limestone Sub-Units

The main mineralization in these sub-units consists of pyrite (1%), minor sphalerite (<1%), chalcopyrite (<1%) and traces of galena.

The mineralization is disseminated throughout the limestone matrix and associated with carbonate-filled fractures within detrital grains and fragments.

The bulk of the pyrite occurs as 0.01-0.03 mm framboids in various stages of oxidation (Plate V-7f). Some of the rounded pyrite framboids are nearly solid with only a thin network of iron oxide. Others are pseudospheres made up of tiny grains (<0.01 mm) of pyrite set in a rounded matrix of iron oxide. Aggregates of the framboids may attain 0.2 mm in size. However, a fair abundance of pyrite occurs as subhedral to anhedral, 0.01-0.03 mm, solid to brecciated and usually discrete grains. Some chalcopyrite infilling of the pyrite fractures is evident. Chalcopyrite and pyrite, whether discrete or intergrown, are set in large masses of opaque to semi-translucent iron oxide.

Chalcopyrite usually occurs as 0.02-0.1 mm, discrete anhedral grains but sometimes shows mutual boundary intergrowth with small, 0.03 mm, sphalerite grains. The sphalerite occurs as smaller blebs within the chalcopyrite, and as equal grain size "one common boundary" intergrowths. Sphalerite, 0.02-0.05 mm, also occurs discretely and in rare mutual boundary intergrowth with galena (Plate V-8b). Traces of subhedral to anhedral, 0.02-0.05 mm, discrete grains of galena sometimes show growth around detrital quartz clasts (Plate V-7e).

Although the relative paragenesis of the chalcopyrite,

Plate V-7

a & b Nearly complete replacement of pyrite (white) by chalcopyrite (light grey). Relict pyrite cubes remain.

Plate V-7

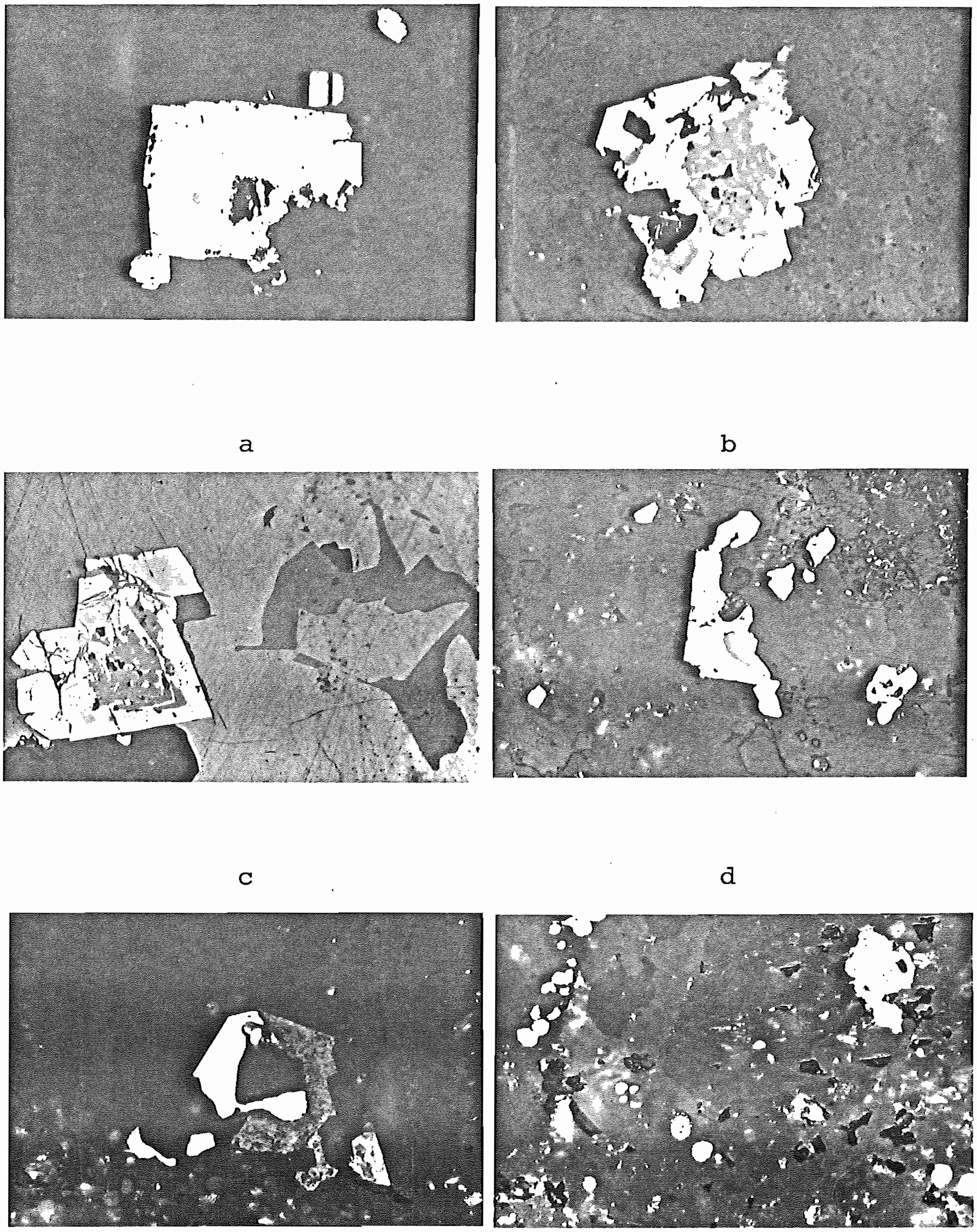
c Replacement of pyrite (white) by chalcopyrite (medium grey) along fractures and crystallographic directions. Darker grey blebs to the right displaying mutual boundary relationships with host, are sphalerite. Predominantly medium grey host of pyrite and sphalerite is chalcopyrite.

d Galena (white), sphalerite (medium grey at top left of galena) and chalcopyrite (medium grey at bottom of galena) intergrowth.

Plate V-7

e Galena (white) growth about a detrital quartz grain.

f Framboidal pyrite (white) in iron oxide masses (medium grey) in limestone units.



a

b

c

d

e

f

Plate V-7 Ohio - MacLean Area

0.2 mm Scale unless otherwise indicated

sphalerite and galena cannot be determined, the evidence suggests the probable replacement of pyrite and/or iron oxide by chalcopyrite.

e) Limestone Unit

The limestone unit is very sparsely mineralized with <1% pyrite and traces of chalcopyrite, sphalerite and rare galena.

Pyrite occurs as 0.02-0.2 mm brecciated crystals, with interfitting fragments set in an iron oxide matrix which in some cases is pseudomorphic after the former pyrite crystals. These are obviously relict pyrite crystals "replaced" by iron oxide. One case of a small calcite vein truncates a pyrite-iron oxide grain.

Chalcopyrite is usually discrete, forming 0.01-0.5 mm, anhedral grains often rimmed by iron oxide. Mutual boundary intergrowths with sphalerite are not uncommon. Discrete 0.03 mm, anhedral sphalerite grains are present in trace amounts. A 0.85 mm, mutual boundary intergrowth of sphalerite, galena and chalcopyrite is shown in Plate V-7d. Rare, discrete, 0.07 mm, anhedral grains of galena occur in the limestone.

No pyrite-chalcopyrite intergrowths were observed, possibly because of the minute amount of sulfides present. The rare chalcopyrite-sphalerite ± galena intergrowths offers no evidence of paragenesis.

f) Shear Zone

Mineralization is sparse in the shear zone and consists of pyrite (1%), chalcopyrite (<1%), and traces of bornite.

Pyrite is generally discrete, forming 0.02-0.1 mm, euhedral to anhedral grains. Some pyrite forms a brecciated texture with infillings of chalcopyrite and/or iron oxides (Plate V-6e). Chalcopyrite is also found replacing mostly intact, subhedral pyrite crystals and forms both solid and veined textures (Schwartz 1951) (Plate V-8a). Chalcopyrite is in some cases rimmed by a thin (0.01 mm) halo of bornite or chalcocite (Plate V-8a).

Chalcopyrite is also found as discrete, 0.03-0.1 mm, anhedral grains disseminated throughout the carbonate matrix. Chalcopyrite and pyrite are found predominantly within iron oxide masses.

Thus chalcopyrite undoubtedly replaces pyrite, while bornite and chalcocite form a secondary halo about chalcopyrite.

Plate V-8

a Pyrite (white) replaced by chalcopyrite (light grey) which is rimmed (replaced) by bornite and/or chalcocite. Solid and veined replacement texture can be seen.

b Sphalerite (medium grey) - galena (white) intergrowth. Although sphalerite apparently replaces galena in this case, paragenesis cannot be determined because of lack of examples.

Plate V-8

c Chalcopyrite (light grey) rimmed by chalcocite (medium grey).

d Typical pyrite (white) and chalcopyrite (medium grey around some pyrite) in limestone unit.

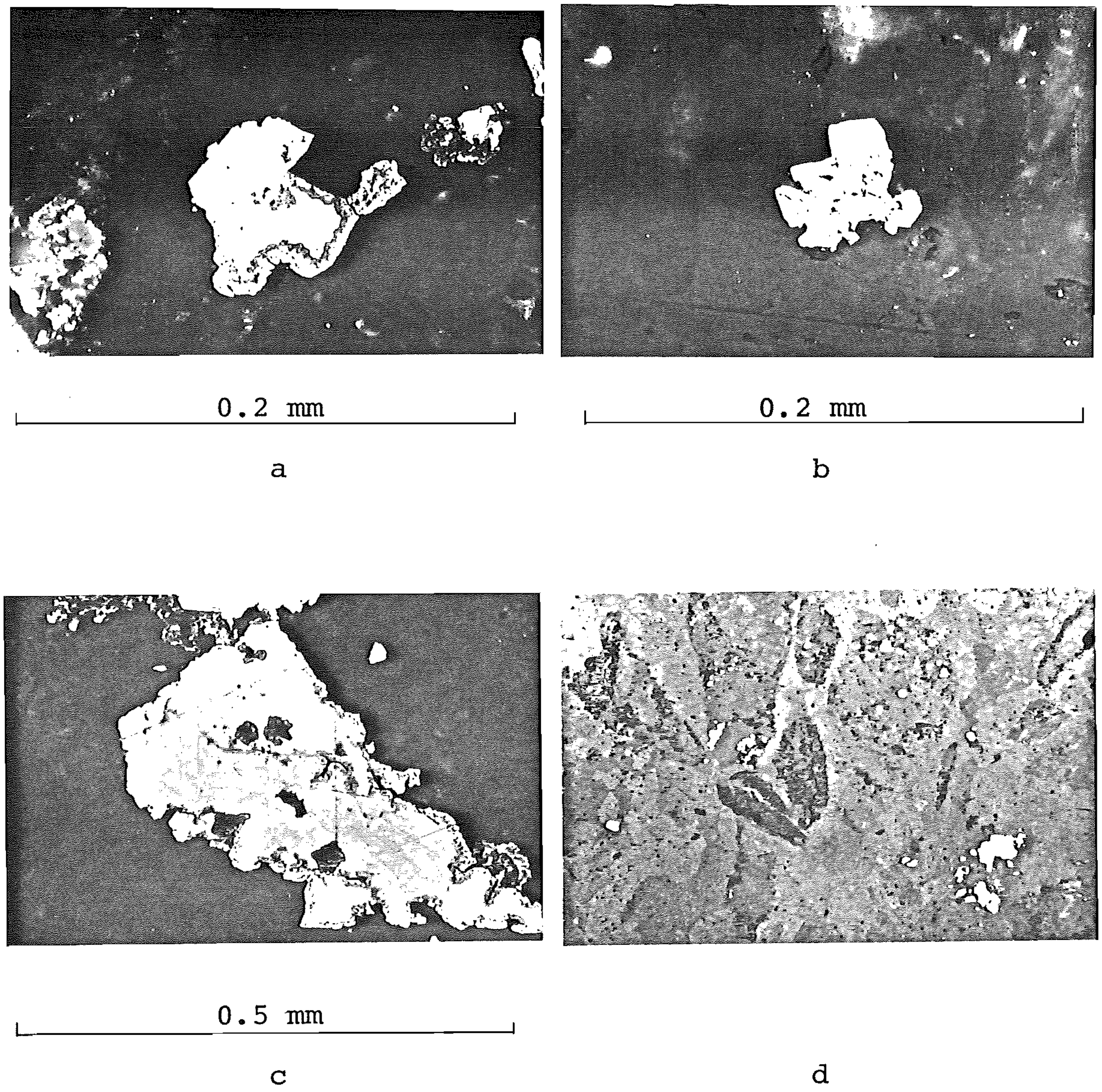


Plate V-8 Ohio - MacLean Area

1 mm Scale unless otherwise indicated

3- Ohio Iron Area

a) Volcanic Units

No significant mineralization other than iron sulfide and oxides are found in any of the acid and basic volcanics. Rare traces of chalcopyrite were encountered in the lapilli tuff units.

Pyrite (5-10%) forms mainly subhedral to anhedral, 0.01-0.2 mm, grains that are disseminated throughout the matrix of the acid porphyry and lapilli tuff units. Dissemination occurs evenly to glomeroporphyryritically (Plate V-9f).

Magnetite (up to 5-10%) often forms oriented intergrowths with hematite which duplicate the classic relict texture of Schwartz (1951) (Plate V-9b). Schwartz (1951) and Ramdohr (1969) interprets this texture as remnants of magnetite replaced by hematite. Magnetite also forms minor, discrete, subhedral, 0.02 mm, grains that are disseminated throughout the rocks. Lamellae are often visible in the hematite and in some cases are separated by thin rims of magnetite. Hematite usually forms from 5-20% and may constitute as much as 25% of the more basic volcanics and lapilli tuff units (Plate V-9a). It occurs as euhedral to anhedral, 0.01-1 mm, grains almost exclusively associated with chlorite grains or chlorite-rich areas of the volcanic matrix (Plate V-9e). Some magnetite replacement by hematite is suggested by the occurrence of hematite following crystallographic directions in the magnetite. This is somewhat akin to a reticulate texture (Schwartz 1951).

One volcanic unit contains only minor, anhedral, 0.02-0.05 mm, ilmenite grains, associated with the chloritic matrix.

Fine layers of smaller hematite grains marked by variable abundances and slight grain lineation indicates probable bedding in some tuff samples (Plate V-10a, b).

Hematite and magnetite are commonly corroded and rimmed by black, opaque to semi-translucent, iron oxidation products.

b) Breccia Unit

The upper portion of the breccia unit contains only traces of chalcopyrite and pyrite in the calcium carbonate matrix. The volcanic tuff fragments contain corroded pyrite (1-2%) as 0.01-0.02 mm, and iron oxide "replaced" grains. Rutile is common (2-3%) and is found as discrete, 0.01-0.02 mm, anhedral grains.

Plate V-9

a Typically disseminated hematite (-magnetite) grains in volcanics.

b Relict magnetite (medium grey) is remains from hematite replacement of magnetite.

Plate V-9

c Relict magnetite laths (medium grey) in hematite (light
& grey). c) triangular lath pattern
d d) parallel lath pattern

Plate V-9

e Hematite (light grey) confined to chlorite (medium grey) grains.

f Hematite (light grey) confined to chloritic (dark and light patchy areas) areas.

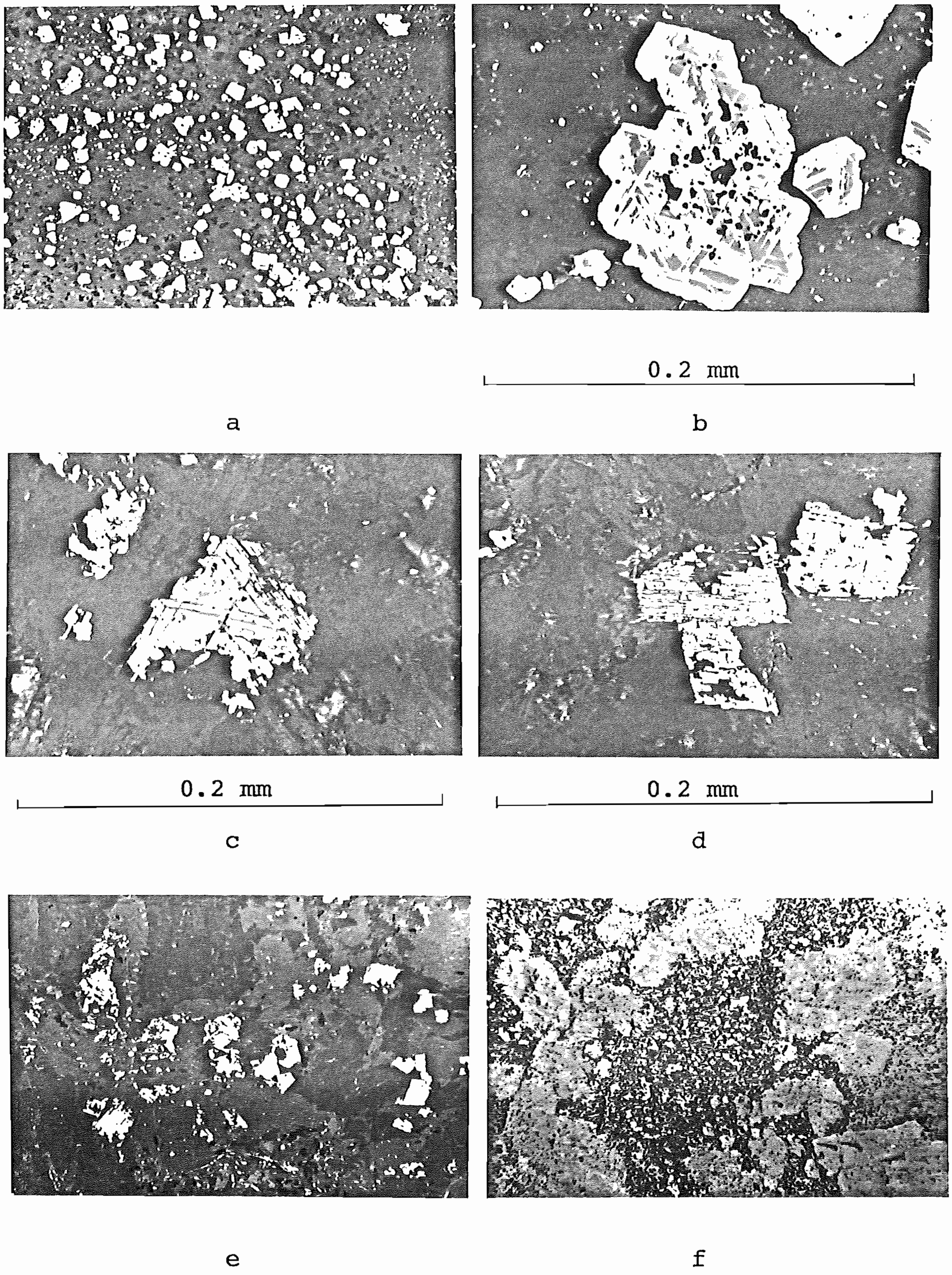


Plate V-9 Ohio Iron Area

1 mm Scale unless otherwise indicated

No significant carbonate matrix exists in the lower breccia unit, although small quantities of carbonate have permiated some areas of the tuff. Mineralization consists of chalcopyrite (5%) and minor pyrite (<1%).

Pyrite occurs mainly in small (0.05 mm) calcite veins as anhedral, 0.03-0.05 mm grains, showing a brecciated texture and commonly bearing iron oxide rims. Chalcopyrite is occasionally found infilling fractures in the pyrite.

Chalcopyrite is disseminated throughout highly altered areas of the aphanitic tuff matrix. It consists of anhedral, 0.05-0.2 mm grains, with very irregular boundaries. The bulk of the chalcopyrite has grown around and replaced the outer boundaries of phenocrysts and fragments of the tuff (Plate V-10c). It also follows fractures in phenocrysts (Plate V-10c). Some unmineralized tuff fragments remained impervious to the carbonate and mineralizing solutions, while very altered fragments with variable amounts of finely disseminated carbonate also contain chalcopyrite. Relict textures are commonly formed by varying degrees of replacement of altered feldspar phenocrysts by chalcopyrite (Plate V-10e, f). Etching with HCL confirmed the presence of carbonate around feldspar phenocrysts and revealed minute carbonate filled fractures throughout the phenocrysts. Obviously some fragments of the tuff were open to mineralizing solutions. Thus, as in previously described areas,

Plate V-10

a Layering of hematite grains (white) in tuff.

b Transmitted light. Possible primary cross bedding evident from hematite layering (black).

Plate V-10

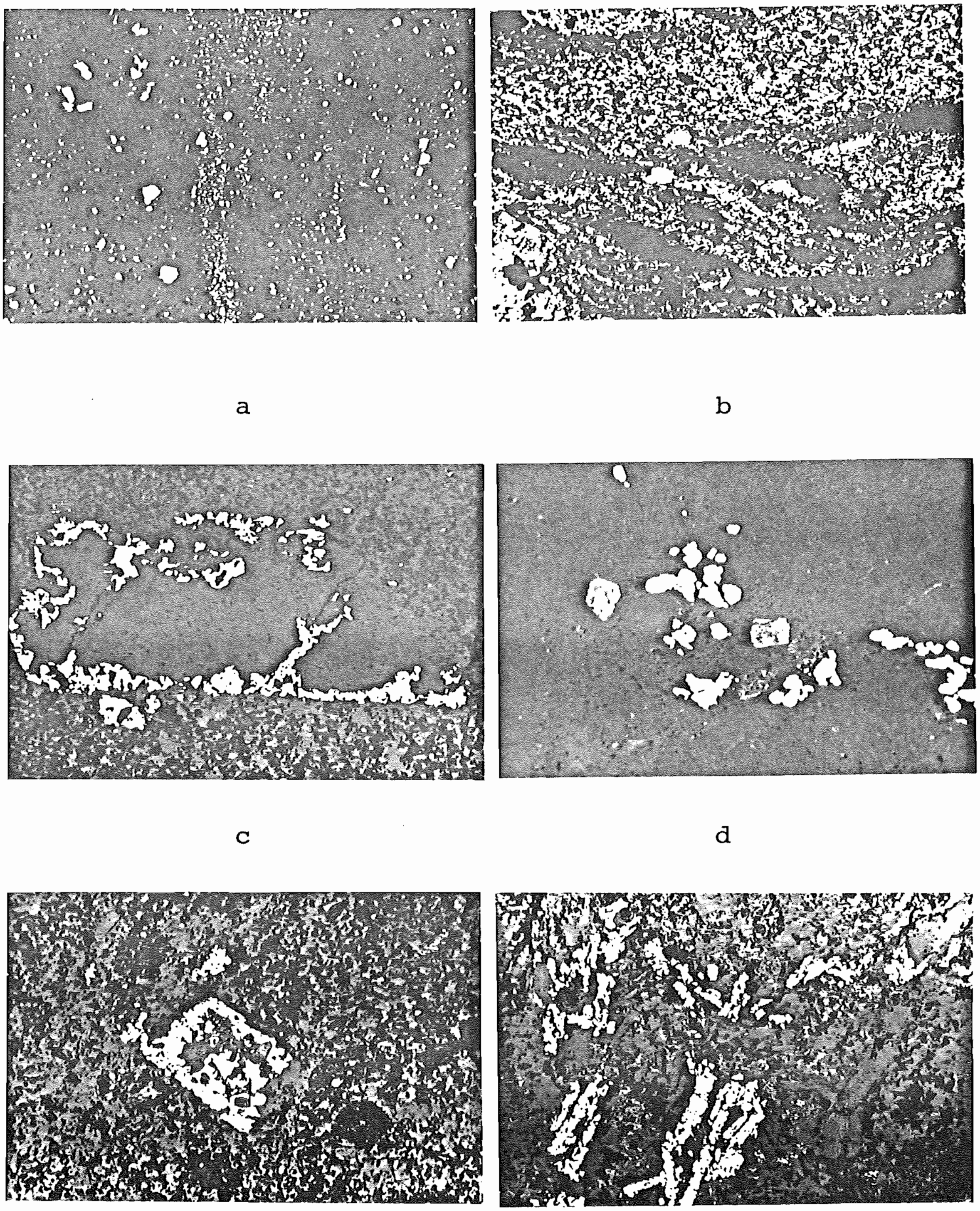
c Chalcopyrite (white) replacing rim and fractures of large phenocryst (medium grey at centre left and right of photo) in tuff.

d Glomeroporphyritic pyrite (white) and hematite (medium grey)

Plate V-10

e Relict feldspar phenocryst. Partially replaced by chalcopyrite (white).

f Chalcopyrite (white) almost totally replacing feldspar laths in highly altered areas of tuff.



a b

c d

e f

Plate V-10 Ohio Iron Area

1 mm Scale unless otherwise indicated

Plate V-11

a Hematite (white) preferentially replacing altered phenocryst in tuff.

Plate V-11

b Hematite "ghosts" probably replacing phenocrysts.

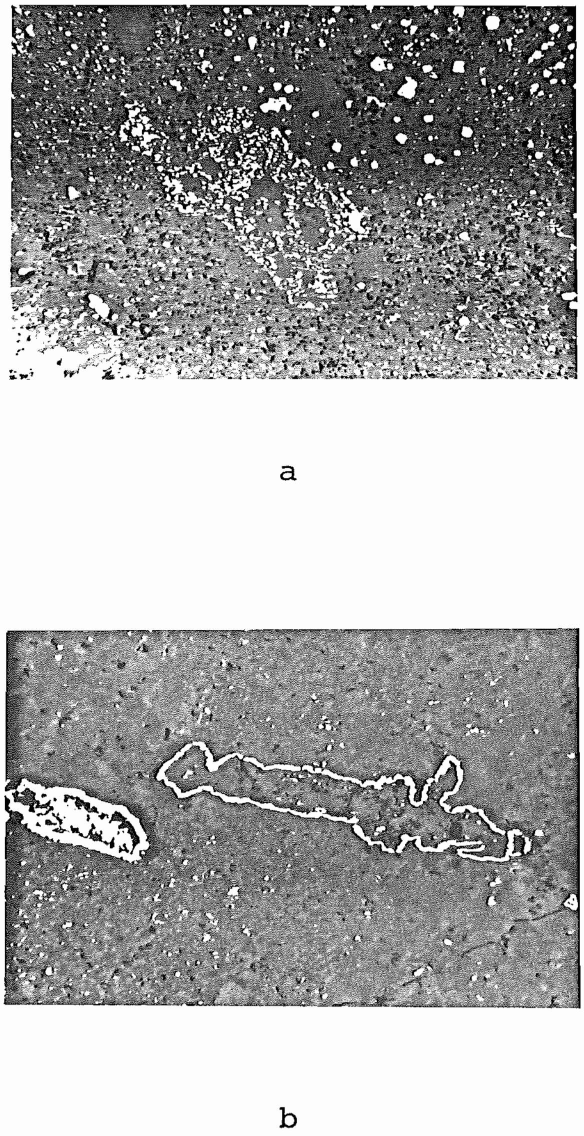


Plate V-11 Ohio Iron Area

1 mm Scale unless otherwise indicated

chalcopyrite is associated with a carbonate matrix, although it is not readily obvious in this case. Based on this evidence alone, either carbonate-bearing fluids provided an alteration path for later mineralizing fluids or mineralization accompanied the carbonate solution.

4- Ohio-Reigle Area

a) Limestone Unit

Although only boulders of limestone are present in this area, they are considered to be relatively in situ and are believed to represent the upper 'A' sub-zone of the Windsor Group.

Mineralization is almost entirely made up of galena (1-2%) with very minor pyrite (<<1%) and traces of chalcopyrite.

Pyrite forms discretely as brecciated, 0.03-0.05 mm, anhedral grains with iron oxide filling fractures and forming relict, subhedral pyrite crystals (Plate V-12a). The pyrite is found coexisting with the galena in calcite filled cavities and fractures.

Galena occurs as discrete, usually subhedral, 0.02-1 mm grains. Oxidation rims around very corroded anhedral grains outline relict subhedral to euhedral crystal shapes (Plate V-12c). Rare, 0.02 mm blebs of chalcopyrite with sharp mutual boundary relationship are found in the galena (Plate V-12d). This mineralization is totally confined to the abundant calcite-filled cavities in the limestone. Galena, formed entirely within the calcite-filled cavities, shows fairly regularly corroded boundaries (Plate V-12b, c). The bulk of the galena, however, forms near the cavity-limestone contact (Plate V-13). These grains show one very irregular boundary in common with the limestone-cavity transition. This transition zone, where micritic limestone becomes crystalline, varies from 0.1-0.2 mm in width, and is marked by small prismatic calcite crystals growing towards the interior of the cavity (Plate V-13a, b, c). The galena appears near the inward termination of the prismatic calcite. The remaining galena boundaries in the cavity are relatively sharp and euhedral, or relict-euhedral, and form mutual boundary relationships with the large (0.5 mm), infilling calcite crystals. Thus, galena probably forms at an early phase in the diagenetic infilling of cavities in the limestone.

b) Volcanic Unit

The volcanics described here are from outcrop and nearby boulders in the vicinity of the Reigle showing (see Map 3).

Plate V-12

a Galena (white, left) and brecciated pyrite (white, right) in calcite cavity filling.

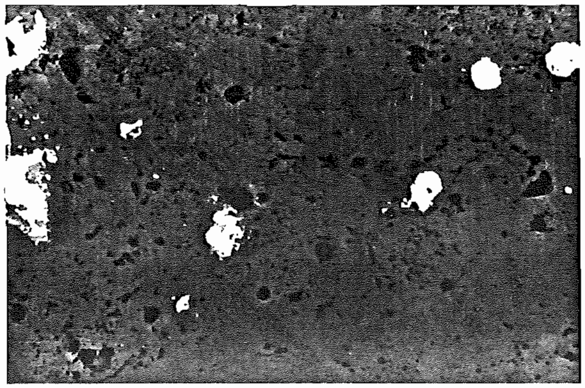
b Relict euhedral galena (white) corroded evenly on all crystal boundaries. Found in the interior of the calcite cavity fillings.

Plate V-12

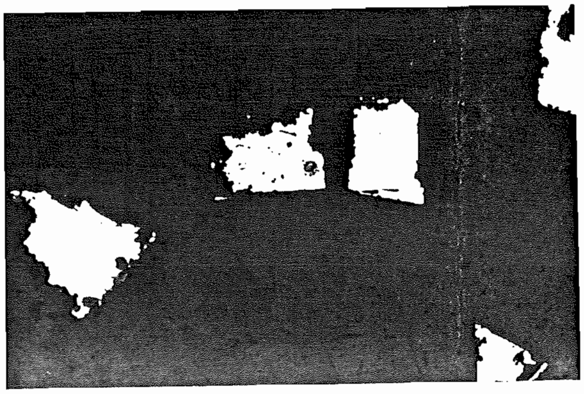
c Corroded galena (white). Euhedral character preserved by oxidation products on crystal boundaries.

Plate V-12

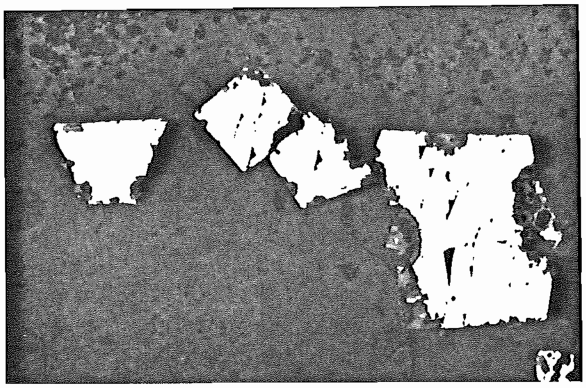
d Chalcopyrite (arrow) forming mutual boundary bleb within galena (grey with black specks covering entire photo).



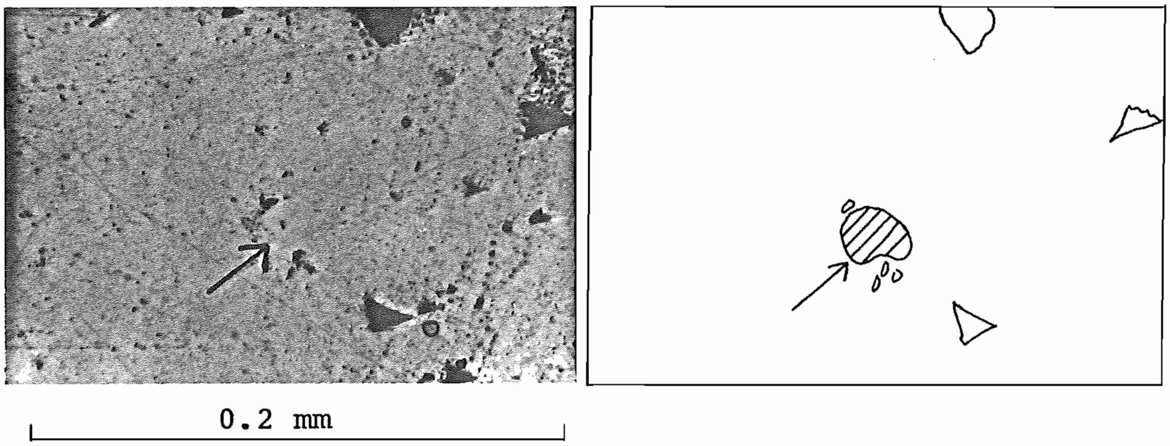
a



b



c



d

Plate V-12 Ohio - Reigle Area

1 mm Scale unless otherwise indicated

These volcanics are heavily mineralized by pyrite (15%) which forms as 0.02-1.0 mm anhedral to euhedral grains rimmed by iron oxide (Plate V-13e). Some volcanic fragments in the tuff contain much less pyrite (Plate V-13f). Most pyrite grains are solid but many show sparce <0.01 mm fractures. Chalcopyrite, which is found only in trace amounts, usually follows some fractures in pyrite and displays classic veined replacement texture (Plate V-14a, b). It also occurs as 0.03-0.1 mm anhedral grains: 1) replacing pyrite (Plate V-14d); 2) as discrete grains; 3) as tiny rare mutual boundary blebs within pyrite and; 4) in mutual boundary intergrowth with pyrite (Plate V-14e, f). Some chalcopyrite is rimmed (replaced) by bornite and/or covellite.

Oriented skeletal-like relicts of hematite and/or ilmenite replaced by rutile, form fairly large (0.2-0.1 mm) subhedral crystals (Plate V-14c). Ramdohr (1969) interprets this texture as oriented intergrowths of ilmenite converted to rutile in a former, dissolved away hematite crystal. These crystals appear to be replaced by both pyrite and chalcopyrite. These grains may provide the source for the ubiquitous detrital titanium (rutile, anatase and ilmenite) grains found in the mineralized sediments.

Plate V-13

a Galena (white) on limestone - cavity contact. Black triangular patterns are cleavage pits.

b Same photo as 13a, in transmitted light. Galena (black) on limestone (medium grey at top) calcite cavity filling (light grey at bottom and right) contact. Galena shows intact crystal faces in interior of cavity and irregular face on limestone - cavity contact.

Plate V-13

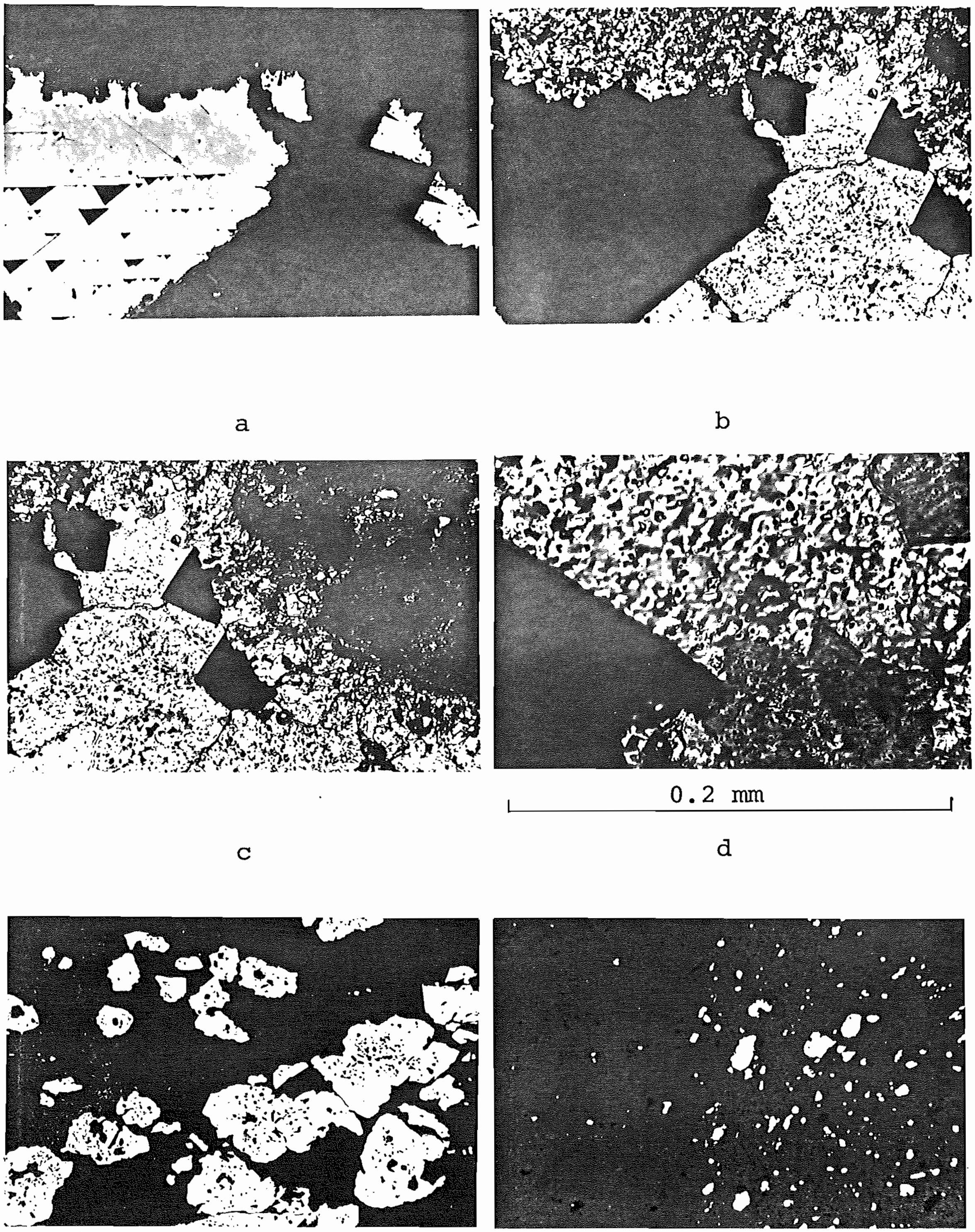
c Transmitted light. Early calcite infilling phase between galena (black) and limestone (dark grey, right). Calcite crystals (light grey) fill interiors of cavities.

d Transmitted light. Fluid inclusions in calcite cavities (galena, black). Inclusion at center is probably primary and contains both a gaseous (bottom) and a solid (NaCl) phase (top).

Plate V-13

e Anhedral to subhedral pyrite (light grey) in volcanics. Chalcopyrite (medium grey) trace in mutual boundary contact with pyrite grains at bottom centre.

f Pyrite (white) abundant in tuff matrix (right), nearly absent in some volcanic fragments (left).



a

b

c

d

e

f

Plate V-13 Ohio - Reigle Area

1 mm Scale unless otherwise indicated

Plate V-14

a Chalcopyrite (medium grey) replacing fractures in pyrite (light grey) and forming veined texture.

b Close up of veined replacement texture in 'a'.

Plate V-14

c Skeletal relicts of hematite (and/or ilmenite) formed by replacing rutile, (medium grey, oriented laths) partially replaced by chalcopyrite (slightly darker grey, irregular shapes, right). Lead from polishing (speckled grey) at right centre.

d Chalcopyrite (medium grey) replacing and cutting pyrite (light grey) crystal face. Thin, darker grey halo around chalcopyrite is covellite.

Plate V-14

e & f Mutual boundary intergrowths of pyrite (light grey) and chalcopyrite (medium grey). Chalcopyrite probably replaces pyrite.

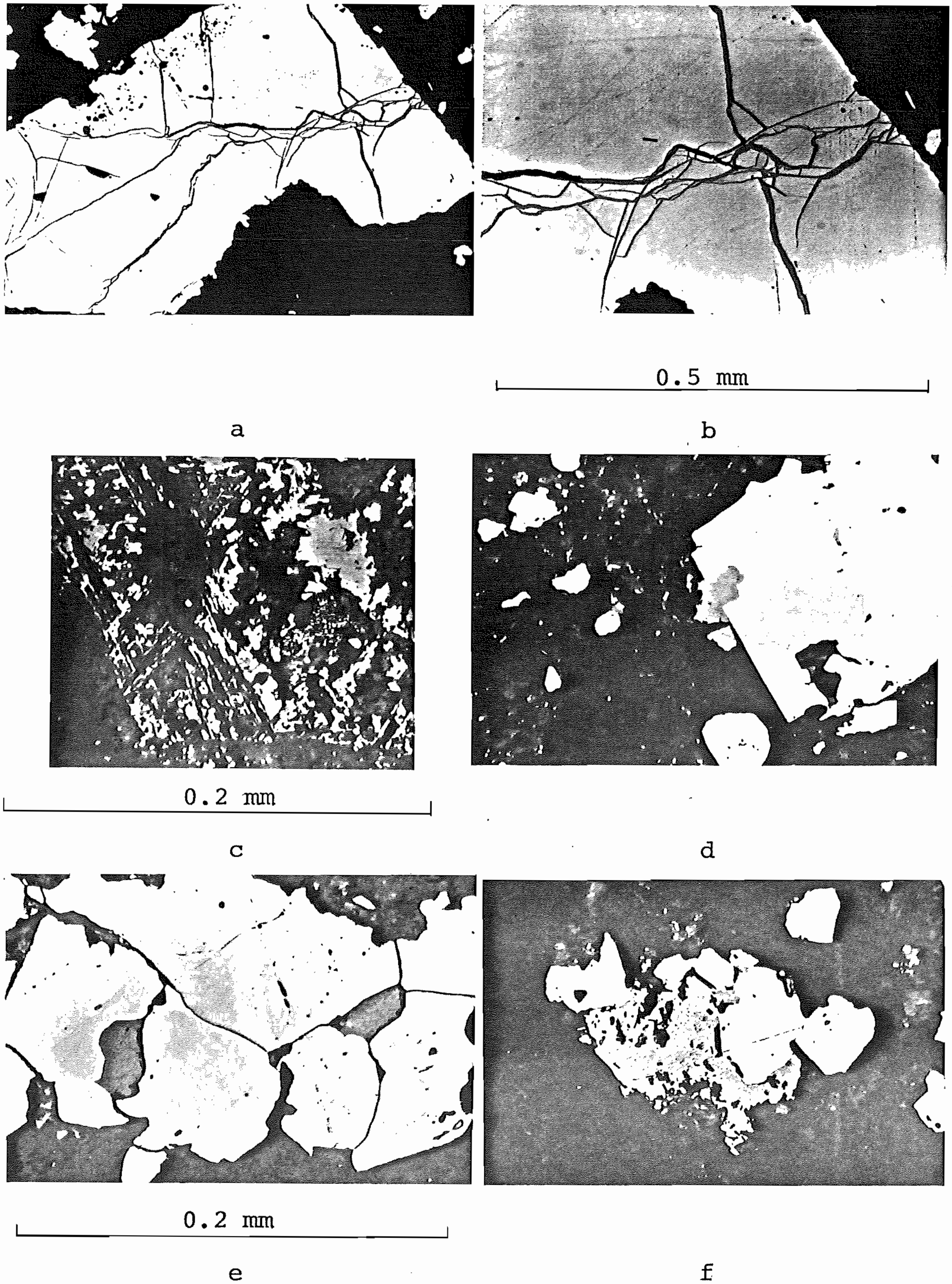


Plate V-14 Ohio - Reigle Area

1 mm Scale unless otherwise indicated

5- Pinkietown Area

a) Breccia Unit

Mineralization in the breccia unit consists of chalcopyrite (1%), minor pyrite (<1%) and traces of bornite and covellite.

The previously described skeletal rutile and/or ilmenite relicts are also common in the volcanic fragments (Plate V-16c).

Pyrite occurs mainly in the volcanic tuff fragments as 0.05 mm brecciated grains with iron oxide forming relict, subhedral to euhedral textures.

Chalcopyrite forms almost exclusively in the carbonate matrix and is associated with fractures that are sometimes carbonate filled and occur throughout the volcanic fragments. It is usually found as discrete, 0.02-0.2 mm anhedral grains with very irregular boundaries. These are rimmed by relatively thick (up to 0.03 mm), grey (red on transmitted light) iron oxide bands which in places form a relict subhedral texture (Plate V-15a). Rare covellite forms around some chalcopyrite grains. The chalcopyrite also forms rare oriented intergrowths with bornite identical to triangular lattice exsolution textures (Ramdohr 1969, Park 1970). The chalcopyrite lamellae are extremely small (0.0005-0.002 mm wide) and thin at lamellae intersections, indicating exsolution genesis (Plate V-15c, d). One large (0.5 mm) chalcopyrite grain shows brecciated bornite with chalcopyrite exsolution lamellae forming mutual relationships with the larger chalcopyrite mass. The bornite-chalcopyrite mutual boundary appears to be brecciated by iron oxide-filled fractures (Plate V-15e, f). The fractures permiate areas of the large chalcopyrite grain only where bornite is present. Solid chalcopyrite remains intact with no iron oxide-filled fractures. Fractures may appear to develop preferentially in bornite because of the subsequent healing of the chalcopyrite fractures. However, fractures in the bornite-chalcopyrite intergrowth would also be expected to be healed since chalcopyrite constitutes a major portion of the area. Thus it appears more than coincidental that fractures appear in chalcopyrite only where bornite is present. Indications of slight narrowing of the fractures from chalcopyrite into bornite are evident in places (Plate V-15f, 16a). Bornite nearly always borders, to some extent, on iron oxide fractures (Plate V-15, 16a). These textures would suggest a replacement process has taken place as discussed in the following section. The chalcopyrite lamellae are undoubtedly of exsolution origin, based on the criteria of Ramdohr (1969). This texture will also be discussed in the following section.

Unfortunately the mutual boundary intergrowth does not provide information to distinguish the genesis of replacement. On the contrary, evidence of both replacement possibilities are found in the grain. Chalcopyrite fingers extend into bornite and bornite fingers into chalcopyrite. Chalcopyrite blebs occur in bornite and bornite blebs in chalcopyrite (Plate V-15e, f).

Traces of iron oxide-rimmed chalcopyrite grains are found in the small sandstone layer within the breccia unit. Detrital rutile grains are very prominent in the sandstone sub-unit.

b) Volcanic Unit

Hematite (5-10%) exclusively forms the mineralization in some parts of the volcanic unit. It occurs as <0.01-0.2 mm, subhedral grains disseminated throughout the matrix of the porphyry volcanic. The larger grains are mostly replaced by ilmenite and/or rutile and commonly show remnant, oriented, skeletal hematite lamellae. Elsewhere in the same volcanic lithology hematite may form only approximately 1 to 2% of the mineralization although copper mineralization (1-2%) becomes quite distinct.

The copper mineralization consists of chalcopyrite, bornite, chalcocite and minor covellite. The minerals are

Plate V-15

a Chalcopyrite (white) rimmed by iron (-copper) oxidation products (medium grey) following fracture in a volcanic fragment (dark grey).

b Chalcopyrite exsolution lamelli (light grey) in bornite (medium grey). Lamelli form triangular lattice pattern.

Plate V-15

c & d Oil immersion close up of grain in Plate V-15b. Chalcopyrite lamelli (white) thin at intersection points indicating an exsolution from bornite (medium grey) origin.

Plate V-15

e Chalcopyrite (light grey) with bornite (medium grey). Iron oxide filled fractures permiate only bornite bearing areas of chalcopyrite. Many bornite areas appear continuous across the fractures.

f Close up of central area of Plate V-15e. Chalcopyrite exsolution lamelli visible in bornite (medium grey). Bornite at centre, right appears continuous over two iron oxide (dark grey) filled fractures, thus forming a brecciated texture.

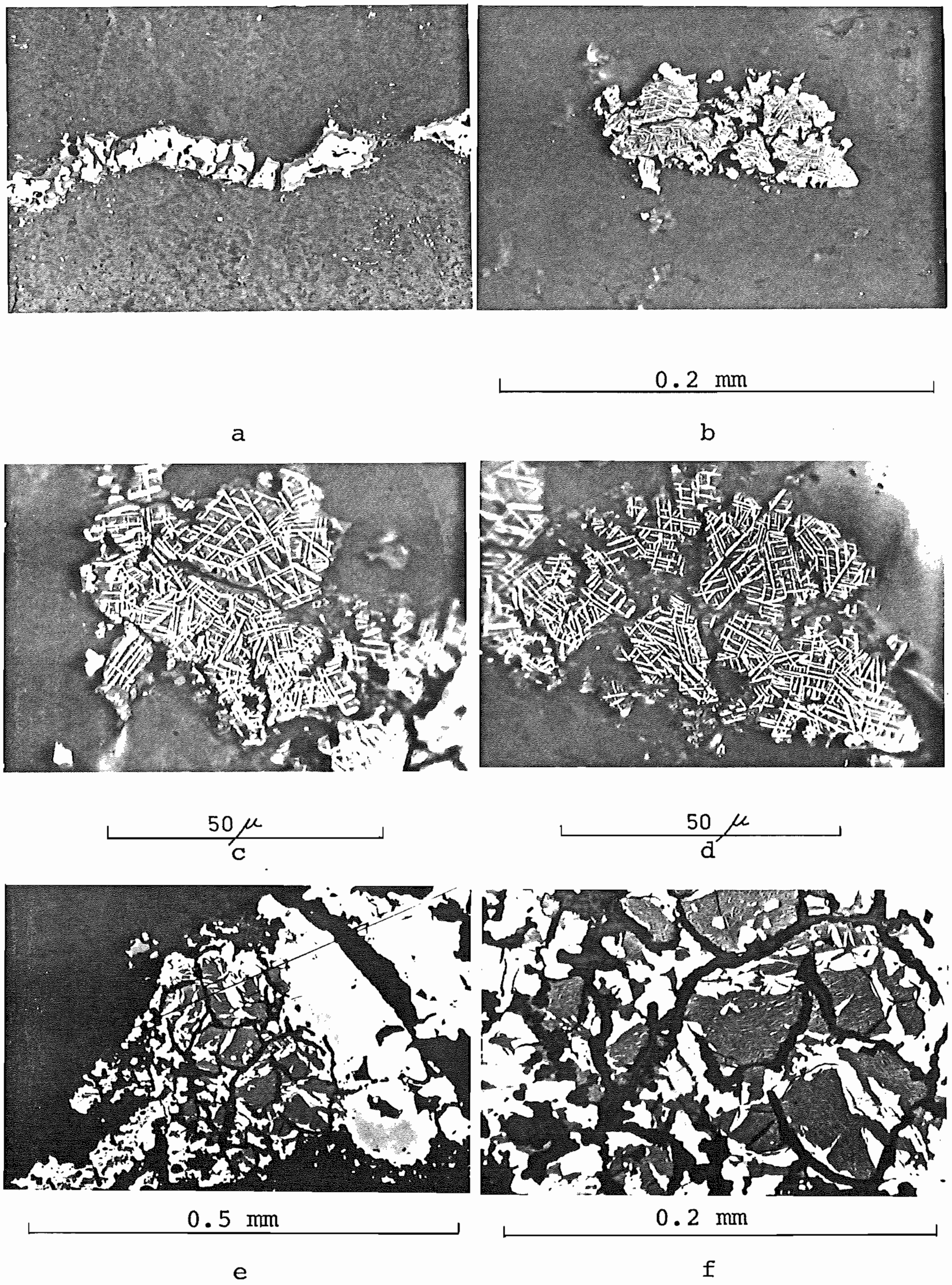


Plate V-15 Pinkietown Area

1 mm Scale unless otherwise indicated

predominantly intergrown as 0.02-0.2 mm, anhedral grains and only traces of small (0.02 mm) discrete chalcopyrite and bornite grains are observed. Bornite, in most cases, contains variable abundances of crystallographically oriented chalcopyrite lamellae displaying exsolution texture. The bornite may contain very few or may be largely made up of chalcopyrite lamellae (Plate V-16d, e).

The bornite very commonly shows mutual boundary and very irregular intergrowths with comparable sized chalcopyrite grains (Plate V-16f). In many cases, the bornite appears to be "replacing" (including 'spontaneous' transformation of the chalcopyrite into bornite) open spaces in the chalcopyrite (Plate V-17a, b). One chalcopyrite-bornite intergrowth, as described in detail in section III-A is found in this unit (Plate V-17e). Most of the bornite displays rims and irregular intergrowths of chalcocite-digenite and minor covellite. This probably represents "spontaneous" conversion of bornite to more copper rich sulfides as chalcocite and covellite commonly form secondary rims. The similarity between the irregular chalcocite-bornite and the bornite-chalcopyrite intergrowth suggests that bornite is a replacement or possibly an alteration product of chalcopyrite, as chalcocite is of bornite. Thus there exists a continuous succession from relatively iron rich chalcopyrite to continually more iron deficient (or copper enriched) copper sulfides. Whether the succession is

Plate V-16

a Close up of upper section of Plate V-15e. Shredded fragments of bornite (medium grey) in chalcopyrite (light grey) suggest a replacement of bornite by chalcopyrite.

b Oil immersion close up of shredded bornite in Plate V-16a.

Plate V-16

c Skeletal relicts of hematite and/or ilmenite formed by rutile replacement in a volcanic fragment.

d Discrete bornite (medium grey) with very few chalcopyrite exsolution lamelli (light grey). Volcanic unit.

Plate V-16

e Discrete bornite (medium grey) containing many chalcopyrite exsolution lamelli and a mutual boundary chalcopyrite bleb (light grey).

f Typical bornite (medium grey) chalcopyrite (light grey) mutual boundary intergrowth. No chalcopyrite exsolution lamelli present in bornite.

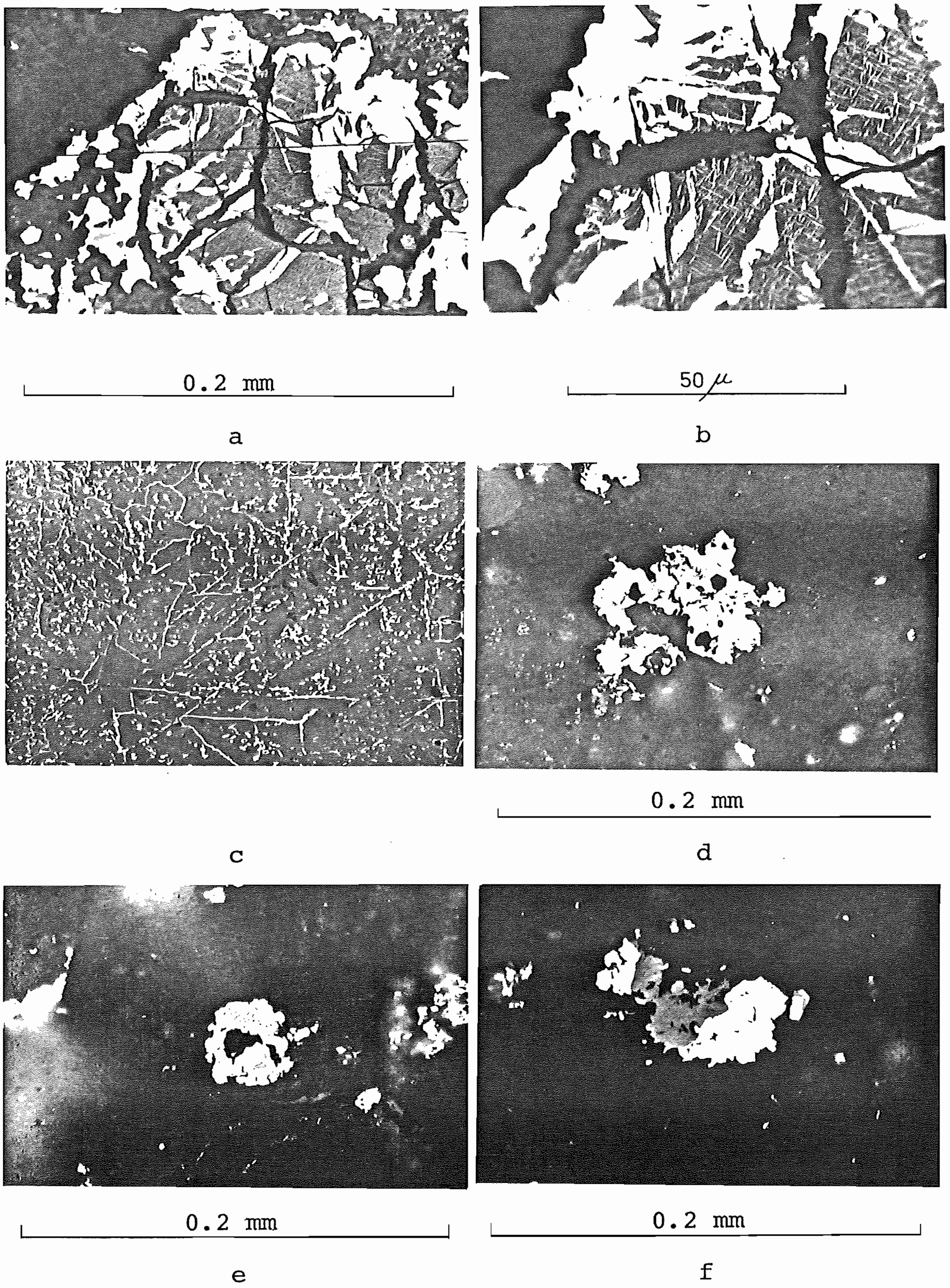


Plate V-16 Pinkietown Area

1 mm Scale unless otherwise indicated

Plate V-17

a Irregular bornite (medium grey) chalcopyrite (light grey)
& intergrowths. Bornite appears to fill voids in the
b chalcopyrite. Exsolution lamelli abundant in bornite.

Plate V-17

c Chalcopyrite exsolution lamelli and blebs (light grey) in bornite (medium grey).

d Oil immersion of lamelli and blebs of chalcopyrite (white) in bornite (dark grey).

Plate V-17

e Brecciated chalcopyrite lamelli containing bornite permiated by iron oxide filled fractures.

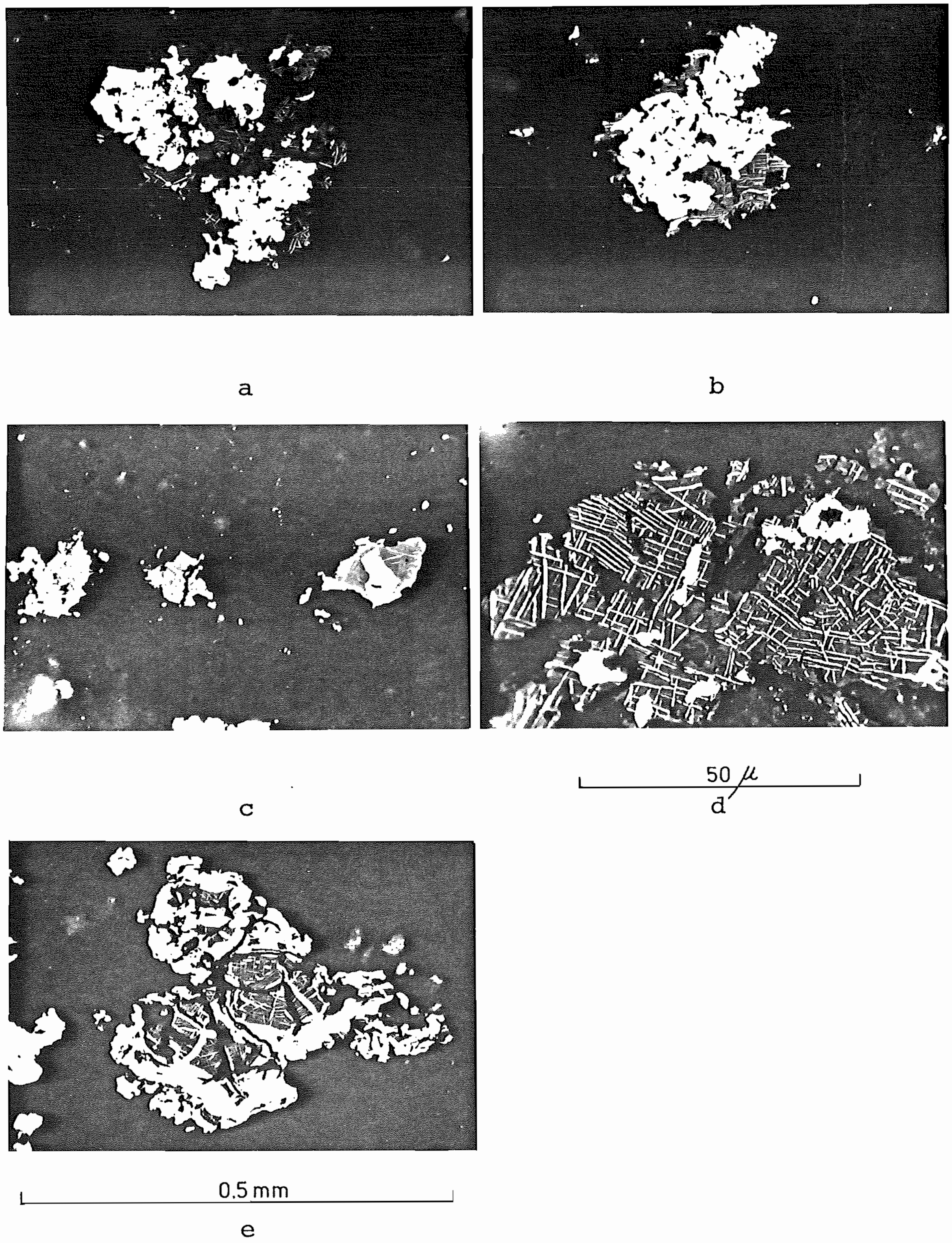


Plate V-17 Pinkietown Area

0.2 mm Scale unless otherwise indicated

a secondary oxidation process with the removal of iron at each successive stage or the result of iron depletion in a solution which was continuously spent, cannot be determined from the textures. However, secondary processes have subsequently operated as evidenced by the rims of black opaque oxidation products (probably iron) around most copper sulfide grains.

c) Conglomerate Unit

Mineralization in the volcanic pebbles of the conglomerate unit consists mainly of hematite with magnetite (5-10%) found predominantly as oriented lamellae in relict titanium-rich subhedral to euhedral, 0.05-0.3 mm crystals. Traces of small brecciated pyrite grains are also present. One small aggregate of pyrite grains is enclosed by chalcocite-digenite and minor bornite. Discrete grains of chalcocite and/or covellite are found in trace amounts in the pebbles.

The greater part of the copper mineralization occurs in the carbonate matrix of the conglomerate. It is made up of chalcocite-digenite (1.5%), bornite (approximately 1%), covellite (approximately 1%), malachite (approximately 0.5%) and traces of chalcopyrite.

Although all the copper minerals occur as small (0.03-0.05 mm) discrete grains, intergrowths form most of the observed textures.

Chalcocite forms as 0.05-1.5 mm, anhedral grains displaying lamellae which, in places, are rimmed by covellite. The chalcocite-digenite varies in colour from whitish-grey to various hues of bluish-grey and is commonly intergrown in a lattice texture (Plate V-18a) (Schwartz 1951). Chalcocite also commonly forms mutual boundary intergrowths with bornite (Plate V-18b). A distinctly more bluish-grey mineral (probably digenite) rims the bornite in the faintly bluish-grey chalcocite (Plate V-18c). Mutual boundary intergrowths of bornite and lamellar covellite are found in many places (Plate V-18d). The bornite colour varies from predominently pinkish to orange. One small brecciated grain of pyrite, infilled and possibly replaced by chalcocite is found in a bornite-chalcocite intergrowth (Plate V-18c). Chalcopyrite exsolution texture lamellae and blebs occur in only a few bornite grains which are intergrown with covellite.

Rare, discrete anhedral grains of chalcopyrite are found in the matrix. All copper mineralization is bordered to some extent by a black opaque oxidation product and, in some cases, traces of malachite. Traces of exsolution texture chalcopyrite are found in bornite grains which have been almost completely transformed to chalcocite.

In larger areas of carbonate matrix, mineralization

Plate V-18

a Chalcocite (light grey) digenite (darker grey) intergrowth in lattice texture, probably reflecting solid solution composition.

b Chalcocite (-digenite) (medium grey) in mutual boundary intergrowth with bornite (darker grey). Chalcocite forms lamelli. Lamellar covellite (medium grey) grain at bottom right. No chalcopyrite exsolution lamelli in bornite.

Plate V-18

c Close up of chalcocite (light grey) bornite (dark grey) intergrowth. Digenite (medium grey) forms a rim between the chalcocite and bornite. Pyrite (white) partially replaced by copper sulfides.

d Bottom right: Lamellar covellite (dark grey grains) intergrown with bornite (medium grey) which contains chalcopyrite exsolution lamelli (light grey). Light grey mass with white grains are titanium products. Top left: Chalcocite (white) intergrown with bornite (medium grey) and covellite (dark grey).

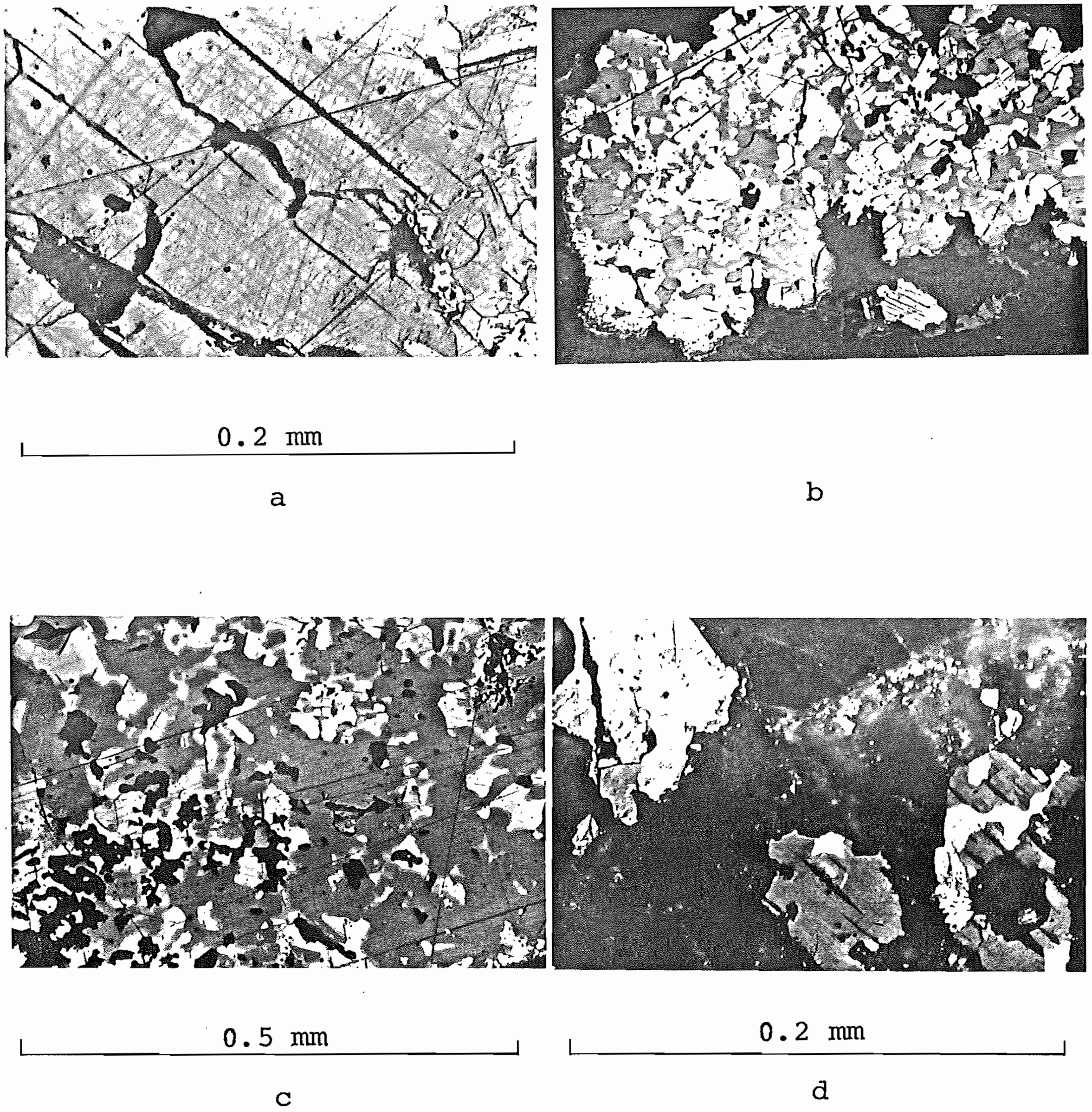


Plate V-18 Pinkietown Area

1 mm Scale unless otherwise indicated

tends to exist near the carbonate-pebble boundaries, while the 'interior' of the matrix is sparcely mineralized. Mineralization is also found in and near carbonate-filled fractures in the pebbles.

Although the chalcopyrite lamellae usually form along triangular octohedral directions, occasional tetragonal directions are present.

6- James River Area

a) Lower Conglomerate Unit

Mineralization in the lower red (oxidized) conglomerate unit comprises hematite (2%) which occurs exclusively in the volcanic pebbles. The hematite forms).02-0.5 mm, subhedral to anhedral grains disseminated throughout the pebbles. No copper mineralization is found in the fairly abundant carbonate matrix.

b) Upper Conglomerate Unit

Anhedral, 0.02-0.05 mm grains of rutile and/or anatase form about 2% of the pebbles in this unit. Traces of anhedral 0.02 mm grains of chalcopyrite in large iron oxide masses are found in isolated matrix areas. The conglomerate is very loose and crumbly and only traces of weathered carbonate remain in the largely open spaces that now occupy the former carbonate matrix (Plate V-19a). Since most copper mineralization is found in the matrix of rocks in the other areas, it can be assumed that any mineralization in this unit would have been carried away with the carbonate matrix. Some of the copper minerals were replaced by malachite, which is fairly abundant in hand specimen, and re-deposited as films around pebbles and in fractures (Binney and Kirkham 1974). This would explain the predominant presence of malachite in this area, while primary sulfides are observed in the more compact conglomerates and breccias. Mineralization, if any, would be found below the oxidized zone. Unfortunately no drill core was available in this area.

c) Limestone Unit

Mineralization in the limestone unit consists of pyrite (1-2%) chalcopyrite (approximately 0.5%), and minor amounts of bornite, chalcocite and sphalerite. Most chalcopyrite is found as small (0.02-0.05 mm) discrete anhedral grains. Pyrite is found exclusively as tiny (0.01 mm) framboids and framboid aggregates (up to 1 mm) disseminated evenly throughout the limestone (Plate V-19b-e).

Chalcopyrite forms several mutual boundary intergrowths with sphalerite. More commonly, however, chalcopyrite,

Plate V-19

a Matrix (white) of conglomerate consists mainly of open space. Remnants of calcite (light grey) show a weathered carbonate matrix. Pebbles, dark grey.

Plate V-19

b Aggregate of framboidal pyrite.

c Oil immersion close up of Plate V-19b.

Plate V-19

d Pyrite framboids completely replaced by iron oxide. Oil immersion.

e Intact pyrite framboids in limestone unit. Oil immersion.

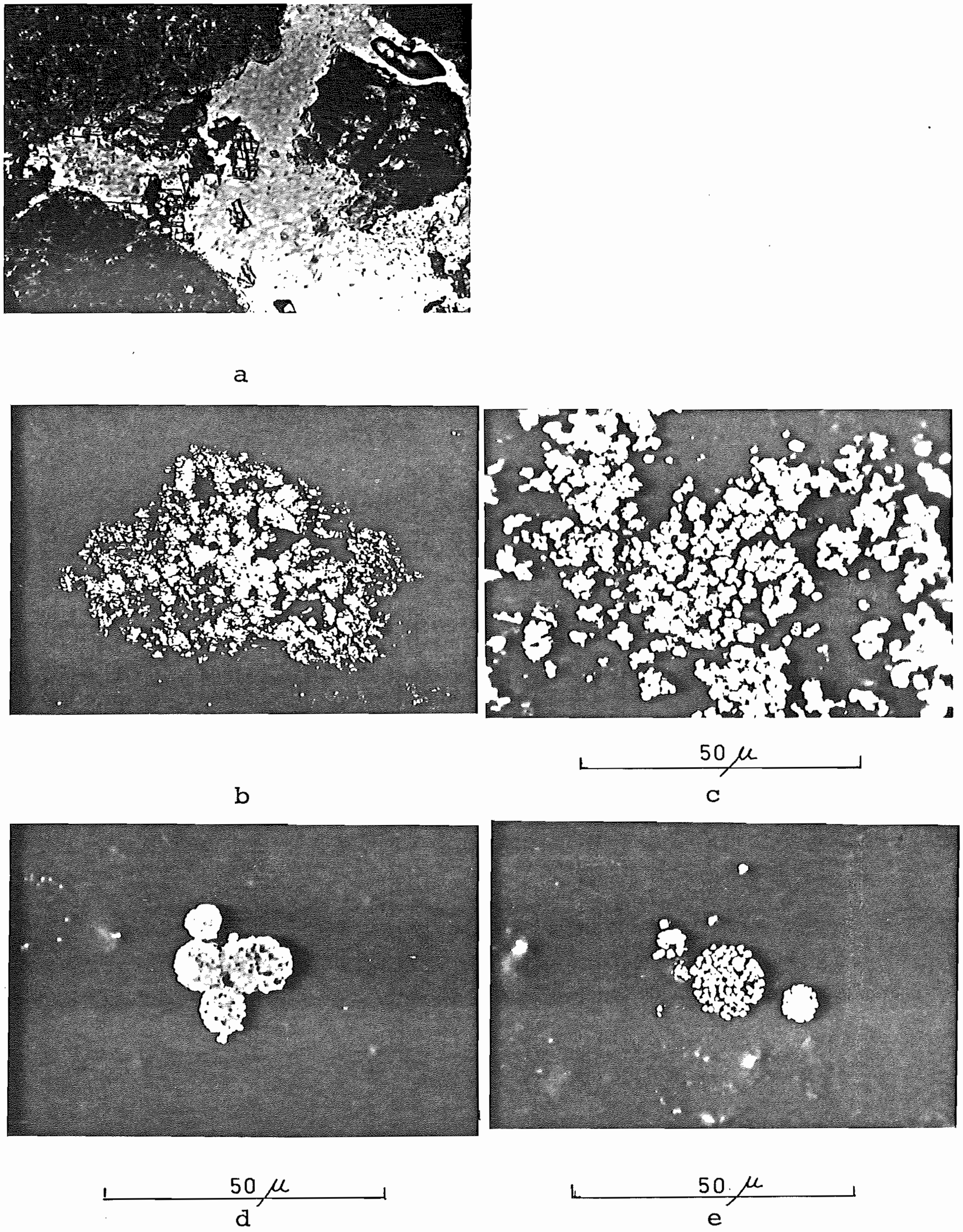


Plate V-19 James River Area

1 mm Scale unless otherwise indicated

sphalerite and bornite form anhedral grain assemblages with mutual boundary relationships (Plate V-20). In places the bornite contains exsolution texture chalcopyrite lamellae and is commonly rimmed to varying degrees by chalcocite. No preferential boundaries between any two mineral combinations exist and mutual boundary contacts exist between all these minerals (Plate V-21). In places, pyrite framboids are found in the intergrown bornite-chalcocite, chalcopyrite and sphalerite (Plate V-20). All sulfides are rimmed by black opaque oxidation products.

Areas of the limestone containing abundant pyrite framboids (approximately 2%) and traces of brecciated pyrite crystals show only traces of discrete, anhedral, chalcopyrite grains. This inverse relationship between pyrite and copper sulfides suggests the possibility of pyrite replacement by copper sulfides.

The mutual boundary and exsolution textures are those discussed in the Breccia Unit of the Pinkietown Area (section IIIA - 5a).

7- Brierly Brook

a) Lower Conglomerate Unit

The mineralization in the lower red conglomerate is

Plate V-20

a Chalcopyrite (light grey), sphalerite (medium grey) and pyrite (white, framboids) intergrowth. Sphalerite and chalcopyrite form mutual boundary relationships.

b Close up of Plate V-20a.

Plate V-20

c Chalcopyrite (light grey, left) sphalerite (medium grey, large mass, middle), pyrite (white framboids, right) and bornite (dark grey, right and top right). Gangue darkest grey.

d Close up of Plate V-20c.

Plate V-20

e Close up of bottom right of grain in Plate V-20c. Bornite (dark grey) containing chalcopyrite exsolution lamelli (white) in mutual boundary intergrowth with sphalerite (medium grey). Pyrite framboids (white) found mainly on contacts. Oil immersion. Limestone gangue darkest grey.

f Oil immersion close up of Plate V-20e.

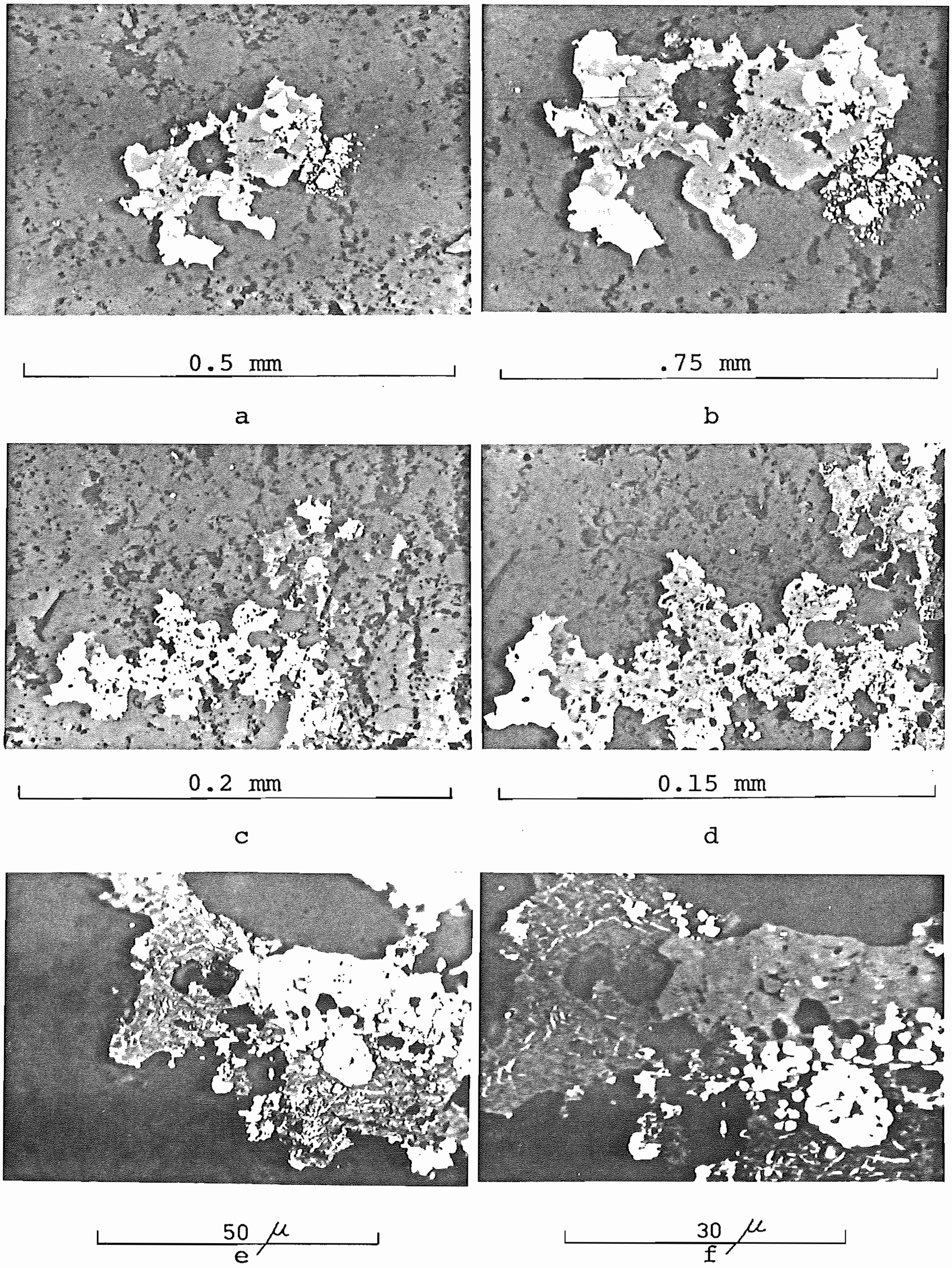


Plate V-20 James River Area

Plate V-21

a Close up of top right area of grain in Plate V-20c and d. Bornite (dark grey) containing chalcopyrite exsolution lamelli (light grey) in mutual boundary contact with sphalerite (medium grey). Pyrite framboid (white) in bornite. Oil immersion.

b Close up of Plate V-21a. Oil immersion.

Plate V-21

c Close up of left end of grain in Plate V-20c and d. Chalcopyrite (light grey), bornite (dark grey) with chalcopyrite exsolution lamelli and sphalerite (dark grey) in mutual boundary contact. Limestone darkest grey. Oil immersion.

d Close up of Plate V-21c. Oil immersion.

Plate V-21

e Pyrite framboids (white) on bornite - sphalerite intergrowth. Oil immersion.

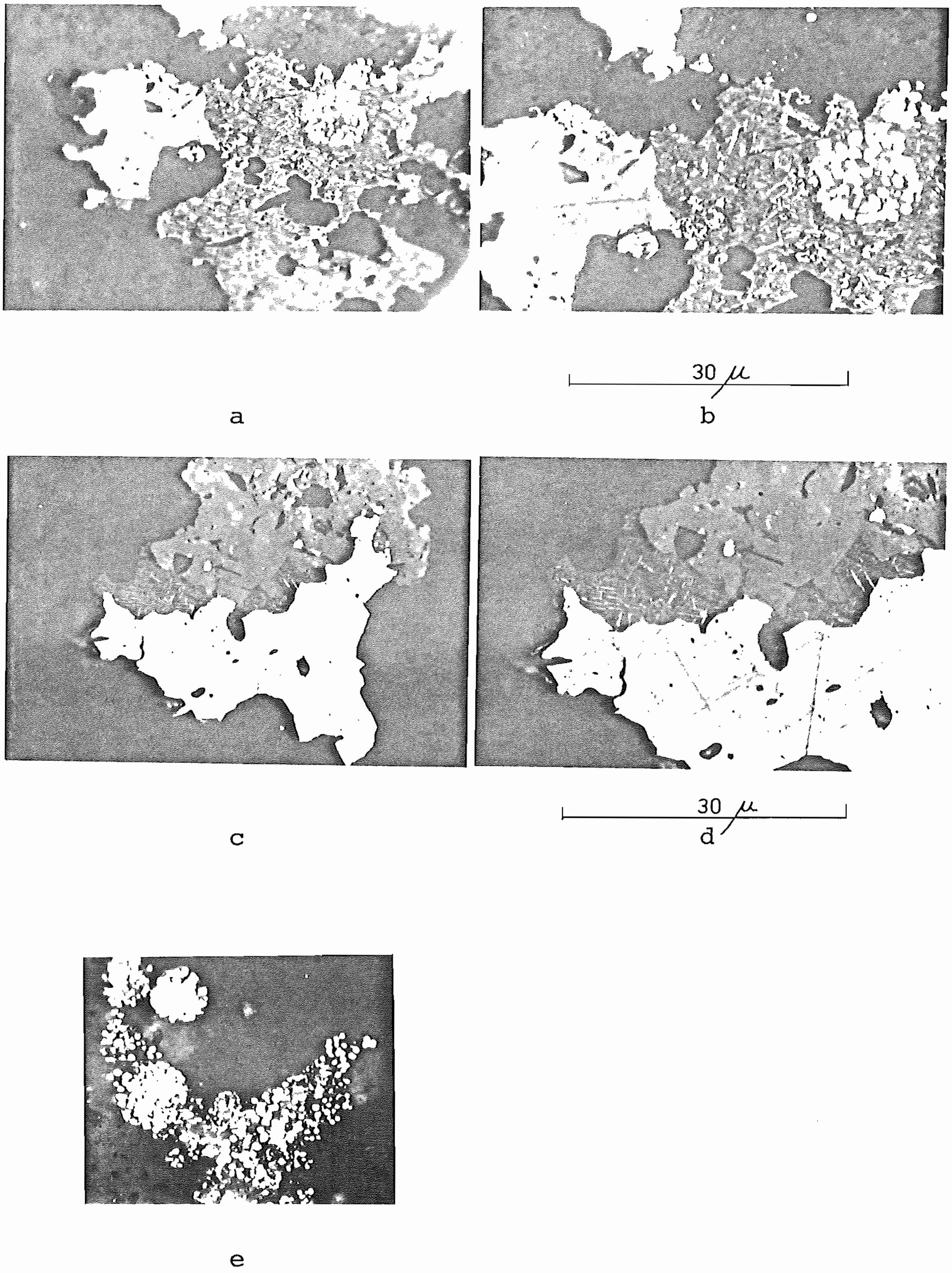


Plate V-21 James River Area

50 µ Scale unless otherwise indicated

contained wholly within the volcanic pebbles and consists almost entirely of hematite. The carbonate matrix is unmineralized.

Hematite forms up to 15% of some pebbles and is virtually absent in others. It occurs as <0.0.-0.2 mm, anhedral to subhedral grains disseminated evenly in each pebble. The size range and texture of the hematite is distinct in each pebble. Some pebbles show large hematite and minor magnetite lamellae forming relict, skeletal, hematite crystals, while others show tiny, solid anhedral grains of hematite.

A trace of chalcopyrite (one grain) exists in the slide of this unit.

b) Upper Conglomerate Unit

As in the upper green conglomerate unit of the James River area, most of the carbonate matrix is weathered out. As a result only traces of chalcopyrite and covellite are found in restricted matrix areas.

The bulk of the mineralization is hematite and pyrite contained within the pebbles of the conglomerate. Pyrite (<<1%) occurring as brecciated grains with relict cubic crystal shapes, is usually found in fractures and in the comminuted silicates where it is associated with abundant

(1%) detrital rutile and/or anatase. The occurrence of hematite and malachite matches the upper conglomerate of James River.

c) Limestone Unit

Mineralization in the limestone unit consists of minor chalcopyrite, bornite, chalcocite, covellite, pyrite and traces of sphalerite.

A number of discrete, 0.01-0.1 mm, anhedral grains of chalcopyrite and solid bornite are disseminated throughout the limestone. Several intergrowths of bornite, chalcocite-digenite (bluish chalcocite being predominant), chalcopyrite and covellite are found in several combinations. They form 0.02-0.1 mm, anhedral grain assemblages displaying irregular and mutual boundary relationships. Bornite is 'replaced' to varying degrees, by chalcocite-digenite. The chalcocite ranges from thin rims to nearly total replacement of the bornite. Chalcopyrite exsolution texture lamellae are found intergrown, in some places, with the chalcocite-bornite assemblages. This chalcopyrite is usually rimmed by or is contained wholly within chalcocite and displays tetragonally oriented lens-shaped lamellae (Plate V-22a-c). Some chalcocite-bornite grains show preferential replacement of bornite by chalcocite around the chalcopyrite lamellae. Chalcopyrite is not found in the solid, discrete bornite

Plate V-22

a Chalcopyrite exsolution lamelli (white) bounded by chalcocite (light grey) in bornite (medium grey). Limestone is dark grey. Black streaks are carbon coating used in microprobing process.

b Oil immersion close up of right side of grain in Plate V-22a.

Plate V-22

c Oil immersion close up of Plate V-22b.

d Chalcopyrite lamelli (light grey) extends from chalcopyrite grain into chalcocite (dark grey). Oil immersion.

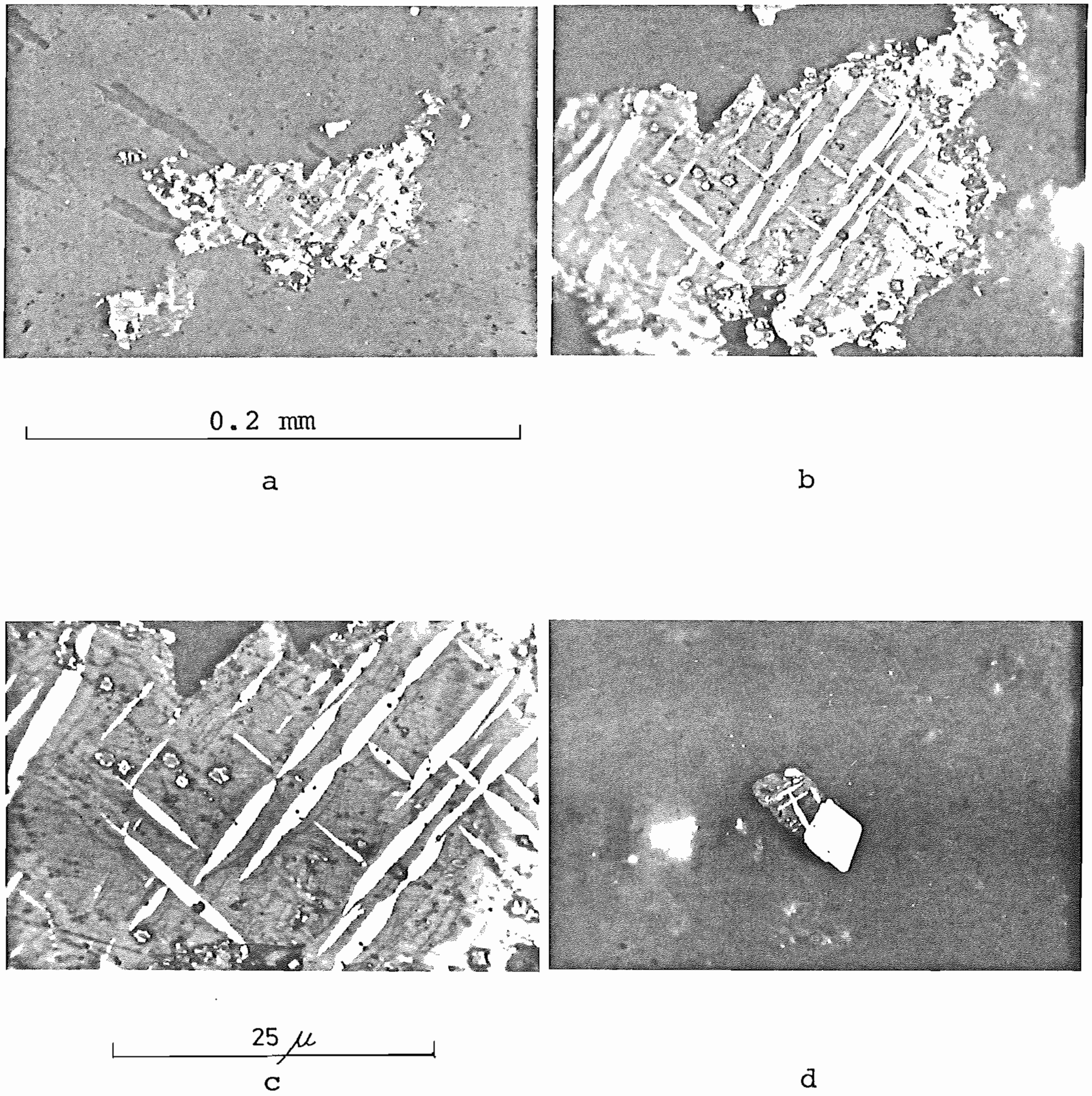


Plate V-22 Brierly Brook Area

50μ Scale unless otherwise indicated

grains. Traces of covellite rim the chalcocite in a few places. One tiny chalcopyrite-chalcocite intergrowth with grains of comparable size and one mutual boundary, shows a chalcopyrite lamellae extending from the solid chalcopyrite grain into the chalcocite (Plate V-22d). Another chalcocite grain contains lamellae and larger blebs of chalcopyrite (Plate V-23b).

Discrete pyrite framboids are not uncommon throughout the limestone. Some tiny framboidal pyrite grains are intergrown with chalcocite-digenite in a few places. Traces of sphalerite are found as minute, discrete grains which show rare mutual boundary intergrowth with chalcocite (Plate V-23c).

The mineralization in this limestone unit is thus very similar to the limestone unit of the James River area (section IIIA-6).

8- Sylvan Glen Area

a) Lower Conglomerate Unit

No mineralization is found in the crystalline calcium carbonate matrix of the lower red conglomerate. The only mineralization is hematite, found in volcanic pebbles, and iron oxide-filled matrix whose occurrence parallels the

Plate V-23

a Chalcopyrite exsolution lamelli in chalcocite (medium grey). Small, darker grey grains to the right are bornite. The chalcocite has probably replaced the bornite. Oil immersion.

Plate V-23

b Chalcopyrite lamelli and blebs (white) in chalcocite (medium grey). Oil immersion.

Plate V-23

c Bornite (dark grey), sphalerite (medium grey) and chalcocite (white) mutual boundary intergrowth. Bright white top of grain is titanium mineral. Oil immersion.

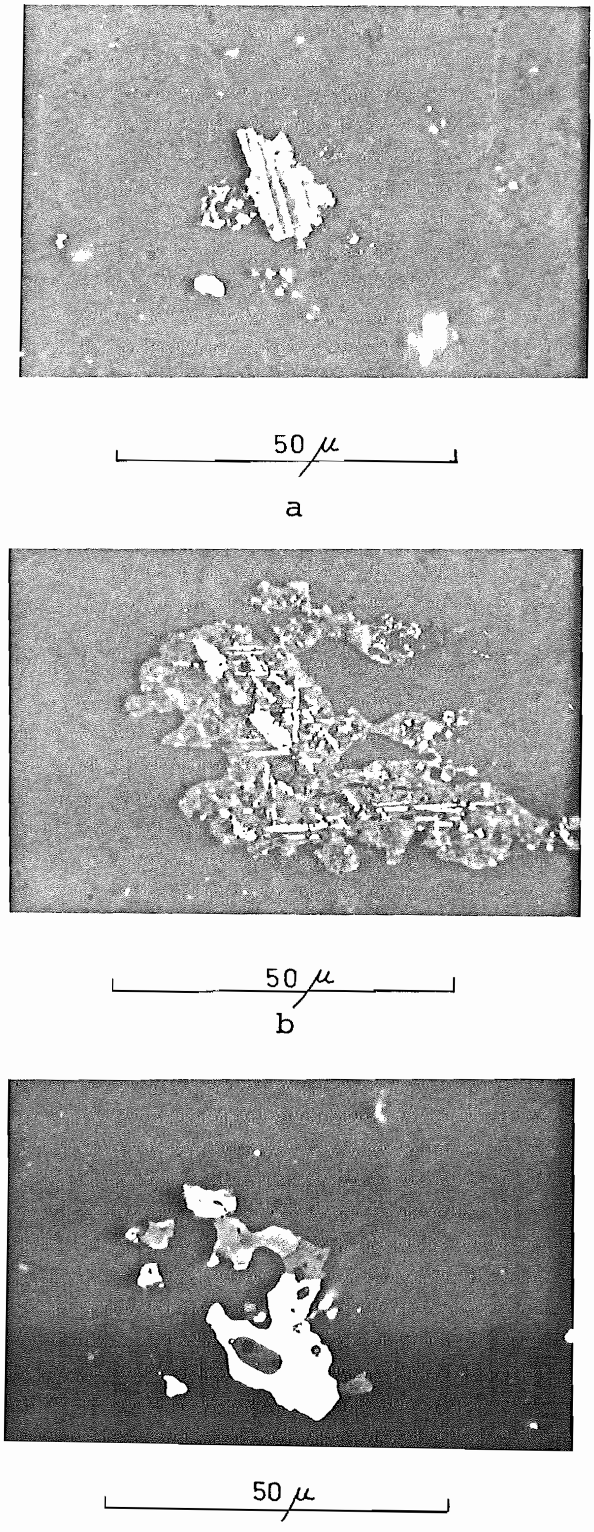


Plate V-23 Brierly Brook Area

James River and Brierly Brook lower red conglomerate units.

b) Upper Conglomerate Unit

Most of the matrix has been preserved in this unit probably because it is mainly a microcrystalline cement of clastic quartz grains and pebbles. The proportions of quartz clasts and carbonate is about equal.

The pebbles of the conglomerate contain some hematite and/or rutile mineralization like that of the upper conglomerate pebbles in other areas.

Minor amounts of covellite, sometimes with traces of chalcocite and bornite, are found associated with the malachite in the matrix and along or near fractures in silicious clasts.

The covellite occurs as 0.03-0.05 mm, anhedral to subhedral grains displaying prominent cleavage cracks (Ramdohr 1969). One grain contains bornite rimmed by chalcocite showing mutual boundary intergrowth with the covellite. The cleavage cracks in the covellite do not penetrate the chalcocite-bornite. One bleb of chalcocite with very irregular boundaries is also found in the covellite grain. The bulk of the covellite, however, occurs as small, discrete grains in malachite and/or iron oxide masses.

Detrital anhedral rutile and/or anatase is abundant while a few minute grains of chalcopyrite are present in some pebbles.

c) Transitional Limestone Unit

Mainly detrital rutile and/or anatase and minor sphene are found throughout the sandy limestone (Plate V-24a). In addition, trace amounts of chalcocite, sometimes rimming bornite, are found as <0.01-0.1 mm, anhedral grains disseminated throughout the matrix of the sandy limestone. Chalcocite rims form semi-transparent halos around bornite or solid chalcocite grains (Plate V-24b).

Only detrital rutile grains are found in the porous limestone sub-unit.

d) Limestone Unit

Mineralization in this unit consists principally of chalcocite (1%) with minor bornite, covellite, pyrite, sphalerite and traces of chalcopyrite. The mineralization, for the most part, is disseminated throughout the unit with the larger grains in particular being strongly alligned parallel to the limestone laminations (Plate V-24c, d).

Some discrete grains are present although intergrowths

Plate V-24

a Detrital rutile (white) and sphene (light grey) in sandy limestone. Sand grains, medium grey; limy matrix dark grey.

b Translucent chalcocite halos (medium grey) around solid chalcocite grains (white).

Plate V-24

c Allignment of chalcocite grains (white) along limestone laminations (dark grey).

Plate V-24

d Pyrite (white) found along inside rim of chalcocite (medium grey). Black areas of limestone are carbon coated.

e Pyrite (white) along rim and interior of chalcocite grain (light grain). Chalcocite(?) halo (medium grey) forms around solid chalcocite.

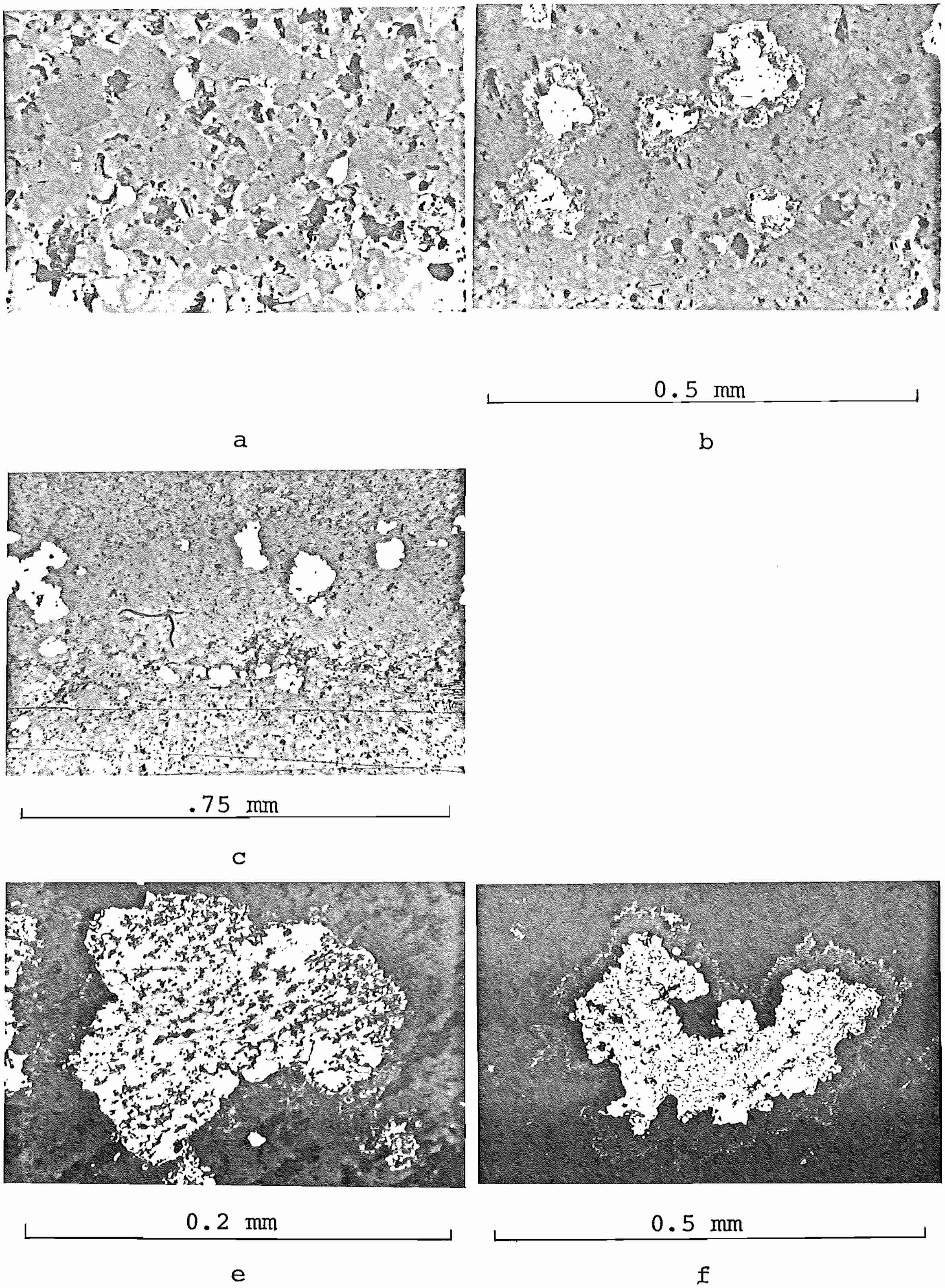


Plate V-24 Sylvan Glen Area

1 mm Scale unless otherwise indicated

are the predominant form of the sulfides.

The main intergrowth consists of 0.02-1.0 mm, anhedral grains of chalcocite containing small anhedral grains of pyrite with sharp but irregular boundaries. The pyrite often occurs near the chalcocite boundaries (Plate V-24e, f) and/or forms adjacent "core texture" (Schwartz 1951) rings within the chalcocite (Plate V-25a, b). The rings are not well defined. This texture strongly suggests replacement of pyrite by copper sulfides (Schwartz 1951, Park and MacDiarmid 1970). Whether chalcocite was the original metasome is not known. However, if it was not, then the chalcocite would have had to completely replace the original metasome. Chalcocite, whether intergrown with pyrite or existing discretely is sometimes replaced, to varying degrees, by covellite. The covellite usually forms thick lamellae, in some cases containing pyrite blebs (Plate V-25c). This indicates formation of covellite by a 'secondary' oxidation process. To a lesser extent chalcocite forms very irregular mutual boundary intergrowths with sphalerite. The pyrite grains are found within both chalcocite and sphalerite, some pyrite showing boundaries within both minerals (Plate V-25d, e). No paragenetic sequence can be formulated from the chalcocite-sphalerite intergrowth. One chalcocite-sphalerite intergrowth contains a more bluish grain of chalcocite rimmed with bornite, all showing mutual boundary intergrowth. Bluish chalcocite also forms mutual boundary

Plate V-25

a Core texture pyrite rings (light grey) in chalcocite (medium grey). Sphalerite (dark grey) forms mutual boundary intergrowth with chalcocite. Halo is speckled areas.

b Pyrite rings in chalcocite.

Plate V-25

c Lamellar covellite (medium grey) replacing chalcocite (light grey). Pyrite (white) is found in both the covellite and chalcocite. Two darkest grey areas are limestone, partially carbon coated.

d Sphalerite (dark grey), chalcocite (light grey) irregular intergrowth, probably replacing pyrite (white).

Plate V-25

e Sphalerite (dark grey) chalcocite (light grey) mutual boundary intergrowth. Some chalcocite appears to form framboids in the sphalerite.

f Chalcopyrite (white) chalcocite (medium grey centre of grain) and sphalerite (light grey, right) irregular intergrowth.

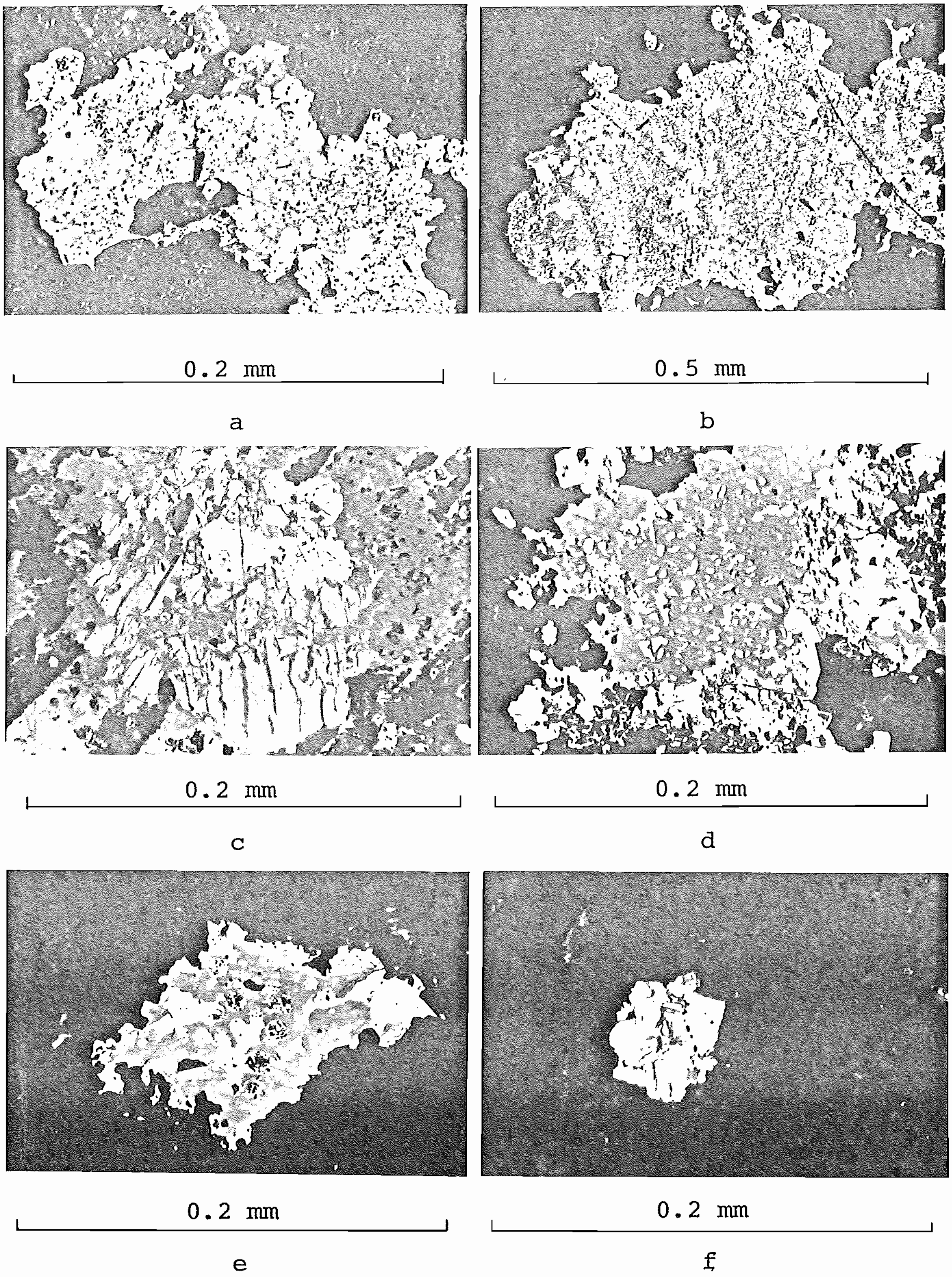


Plate V-25 Sylvan Glen Area

intergrowths with bornite which contain some tiny blebs of whitish-grey chalcocite. Bornite and chalcopyrite also form a common mutual boundary intergrowth and in some cases the chalcopyrite contains bornite blebs (Plate V-26b). Covellite may be associated with some bornite grains.

A trace of chalcopyrite exsolution lamellae in bluish chalcocite is found in a chalcocite-chalcopyrite mutual boundary intergrowth. Since chalcopyrite lamellae have previously only been found in and associated with bornite, this texture may represent replacement of bornite by chalcocite.

Pyrite (<1%) commonly occurs as small framboids disseminated throughout the limestone.

Addendum

Although tennantite was not observed in the Ohio Mineral assemblage, several stratiform copper deposits do report its presence. Tennantite does occur in copper bearing basal Windsor sediments elsewhere in Nova Scotia and has been identified by microprobe analysis in basal Windsor limestone at Cape Jack in Eastern Antigonish County (Plate V-27). This area is a site of the Horton-Windsor contact. Although only a reconasaince of this area was carried out, it undoubtedly has many similarities both stratigraphically

Plate V-26

a Chalcocite (grey) replaces a pyrite framboid. Oil immersion.

b Typical chalcopyrite (light grey) bornite (dark grey) mutual boundary intergrowth.

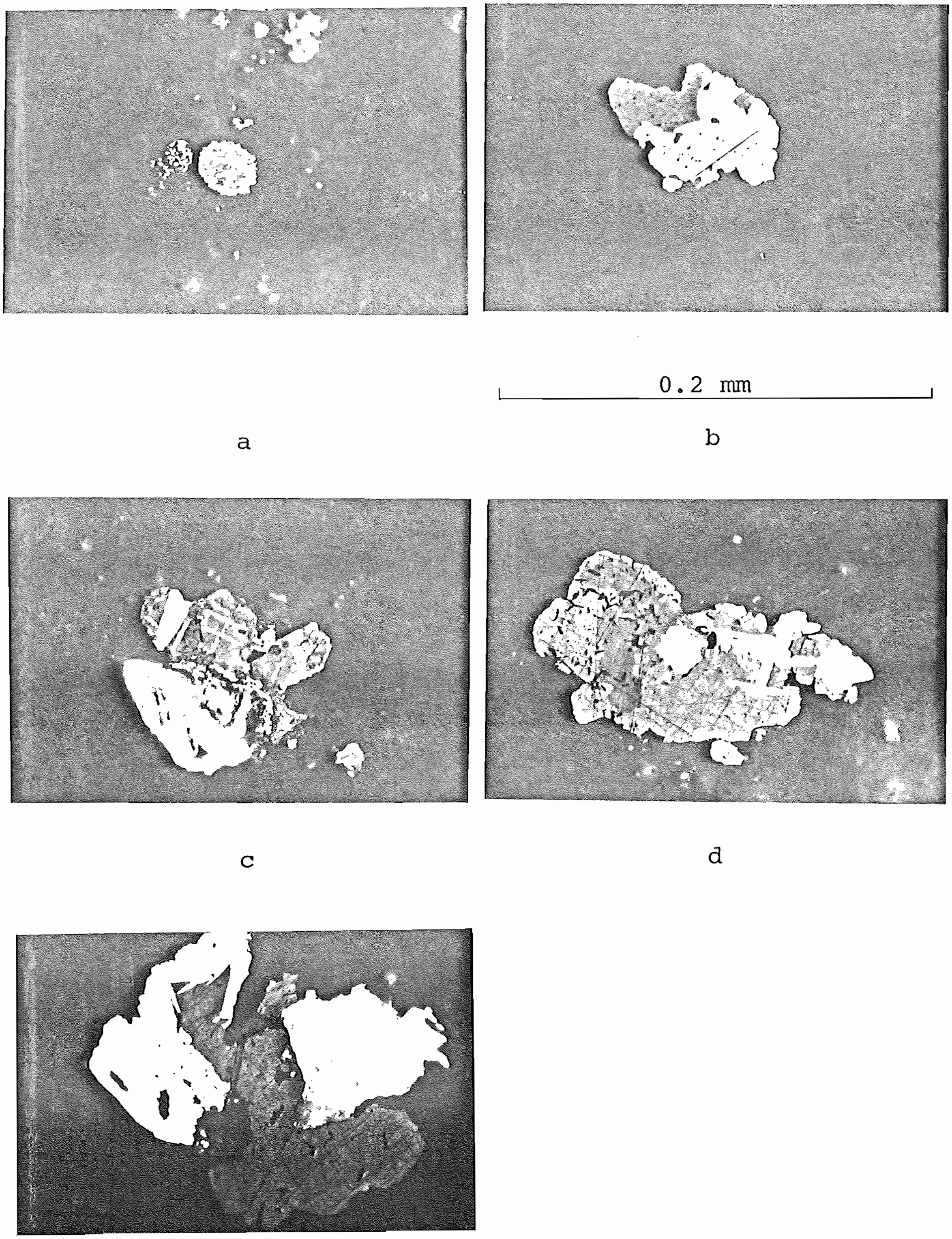
Plate V-26

c Chalcopyrite exsolution lamelli (white) in chalcocite (dark grey). Bright white at bottom is a rutile grain. Oil immersion.

d Chalcopyrite exsolution lamelli, blebs and lenses (white) in bornite (dark grey).

Plate V-26

e Chalcopyrite (white, left) bornite (dark grey) intergrowth. Bright white (right) is rutile grain. Oil immersion.



a b

c d

e

Plate V-26 Sylvan Glen Area

Plate V-27

From Basal Windsor limestone at Cape Jack, Antigonish County. Complex intergrowth consisting of tennantite (light grey), bornite (dark grey, right), sphalerite (medium dark grey, centre), chalcopyrite (medium light grey, left), chalcocite (white, bottom centre) and possibly galena (white, middle left). One tiny intergrown pyrite grain is not visible at this magnification.

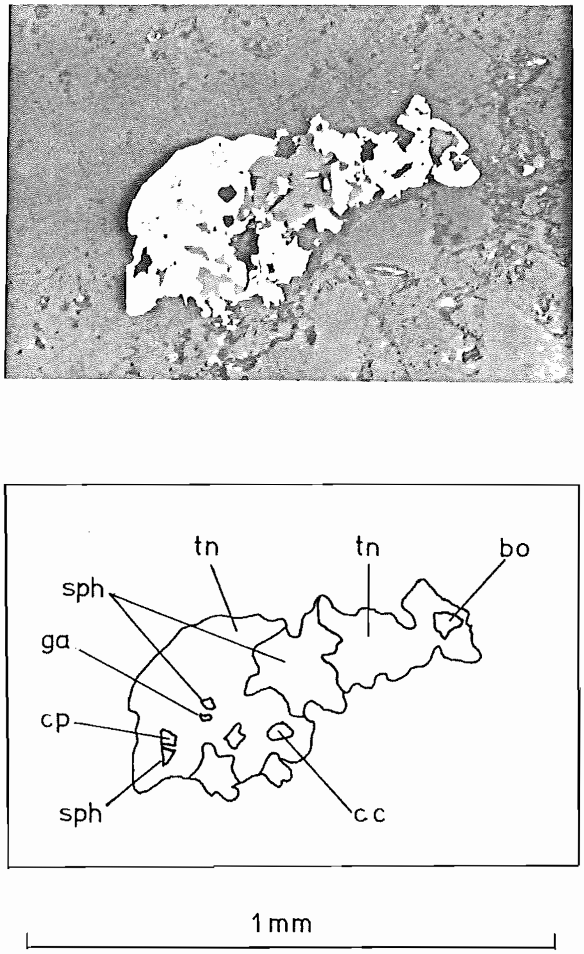


Plate V-27

and mineralogically, to the Antigonish Basin.

B) Mineralization Summary

1- Texture

a) Chalcopyrite

Chalcopyrite generally forms as anhedral, 0.02-1.0 mm grains disseminated throughout the host lithologies. It may constitute up to about 5% of the rock, but generally averages from 0.5% to only trace amounts.

Chalcopyrite commonly replaces pyrite, and forms the only unambiguous paragenetic relationship in the mineral assemblage. Mutual boundary intergrowths of chalcopyrite with much less abundant sphalerite, and rare galena are found in places. Chalcopyrite forms exsolution lamellae in bornite and possibly digenite-chalcocite as well as mutual boundary relationships with both minerals. It also forms less abundant mutual boundary textures with digenite and covellite.

Bateman (1923 in McKinstry 1959) reports that chalcopyrite-chalcocite assembalges are uncommon, thus the chalcocite referred to above may not be stoichiometric.

b) Pyrite

Pyrite forms anhedral to euhedral, usually brecciated, 0.01-0.03 mm grains disseminated throughout the host lithologies. It also is found discretely as 0.01-0.03 mm framboids in the limestone units. It usually occurs discretely and constitutes about 1-2% of the host rock. Pyrite shows replacement by chalcopyrite and mutual boundary intergrowth, to some extent, with all other 'ore' minerals.

c) Sphalerite and Galena

Sphalerite usually occurs in trace amounts but may constitute 1% of the host and forms anhedral, 0.01-0.05 mm grains. It shows mutual boundary intergrowths with chalcopyrite and, rarely, galena, but in most cases occurs discretely. The sphalerite, where intergrown, is usually found as blebs within larger chalcopyrite grains.

Galena occurs only as rare, subhedral, 0.02 mm grains, usually discrete but in some cases showing mutual boundary relationships with chalcopyrite and sphalerite. One exception is the Reigle showing, where boulders of upper basal carbonate may contain 1-2%, subhedral to euhedral grains of galena.

d) Bornite-Chalcocite-Digenite-Covellite

These copper sulfides may constitute 1-4% of the host rocks. The minerals usually occur as discrete, 0.02-1 mm, anhedral grains disseminated throughout the host lithologies. However, mutual boundary intergrowths of all four minerals, in all combinations (covellite is probably secondary) are very common. Pyrite commonly forms blebs within the chalcocite-digenite.

2- Distribution

The location of the various areas is shown on Map 3. The area from Cross Roads Ohio to Pinkietown (St. Joseph) is considered the Southern section while the area between James River and Sylvan Glen forms the Northern section. No conclusions on vertical zoning of the mineralization are possible as the whole mineralized stratigraphic assemblage is not present at all locations. A study of drill core mineralization may reveal this relationship.

a) Chalcopyrite

Chalcopyrite is distributed mainly in the Southern section of the area. It constitutes an average (from polished thin section estimates) of about 0.5%, but may make up to 25% of the breccia and tuff units in some areas

(Fig. V-5). A few slides were comprised almost entirely of chalcopyrite, but these anomalous values were selected for study of the textures and are not considered in the estimation of averages.

Chalcopyrite is most abundant in the calcite-shear zone in the tuff unit at Cross Roads Ohio as well as the breccia unit at the MacLean showing. It also occurs in quantities of about <0.5-1% in the limestones and shear zone of the MacLean Showing, the breccia of the Ohio Iron occurrence (no data is available for the limestone at this area), the volcanics of the Reigle Area, and the breccia and volcanics of the Pinkietown occurrence (no limestone data available). It is found only as traces in the volcanics of the Ohio Iron Area.

In the Northern section, it is found in quantities up to about 0.5%, only in the limestones of James River. Northeast of this area, the chalcopyrite is found only in trace amounts. However, since the conglomerate in this area has been leached and oxidized (see section II-A), no conclusions on the abundance of chalcopyrite in this unit may be reached. Nevertheless, the chalcopyrite abundance does diminish greatly in the limestone at Sylvan Glen and bornite-chalcocite predominates the limestones in the Northern section. This would indicate a change in mineralogy from iron-rich copper sulfides in the south to relatively iron deficient copper sulfides in the the north.

b) Pyrite

Pyrite constitutes approximately 1-3% of all rock lithologies in the Southern section as well as the limestone at James River. Northeast of this area the pyrite decreases to about 0.5% or less in all units.

Pyrite and hematite each commonly constitutes 5-15% of the volcanic units studied and usually form an inverse relationship of abundance in any one volcanic unit (Fig. V-5).

c) Sphalerite & Galena

Sphalerite is found almost exclusively in the breccia and limestone units of the MacLean Showing. It constitutes approximately 0.5-1% and its abundance generally increases with the proportion of chalcopyrite.

Traces of sphalerite are found in the limestones at all locations in the Northeastern section.

The galena distribution parallels that of sphalerite in the MacLean units although it occurs only in trace amounts. A higher concentration of galena (1%) is found in boulders of the upper basal limestones at the Reigle showing. These boulders are believed to be nearly in situ (Boehner 1979).

d) Bornite-Chalcocite-Covellite

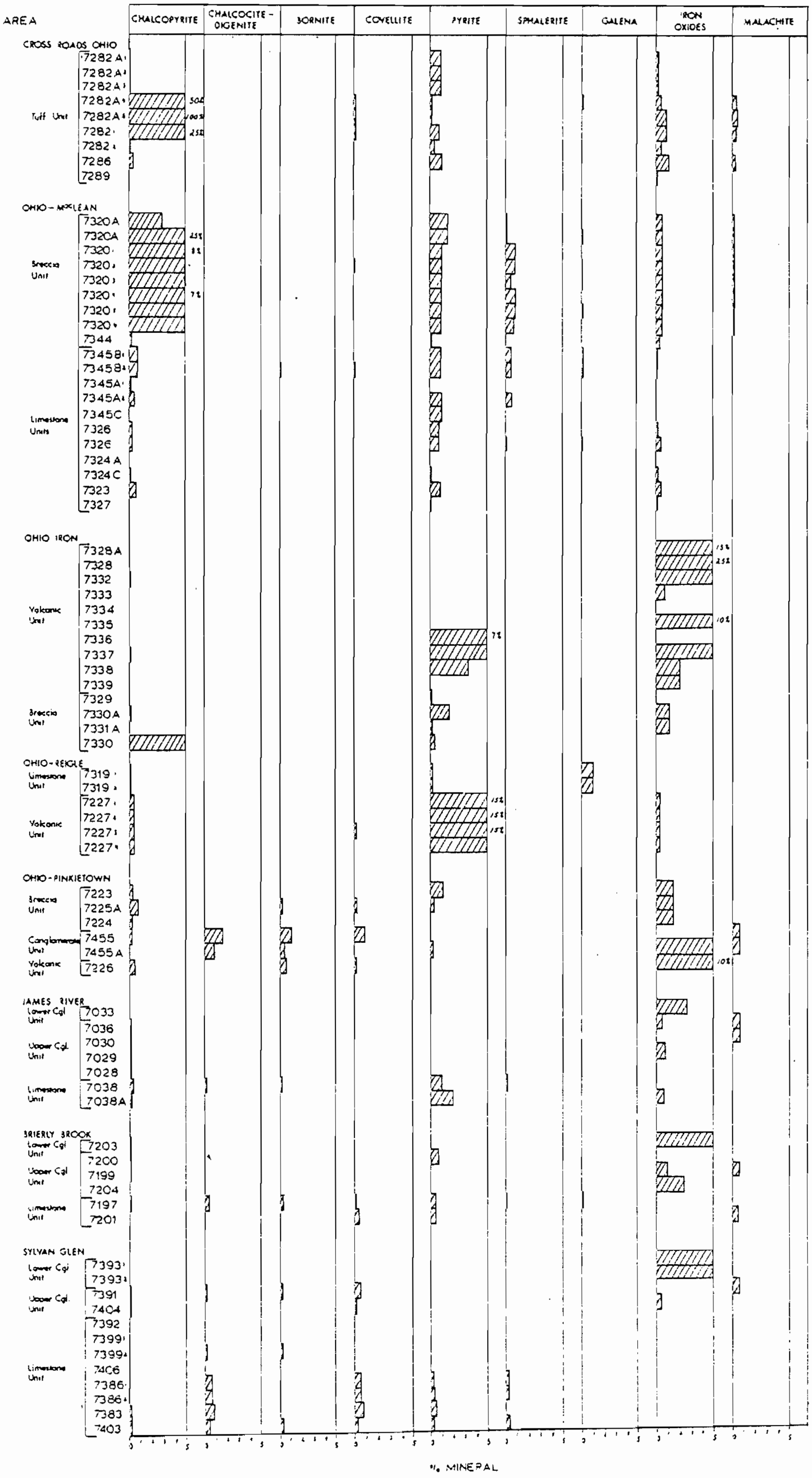
These three minerals generally occur together. Covellite is probably a secondary oxidation product and is thus more widespread than bornite and chalcocite. However, its greatest abundances are associated with the copper rich sulfides, while only trace amounts are found associated with chalcopyrite.

Traces of bornite are found in the breccia units of the MacLean and Pinkietown occurrences. However, its abundance sharply increases to 0.5-1% in the conglomerate unit at Pinkietown. It is also found in moderate abundances in the James River and Brierly Brook limestones, and the upper conglomerate and limestone of Sylvan Glen.

The chalcocite distribution generally parallels that of the bornite. However, chalcocite is found only in, and to the northeast of, Pinkietown conglomerate (north of Pinkietown breccia). Its greatest concentration (0.5%) is in the limestone unit at Sylvan Glen and the conglomerate at Pinkietown.

With the exception of the barren conglomerates at James River and Brierly Brook, a change in the mineralogy

Figure V-5 Visual modal analysis of ore minerals from the Ohio - Sylvan Glen copperbelt. Numbers refer to sample numbers in Appendix II-A. Cgl = Conglomerate.


AREA
CHALCOPYRITE
CHALCOCITE - DIGENITE
BORNITE
COVELLITE
PYRITE
SPHALERITE
GALENA
IRON OXIDES
MALACHITE
CROSS ROADS OHIO
Tuff Unit
7282 A
7282 A
7282 A
7282 A
7282 A
7282
7282
7286
7289
50%
100%
25%
OHIO - McLEAN
Breccia Unit
7320A
7320A
7320
7320
7320
7320
7320
7320
7344
25%
8%
7%
Limestone Units
7345B
7345B
7345A
7345A
7345C
7326
7326
7324 A
7324 C
7323
7327
OHIO IRON
Volcanic Unit
7328A
7328
7332
7333
7334
7335
7336
7337
7338
7339
15%
25%
10%
7%
Breccia Unit
7329
7330A
7331 A
7330
OHIO - REIGLE
Limestone Unit
7319
7319
Volcanic Unit
7227
7227
7227
7227
15%
15%
15%
OHIO - PINKIETOWN
Breccia Unit
7223
7225A
7224
Conglomerate Unit
7455
7455 A
Volcanic Unit
7226
10%
JAMES RIVER
Lower Cgl Unit
7033
7036
Upper Cgl. Unit
7030
7029
7028
Limestone Unit
7038
7038A
BRIERLY BROOK
Lower Cgl Unit
7203
7200
Upper Cgl Unit
7199
7204
Limestone Unit
7197
7201
SYLVAN GLEN
Lower Cgl Unit
7393
7393
Upper Cgl. Unit
7391
7404
Limestone Unit
7392
7399
7399
7406
7386
7386
7383
7403
0 5
% MINERAL

of all units from iron rich copper sulfide (chalcopyrite) to iron deficient copper sulfides (bornite-chalcocite) occurs from the Southern to the Northern sections of the area. The change is quite abrupt and occurs where the breccia and conglomerate units pinch out laterally at Pinkietown. Chalcopyrite is generally associated with the breccia-limestone contacts whereas bornite-chalcocite is generally found along the conglomerate-limestone contacts.

C) Interpretation of Ohio - Sylvan Glen Prospect

1- Comparison of Ohio with Stratabound Base Metal Deposits

a) Missippi Valley Type Deposits

Although it is not immediately obvious, the Ohio area offers some similarities to the Mississippi Valley type deposits, since the mineralization, although containing only traces of lead-zinc, is predominantly associated with carbonate rocks (Brown 1967). However, more detailed comparison of the Ohio area with the literature concerning these Mississippi Valley deposits (Snyder 1966, Callahan 1966, Ohle 1966, Maucher and Schneider 1966, Taupitz 1966, Dunoynik 1966, Kautzsch 1966, Beales and Jackson 1968) precludes classifying its mineralization and depositional environment as Mississippi Valley type. Nevertheless this does not preclude the possibility that mechanisms involved in the Mississippi Valley deposits were also operative at Ohio. The environment of deposition at Ohio is fully discussed in the following section.

One Ohio occurrence (Reigle) however, may possibly be classified as Mississippi Valley type mineralization. Its diagenetic (galena) infilling of calcite cavities in skeletal limestone shows great similarity to the Gay's River deposit near Halifax, Nova Scotia (MacLeod 1978, Schenk 1979, MacEachern and Hannon 1974). However, within the map area the only evidence of this mineralization comes from boulders. Nevertheless a Gay's River type of deposit could conceivably exist (above the copper mineralization?) and deeper in the structural basin. Processes involved in the copper deposition may have been associated with the lead mineralization higher in the stratigraphic sequence as is briefly discussed in the following section.

b) Stratiform Copper Deposits

(I) Comparison of Stratigraphy and Mineralization

(i) Kupferschiefer

Ohio shows an immediate similarity to Kupferschiefer deposits in that it is almost exclusively a copper bearing, carbonate-rich sediment. Fig. V-7 indicates that the elemental distribution in rock units at Ohio approximates that of the deposits used in comparison. However, similarities become even more evident on microscopic examination of the ore minerals and the host rocks.

Data concerning the geology of the Kupferschiefer is taken largely from Jung and Knitzschke (1976) and Rentzsch (1974). The Kupferschiefer is contained within a molasse sequence above a palaeozoic basement in the German Democratic Republic as well as elsewhere in Europe. The Kupferschiefer itself consists of a marine sequence with a basal unit of grey, sandy to limy, conglomerates and sandstones. Transgressive over this is the "ore horizon" or Kupferschiefer, made up of finely laminated carbonaceous clayey marlstones and clayey carbonate rocks. Its thickness varies between 25 and 60 cm. Overlying this unit is the hangingwall made up of a shallow water, grey limestone. A sequence of evaporites lies above the limestone. A generallized stratigraphic column of the Kupferschiefer is remarkably similar to that of the Ohio area (Fig. V-6).

The depositional environment of the Kupferschiefer is interpreted as a shallow sea with an euxinic saprolitic facies (Jung and Knitzsche 1976).

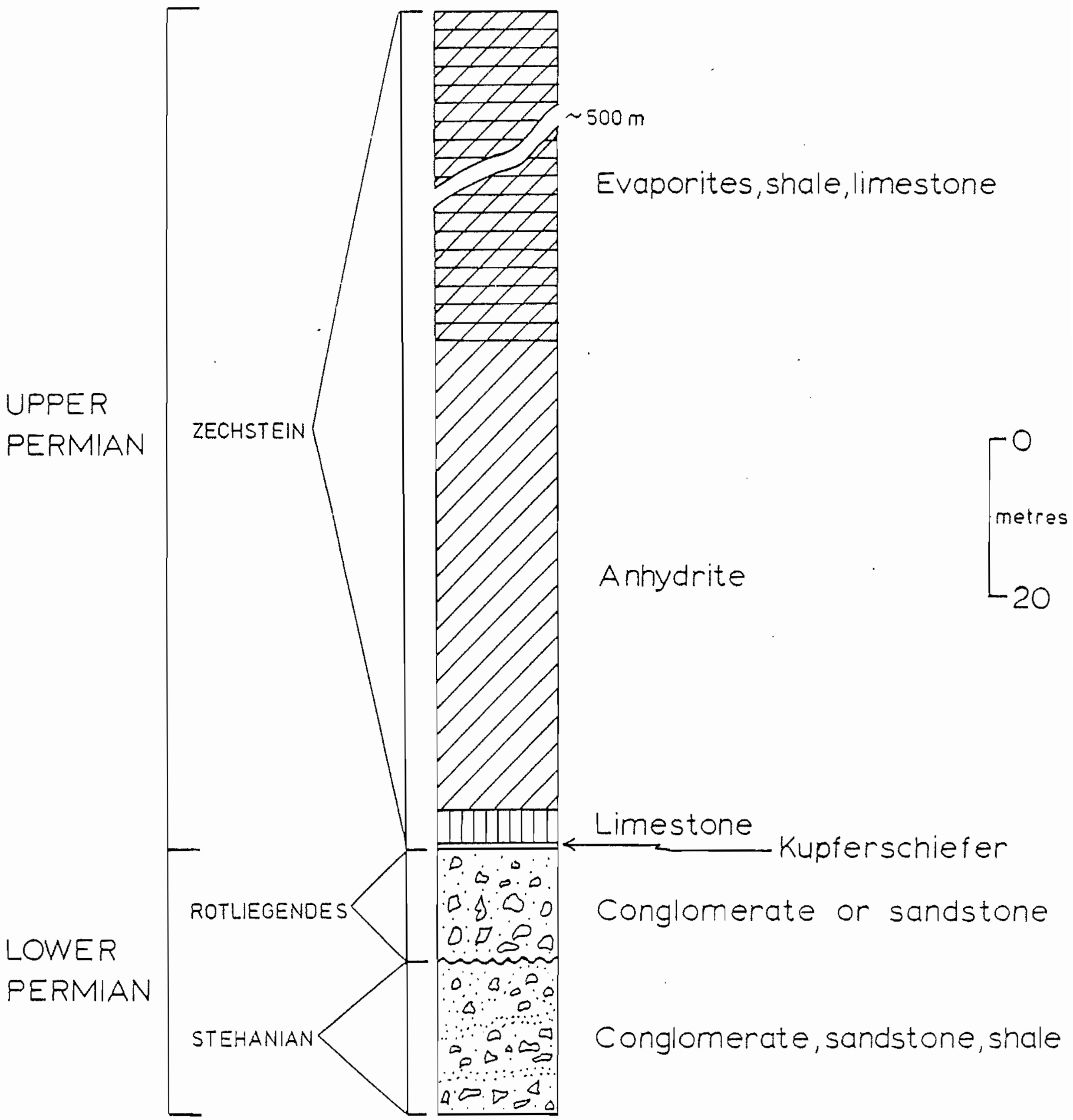


Figure V-6 Stratigraphic sequence of the Kupferschiefer. Thickness of units (after Jung and Knitzschke 1976) are averages.

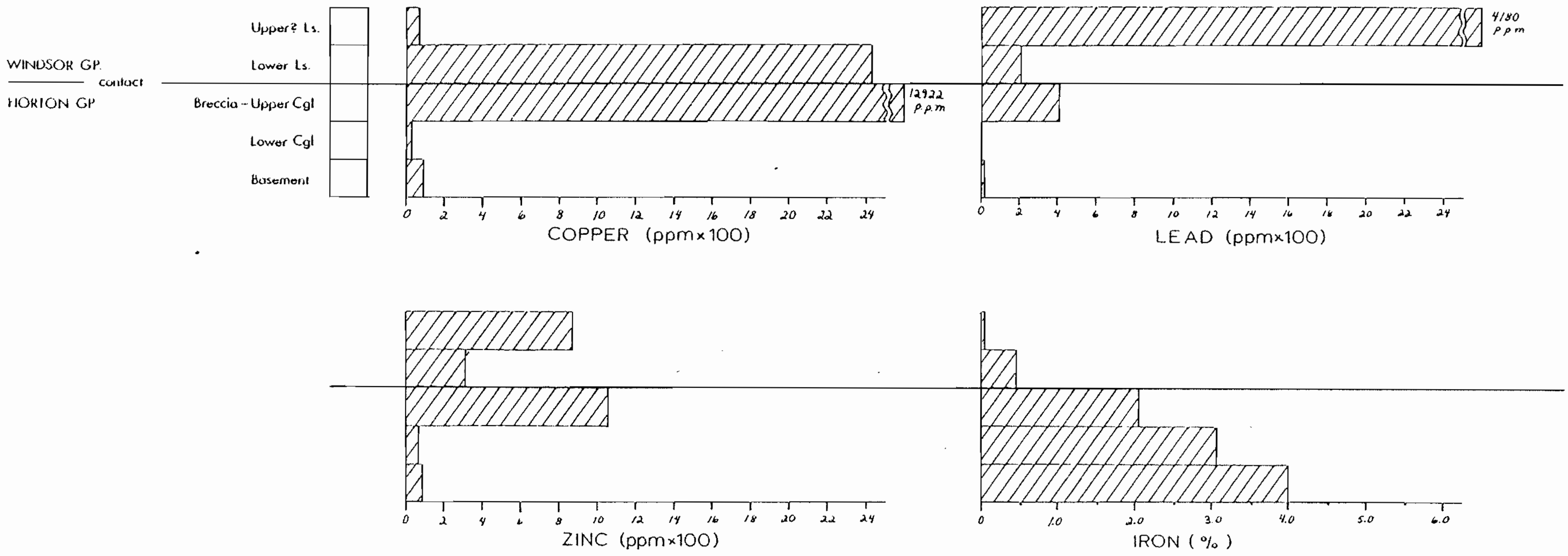


Figure V-7 Elemental distributions in the stratigraphic sequence of the Ohio-Sylvan Glen copperbelt. Rock unit thickness not drawn to scale. Cgl. = conglomerate, Ls = limestone.

Ore Minerals

Mineral assemblages in the Kupferschiefer nearly duplicate those found at Ohio. Hematite is the predominant mineral in the red coloured parts of the ore zone. Covellite forms as a lamellar decomposition product of bornite. Chalcocite-neodigenite occur discretely as well as in intimate intergrowth (replacement?) with bornite. Some bornite contains chalcopyrite (replacement?) lamellae. Chalcopyrite commonly replaces pyrite. Pyrite forms framboids in some cases. Galena and sphalerite are present to a minor extent. The ore minerals are disseminated throughout the ore horizon and are believed to replace the carbonate matrix (Jung and Knitzschke 1976). Although the total mineral assemblage (Renizsch 1974, Jung and Knitzschke 1976) varies somewhat from Ohio in minor and trace sulfides, the resemblance of the two mineralizations is obvious (see section III-A).

(ii) Zambian Copper Belt

Data concerning the geology of the Zambian (Rhodesian) Copper Belt are obtained from Bateman (1930), Mendelsohn (1961), Davis (1954) and Fleischer, Garlick and Haldane (1976).

Unconformably overlying the granitic basement of this copperbelt is a basal sequence of talus screes, conglomerates and sandstones (footwall). A transgressive sequence of carbonate-containing argillaceous rocks (the ore horizon) overlies the basal unit. The mineralization is restricted to these near-shore sediments. This succession, known as the Lower Roan, gives way to the Upper Roan comprising dolomites and dolomitic argillites with beds of anhydrite. The environment of deposition is generally regarded as transgressive, shallow marine (Van Eden 1974).

Ore Minerals

Pyrite is probably the earliest sulfide, although it also grows contemporaneously with chalcopyrite in some cases. Chalcopyrite generally occurs as discrete grains and stringers which in many cases replace detrital quartz and feldspar grains. It also commonly forms mutual boundary relationships with bornite. This texture is interpreted by Davis (1954) as contemporaneous growth, while Jackson (1932) believes the bornite is an intermediate stage in the replacement of chalcopyrite by chalcocite. Chalcocite is commonly found as discrete grains. The significance of the ore textures will be discussed in section C-II.

The mineralogy of the ores of the Zambian copper belt consequently show a striking similarity to those of the Ohio area.

(iii) White Pine, Michigan

The geology of the White Pine Deposit in Michigan is described in White and Wright (1954, 1966), Ensign et al (1968) and Brown (1971). The copper mineralization is found in the lower Nonsuch Shale, a unit comprising grey, well bedded siltstone and shale. The shale overlies a thick sequence of red sandstones and conglomerates which, in turn, overlie Keweenawan volcanics. Copper mineralization also occurs near the grey, calcareous top of the predominantly red, non-calcareous conglomerate unit.

Overlying the cupriferous zone are thick units of siltstone, shale and sandstone belonging to the Nonsuch Shale, above which is the Freda Sandstone.

A repetition of sediment sequence at White Pine represents cyclic sedimentation. The sequence suggests "progressive inundation of a sand plain, with deltas of sand built out beyond the main shoreline at the mouths of streams" (White and Wright 1954). The shale and silts are believed to have been deposited in a lagoonal environment. Sedimentary features suggest a shallow water origin for the sequence.

Ore Minerals

Pyrite forms the dominant sulfide in the pyritic zone which overlies the cupriferous zone, and occurs as discrete euhedra and framboids. In the cupriferous zone, chalcocite forms pseudomorphs after pyrite and shows mutual boundaries with digenite and bornite. Chalcocite also forms lamellar intergrowths with digenite and, in many cases, contains core fragments of replaced pyrite. Digenite forms mutual boundary associations with bornite, covellite, chalcocite, chalcopyrite and pyrite. Bornite occurs in two forms; one which readily tarnishes purple and one which retains its pink colour. The pink bornite is strongly suggestive of the "sulfur-rich bornites" found experimentally by Brett and Yund (1964), since chalcopyrite exsolved from them with artificial annealing (Brown 1971). The purple bornite is commonly found in mutual boundary contact with chalcocite while the pink bornite generally occurs as discrete grains and in mutual boundary association with digenite. Because of the difficulty in optical differentiation of chalcocite and digenite (several bluish-grey hues were observed, see section III-A) and the scarcity of sulfur-rich bornites in the Ohio rocks, no correlation between purple bornite - chalcocite and pink bornite - digenite could be derived from the Ohio area. However, the relationships found by Brown (1971) probably also hold for Ohio since the textural descriptions match very closely. Also found at White Pine is chalcopyrite which occurs as discrete grains and in associations with bornite and digenite. Sparcely disseminated grains of galena and wurtzite have also been found in the mineralized zone.

Other minor sulfides (usually in trace amounts) are reported from all the above-mentioned copper deposits. These have not been described here since they have not been identified at Ohio. However their presence may be detected in a more detailed petrographic study of the area.

(iv) Other Deposits

Stratigraphies and mineralization similar to those of the Ohio area are reported for 'red bed' deposits all over the world. Among these are the occurrences of copper in the shales and siltstones of the Adline Island Formation (Seal Lake Group) of Labrador (Grandhi and Brown 1975). The copper shales are very similar to those of White Pine. The ore minerals consist mainly of chalcocite, digenite and bornite, which occur as discrete grains or intergrown in all combinations. A digenite rim commonly separates bornite from chalcocite. This relationship has been observed at Ohio (section III-A) and will be discussed further in section III-C-II. Bornite occurs as both pink and purple varieties. The same intergrowth relationships with chalcocite and digenite are found here as at White Pine. The pink bornite may show lamellae of chalcopyrite which indicates annealing at temperatures over 75°C (Brett and Yund 1964), probably during metamorphism. This area is the only one of the four deposits studied from which natural chalcopyrite exsolution lamellae in bornite have been reported. However, chalcopyrite 'replacement'(?) lamellae in bornite have been reported in the Kupferschiefer (Jung and Knitzschke 1976) while exsolution lamellae are suggested in sketches of photomicrographs of the ores of the Road Antelope Deposit (Davis 1954). MacKay and Zentilli (1976) report chalcopyrite exsolution lamellae in bornite from Black Brook, Nova Scotia.

Similar mineralogy in the "red beds" of Wentworth Centre, Nova Scotia and Dorchester, New Brunswick are reported by Papenfus (1931) and at Black Brook, Nova Scotia by MacKay and Zentilli (1976). Chalcocite replacing pyrite which has replaced plant remains and cement in the sediments belonging to those deposits suggests a low temperature mode of formation since the cell structures of replaced plants have not been destroyed.

Binney (1975a) reports similar mineralogy to Ohio, with the exception of chalcopyrite exsolution, in a Carboniferous basin in Cape Breton. The stratigraphy of the basin is nearly identical to the Antigonish Basin. Binney (1975b), Binney and Kirkham (1974, 1975) and Kirkham (1971, 1978) report similar copper occurrences in Carboniferous basins elsewhere in Atlantic Canada.

Other stratiform 'red bed' copper deposits occur in Colorado, Oklahoma, Texas, New Mexico, Idaho, Utah and Arizona (Finch 1933, Woodward et al 1974). Uranium may be a major constituent of these ores (Fischer 1968) although it was not detected at Ohio. The Dzhezkazgan deposit in the U.S.S.R. is also classified as a stratabound sedimentary copper deposit (Bogdanov and Kutyrev 1973, Samonov and Pozharisky 1977).

With the exception of chalcopyrite exsolution, the mineral assemblages discussed have been noted by McKinstry (1959) to be especially common in the higher temperature deposits such as Butte, Montana. Covellite in these deposits is generally a supergene, secondary mineral (McKinstry 1959, Yund and Kullerud 1966).

It is, therefore, evident that the Ohio Area shows stratigraphic similarities to all the described deposits. However, the lithologic succession most closely resembles that of the Kupferschiefer (Fig. V-6). Similarily, the mineralization at Ohio parallels nearly all of the discussed deposits. However, before examining models for the origin for the deposit, some interpretation of the ore textures must be made.

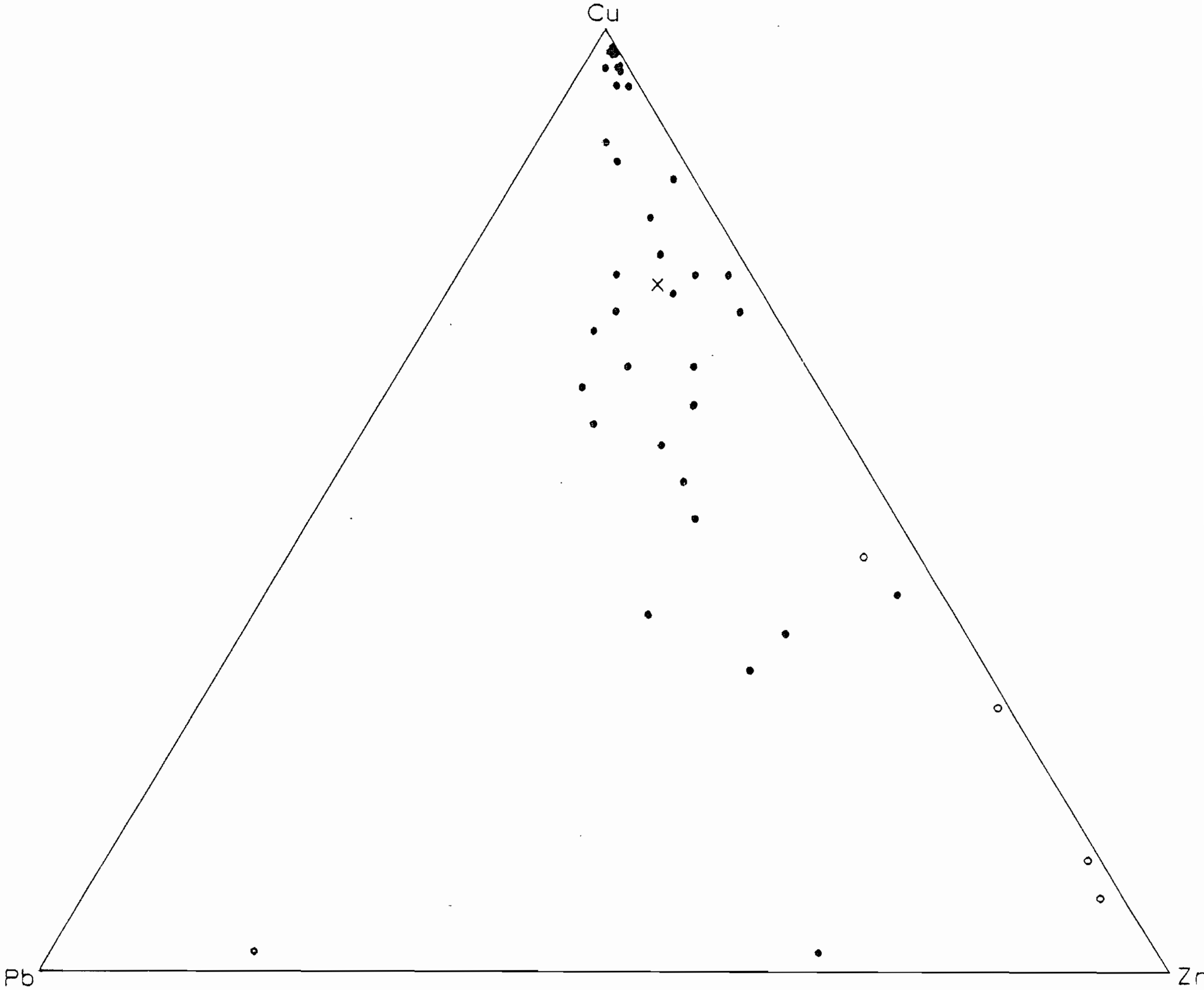


Figure V-8 Atom per cent copper-lead-zinc relations in samples from the Ohio-Sylvan Glen Copperbelt.

- ● sample from copper bearing zone
- ○ sample in sediment below copper bearing zone
- ∘ sample in limestone above copper bearing zone
- × average atom per cent relations of samples from the copper bearing zone

Name	Ore Minerals	Host Rock - Age	Morphology - Ore Characteristics
Ohio - Sylvan Glen Copperbelt	cp, bo, cc, di	conglomerate limestone - Lower Carboniferous	stratiform - disseminated
Kupferschiefer	bo, cc, di, cp	carbonate bearing marlstone - Permian	stratiform - disseminated
Zambia	cp, bo, cc	conglomerate carbonate bearing argillaceous rocks - Upper Proterozoic	stratiform - disseminated
White Pine	cc, di, bo, cp	shale - Upper Proterozoic	stratiform - disseminated
Adline Island	cc, di, bo	shale - Late Proterozoic	stratiform - disseminated
Lake Enon, Nova Scotia	cp, bo, cc	conglomerate limestone - Lower Carboniferous	stratiform - disseminated

Table 3

Summary Comparison of Ohio -

Ore Genesis	Paragenesis	Framboids	Stratigraphy	Exsolution
epigenetic replacement by compaction and dewatering	cp replaces pyrite cu-rich sulfide replace cp	pyrite	evaporites ore horizon basement	cp in bo
epigenetic syngenetic?	cp replaces py cu-rich sulfides replace cp	pyrite	evaporites ore horizon basement	cp in bo?
epigenetic syngenetic?	cp replaces gangue cu-rich sulfides replace cp	?	evaporites ore horizon basement	cp in bo?
epigenetic	cu sulfides replace py	pyrite	shales ore horizon conglomerate basement	cp in bo
epigenetic	cu-rich sulfides replace fe-rich sulfides	pyrite	quartzite ore horizon conglomerate volcanics basement	cp in bo
epigenetic	cu-rich sulfides replace matrix of host	pyrite	evaporites ore horizon basement	

Sylvan Glen With Other Deposits

(II) Interpretation of Ore Intergrowths

(i) Mutual Boundary Textures

The ore intergrowths of other deposits, where referenced, are identical or nearly so to those of the Ohio area. Comparison is made on the basis of descriptions and photomicrographs. Thus the photomicrographs of the Ohio area may proxy for the ore textures of other areas.

White and Wright (1966) and Brown (1971) interpret the White Pine ore textures as copper sulfide replacement of pyrite. This conclusion is based on copper and copper-iron sulfide pseudomorphs after pyrite, and remnant pyrite cores in copper sulfides (see Plates V-2, 25a & b for similar textures at Ohio). The replacement of pyrite by chalcopyrite is a very common ore texture. Gustafson (1963) speculates that the texture is due to an incongruent precipitation of chalcopyrite with pyrite from solution. Brett (1962b) postulates that all assemblages involving pyrite cannot be definitely regarded as equilibrium assemblages. Brown (1971) further suggests that the replacement of pyrite is a step by step process to ultimately produce chalcocite from decreasingly iron rich copper sulfides (i.e. bornite to digenite to chalcocite). Brett (1962b) also suggests that a pyrite-chalcocite assemblage that lacks digenite or bornite indicates that the two minerals were not formed simultaneously.

Further evidence suggesting a step by step replacement of pyrite is found in the Adeline Island shales in Labrador. Here, a rim of digenite commonly separates bornite from chalcocite (Gandhi and Brown 1975). Conclusions based predominantly upon mineral zoning and ore texture at White Pine and Adeline Island have led to the same paragenetic model for the two deposits. Since this texture is also observed in the Ohio assemblage together with crude mineral zoning like that at White Pine (Figs. V-5, V-7) it is concluded that the paragenesis of the deposits are similar.

Similar ore intergrowths in the Zambian Copperbelt (Davis 1954, Bateman 1930) have been interpreted as contemporaneous growth (Bateman 1930), partly contemporaneous and partly replacement (Gray 1932) and solely replacement (Jackson 1932). Their origin is probably similar to the above model as suggested by Davis (1954). Graphic intergrowths reported in the Zambian and Kupferschiefer deposits are not found at Ohio but do not conflict with a hypogene replacement model (Davis 1954). Replacement textures of pyrite are also evident in the Kupferschiefer, as are the chalcopyrite, bornite, digenite, chalcocite relationships. Jung and Knitzschke (1967) also interpret these textures as successive replacements by increasingly copper rich sulfides.

The difficulties and falacies in assuming replacement or any other paragenetic relationship of two or more intergrown minerals has been established by Schwartz (1939), Ramdohr (1969), Brett (1964) and Schouten (1934, 1946). Barton (1963) shows how subsequent remobilization of sulfides may hinder the paragenetic interpretation of ore intergrowths.

Whether actual structural replacement of stoichiometric minerals is involved in the processes (other than pyrite replacement) discussed above is unknown. Exchanges of iron and copper by diffusion in copper-iron assemblages may be sufficient for the transformation of copper-iron minerals to more copper-rich minerals.

The physics and/or chemistry of these exchanges is beyond the scope of this paper. However, low temperature, solid state and solution ion exchange has been demonstrated to be involved in the production of new minerals from various metasomes.

Zies et al (1906) produced various interchanges of copper and iron sulfides by heating various sulfides up to 200°C in solutions of copper sulfate. Park (1931) showed that steam passing over chalcopyrite forms bornite, chalcocite and magnetite. Many other combinations of reactants were used in Park's experiments including copper chloride complexes plus steam and hydrogen sulfide which yielded chalcocite and covellite. Thus the production of sulfides from chloride complexes (Helgeson 1964, Barnes and Czamanske

1967, Vaughan 1976, and Krauskopf 1967) on encountering hydrogen sulfide of probable organic production, appears feasable. Roberts (1961) formed chalcopyrite by the contact of chalcocite and pyrrhotite in distilled and seawater at room temperature. Bornite was precipitated from the sulfide ion in an acid ferrous sulfate solution (Cuthbert 1962) showing the need for a reducing environment at atmospheric temperature and pressure for the precipitation of copper sulfide. Moh (1963) formed covellite by the addition of carbon disulfide to chalcocite and digenite at 50°C. Roberts (1963) postulated ionic recombination in solution as the process which converts chalcopyrite to bornite in a copper sulfate solution but reconverts the bornite to chalcopyrite when excess sulfide and ferrous ions are added. Roberts also synthesized chalcopyrite and bornite from simple iron and copper sulfides (i.e. FeS & CuS). The reactions:

pyrite ⇋ chalcopyrite ⇋ bornite ⇋ covellite ⇋ chalcocite

were shown to proceed either way depending on concentrations of $CuSO_4$ and ferrous or ferric sulfate. Increasing temperature (to 150°C) only increased the rate of reaction showing that many of these assemblages may be produced at very low temperatures. At 120°C and 2,000 atmospheres, precipitates produced in these experiments formed intergrowths of chalcopyrite-covellite-bornite. These intergrowths (Roberts 1963) in some respects resemble the natural assemblages of the ore deposits discussed. The formation of these textures clearly show that replacement (Davis 1954, Brown 1971) need not involve processes requiring solid state ionic diffusion at high temperatures or actual displacement of one mineral by another, as sulfides would replace a calcite matrix. Indeed, the concept of the term "replacement" (Gary et al 1974) may be extended to encompass relative transfer of selective ions in one mineral. For example: the "replacement" or transformation of bornite to chalcocite by the removal of iron and/or the addition of copper during a continual process of ion transfer from solution possibly similar to the process of formation of intermediate sulfide phases in the solid state (Ross 1954). McKinstry (1959) discussed the possibility of progressive replacement of pyrite by more copper rich minerals due to a change in the composition of the solutions or various chemical changes in the environment. The degree of replacement by this process may act on any scale from the replacement of one grain to the mineral zonation in an ore deposit. These experiments also show the possibility of precipitating simple copper and iron sulfides by synsedimentary processes and subsequently forming intergrowths of more complex sulfides during metamorphism. These complex sulfides would replace the matrix of sediments and appear to have been introduced epigenetically.

The experiments discussed clearly show that ion exchanges under conditions other than those of the high temperature solid state diffusion (Merwin and Lombard 1937) are feasable within the Cu-Fe-S system.

(ii) Chalcopyrite Exsolution

The significance of chalcopyrite exsolution lamellae in bornite was first examined by Schwartz (1931a, b). Experimental dry heating of these minerals showed that at a minimum temperature of 475°C chalcopyrite will mix with and exsolve from bornite. Work with bornite-chalcocite assemblages (Schwartz 1928) revealed that a very limited quantity of bornite will dissolve in chalcocite at temperatures as low as 170°C. Reaction rates at this temperature are very slow, but within a geologically reasonable time span mixing would be complete. Schwartz (1928) also concluded that the percentages of the minerals present determines the nature of the intergrowth, and that the intergrowth texture is controlled by the crystal lattice of the mineral in excess. More recently, MacLean et al (1972) and Barton (1973) report chalcopyrite exsolution lamellae in bornite in high temperature heating experiments in the Cu-Fe-S system. Barton (1973, 1979) suggests that a bonding change between chalcopyrite and intermediate solid solution (Sugaki 1975) may explain why chalcopyrite and bornite do not form a continuous solid solution. Yund and Kullerud (1966) show that at temperatures just below 700°C, chalcopyrite exsolves from bornite indicating non-stable conditions. Consequently, no solid solution of these minerals exists up to the temperatures investigated.

Similar experimental results in the system Cu-Fe-S are found in Cabri (1973), Greig et al (1955) and Craig (1974). This work, although largely beyond the field of this thesis, shows extensive solid solution of the chalcopyrite field and the bornite field (Fig. V-9) and thus provides an explanation of the highly variable compositions of minerals in these fields (see description of chalcocite in Ohio, section III-A). The fields remain stable to a fairly low temperature (200°C) (Yund and Kullerud 1966). The phase diagram for the Cu-Fe-S system at 25°C (Barton and Skinner 1967, Stanton 1972) and from observed mineral assemblages (McKinstry 1959) show that the observed mineral assemblages at Ohio were in equiligrium at low temperature.

Thus, although chalcopyrite exsolution in bornite is a commonly encountered texture in experimental ore petrology, no solid solution phase of bornite-chalcopyrite exists at least up to 700°C (Kullerud 1959). This work largely reflects experiments on highly refined and pure substances under dry conditions, unlike the wet geological system(s) operating in a sedimentary deposit. For this reason, factors not taken into consideration in experimental ore petrology must have been operative in low temperature sedimentary deposits where chalcopyrite exsolution is observed.

The high temperature work discussed above have led

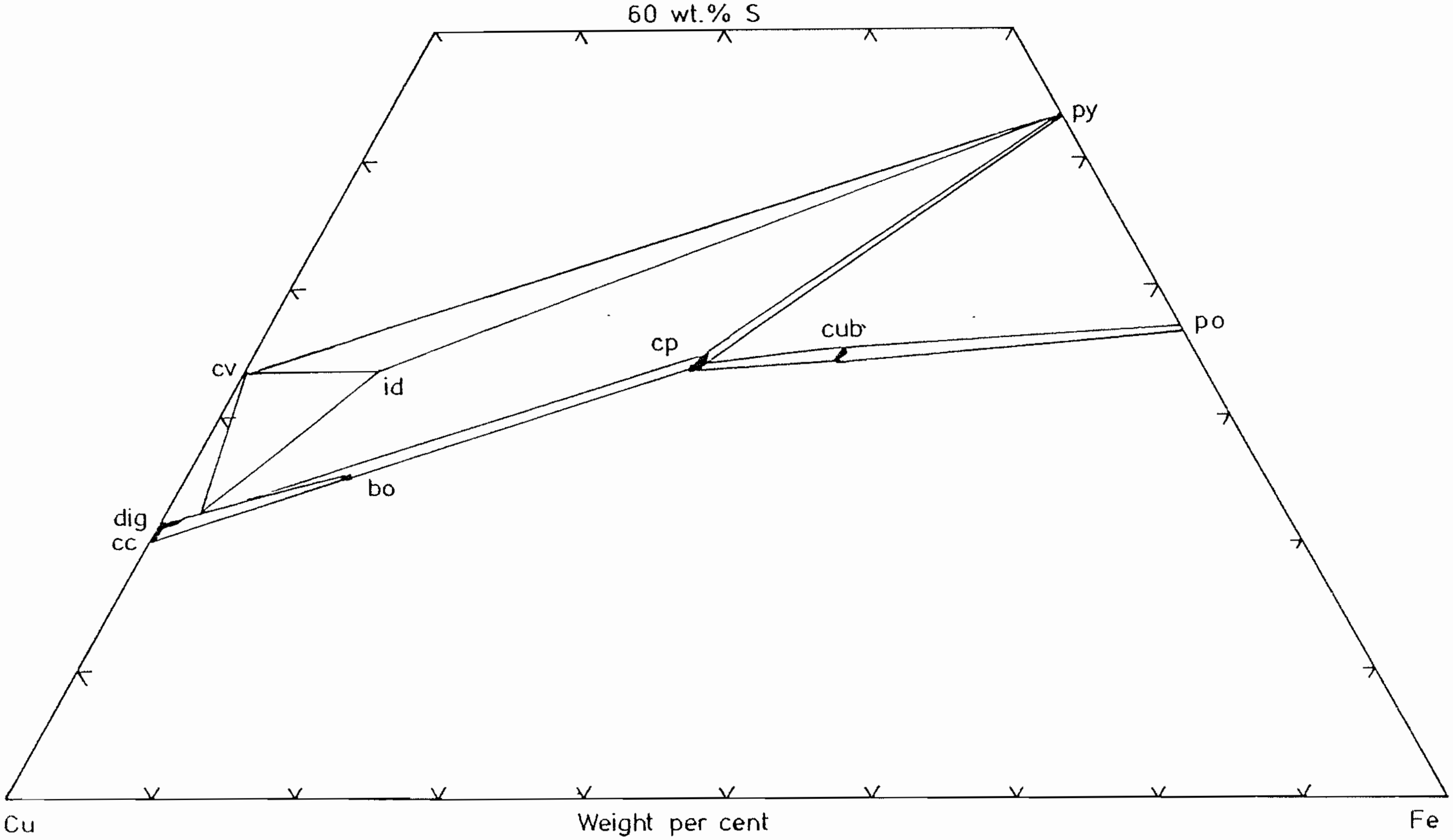


Fig.V-9 Section of the Cu-Fe-S system interpolated at 100°C (approximately) from Yund and Kullerud (1966) and Barton and Skinner (1967). Solid areas are single solid phase. cv=covellite, cc=chalcocite, bo=bornite, cp=chalcopyrite, cub=cubanite, dig=digenite, id=idaite, py=pyrite, po=pyrrhotite.

many workers to the conclusion that chalcopyrite exsolution lamellae in bornite suggested higher temperatures of formation than a sedimentary environment would allow (McCauley 1958). However, Brett (1962) reports chalcopyrite exsolving from natural bornite at a minimum of 75°C. Brett and Yund (1964) further report that chalcopyrite, in some cases with chalcocite, is exsolved from bornites which are richer in sulfur than stoichiometric bornite, when heated to temperatures between 75°C and 400°C. Stoichiometric bornites do not exsolve chalcopyrite in this temperature range. Sulfur-rich bornites have since been identified in many "red bed" copper deposits (Brett & Yund 1964, Kullerud 1967). Sulfur-rich bornite with no chalcopyrite exsolution is thus indicative of a temperature of formation (and subsequent diagenetic-metamorphic processes) of less than 75°C, while sulfur-rich bornites with chalcopyrite exsolution lamellae show formation or subsequent annealing temperatures of over 75°C but under 400°C. These figures are certainly within reasonable limits of the temperature of formation of sedimentary stratiform ore deposits. Kullerud (1959) notes an orange sulfur-rich (Cu_5FeS_6) bornite phase. One Ohio slide ((#7455) contains traces of an orange bornite, quite distinctive from other pink or purple phases. This is a further indication of the presence of this anamalous bornite phase at Ohio. Bornite ($Cu_5FeS_{4.09}$) exsolved digenite as well as chalcopyrite on heating (Brett and Yund, 1964). The resultant texture remarkably resembles Plate V-22 of the Ohio assemblage.

The results of the work of Brett and Yund (1964) indicate that a digenite and chalcopyrite exsolution in bornite is stable at 200°C and below. Since sulfur-rich bornite exsolves only chalcopyrite above 200°C, a temperature between 75°C and 200°C is fixed for bornite showing chalcopyrite and digenite exsolution (Plate V-22) if indeed the digenite represents an exsolution product. Since only one grain showing this texture is present, ambiguity as to its origin is present. The digenite may represent subsequent replacement of bornite.

Some of the pink Ohio bornites do not contain exsolved chalcopyrite and this indicates a temperature of formation below 75°C. Consequently the temperature of formation of the copper sulfides was probably very close to and locally fluctuated about 75°C.

Yund and Kullerud (1966), Cabri (1973, Sugaki et al (1975) and Barton (1973) noted that the chalcopyrite solid solution field does not include stoichiometric chalcopyrite ($CuFeS_2$). Brett (1962) shows that chalcopyrite always contains less sulfur than its stoichiometric formula would indicate. Thus several minute variations in chalcopyrite compositions are common.

With respect to chalcopyrite exsolution from bornite, Brett (1962b) postulates that the chalcopyrite must become more sulfur rich as cooling proceeds while bornite in equilibrium with the chalcopyrite must become increasingly sulfur poor and form a chalcocite-bornite solid solution that breaks down at low temperature.

Brett (1962a) points out that chalcopyrite exsolution lamellae have been obtained at cooling rates as slow as 3°C/day for six months, whereas this texture was previously thought to have involved rapid cooling. Few interpretations of the thermal history of this assemblage can therefore be made from textural characteristics alone.

(iii) Low Temperature Indicators

Although the temperature range (75°-?200°C) based on exsolution is not conclusive, several indications, classed as "permissive types" of evidence by Snyder (1967), suggest a low temperature origin for the Ohio mineralization.

The mineralization has selectively replaced the carbonate matrix and followed fractures within the volcanic fragments. No high temperature hydrothermal alteration of any of the host lithologies is present.

Framboidal pyrite is widespread in the Lower Windsor limestones and have been interpreted as having bacterial origins (Park & MacDiarmid 1970, Love 1962). Thus, the temperature at the time of pyrite formation could not have exceeded that which will sustain bacterial life (100°C).

Although it is not conclusive (Stanton 1976) the sphalerite geothermometer proposed by Kullerud (1955, 1959) does provide some parameters for the relationship between iron content of sphalerite and the temperature of its formation. At high temperatures the sphalerite lattice is more 'open' than at lower temperatures and thus if conditions are met and the iron is available, more iron will be incorporated into the sphalerite lattice. The low iron content (1% or less) of the Ohio sphalerites may therefore correlate with a low temperature origin.

(iv) Non-Detrital Indicators

Apart from the close similarities between the Ohio deposit and well studied stratiform copper deposits, a number of other characteristics indicate that the sulfide mineralization is non-detrital.

The grains of sulfide show highly irregular edges although the roundness of the host conglomerate pebbles indicate significant transportation of the clastic sediments.

The sulfides are not found in the lower red conglomerates although there is no lithological difference between these and the sulfide-bearing green conglomerates. Detrital sulfides might therefore be expected in both units.

Where sufficient carbonate matrix has precipitated, sulfides are found near the carbonate-fragment boundary. Detrital sulfide grains should be distributed evenly throughout the matrix.

Studies of the volcanic pebbles of the conglomerate, as well as several units of basement volcanics revealed no significant copper mineralization. It is therefore highly unlikely that processes involved in detrital transport selectively withdrew the sulfides from the volcanics and transported them elsewhere. If the volcanics were the sulfide source (as they are for the pebbles) then significant copper mineralization should remain both in the basement and the pebbles.

Rather than a detrital origin, the mineralization processes involved in the Ohio deposit, like those of other stratiform base metal deposits, probably involved transportation of metals in solution (Helgeson 1964, Stanton 1972, Roedder 1967a, b). This will be examined in section III-C-2(b).

(v) Mineral Zonation

Although no quantitative mineral zonation could be delineated at Ohio, indications of a zonation exist. Figure V-7 is compiled from Cu-Pb-Zn analysis of selected samples. It reflects the microscopic study (section III-A) of the ores and shows an abrupt coincidence of mineralization with the upper green conglomerates and limestone. However, the stratigraphic interval represented by Figure V-7 is not extensive nor complete enough to delineate a distinctive Cu-Pb-Zn zonation. Generally, however, lead and zinc increase as copper content increases. The anomalous lead value of the Reigle showing may also give an indication of an upward increase in lead (galena) in the stratigraphic column. Furthermore, an increase in lead content of the conglomerate and limestone is found outward (eastward) into the structural basin (MacLeod, pers. comm.). In both these cases copper becomes insignificant as lead values increase. Thus a copper-lead zonation with lead becoming more abundant, exists upward and outward within the structural basin.

Indications of copper mineral zonation also exist at Ohio (Fig. V-5) and takes the form of a lateral change from iron-rich copper sulfides in the south to copper-rich sulfides in the north. However, because of the scarcity of limestone outcrop in the south, and the oxidized nature of the conglomerates in the north, a definite vertical zonation cannot be delineated. Nevertheless, there are indications, such as the absence of copper-rich sulfides (bornite-chalcocite) in the few limestone outcroppings in the south and the absence of iron-rich copper sulfides (chalcopyrite) in the limestones of the north, that a vertical change from iron-rich to copper-rich sulfides exist upwards in the stratigraphic column. This zonation may also reflect lateral facies zonation such as in the Zambian ore bodies (Fleischer et al 1976). It is discussed in section III-2-c but a much more detailed study would be necessary to quantify this.

This general change in copper mineralogy is seen in other deposits where detailed zonation patterns have been mapped. At White Pine the vertical zonation is stratigraphically reversed relative to Ohio (White and Wright 1966, Brown 1971) copper-rich sulfides giving way upwards to more iron-rich sulfides (Fig. V-10b).

The highest metal content is found in the lower part of the Kupferschiefer within the area of the transgressive cycle (Jung and Knitzsche 1976). A vertical and horizontal zoning of chalcocite-bornite-chalcopyrite-pyrite corresponds to transgression. This is similar to the mineral zoning at White Pine. In addition, a lead-rich layer is found above the copper-rich layer in the Kupferschiefer.

Some deposits of the Zambian copper belt show a similar zonation with transgressive cycles while in others the sequence is reversed. The reversal in sequence is attributed to a slowly regressive environment (Fleisher et al 1976)

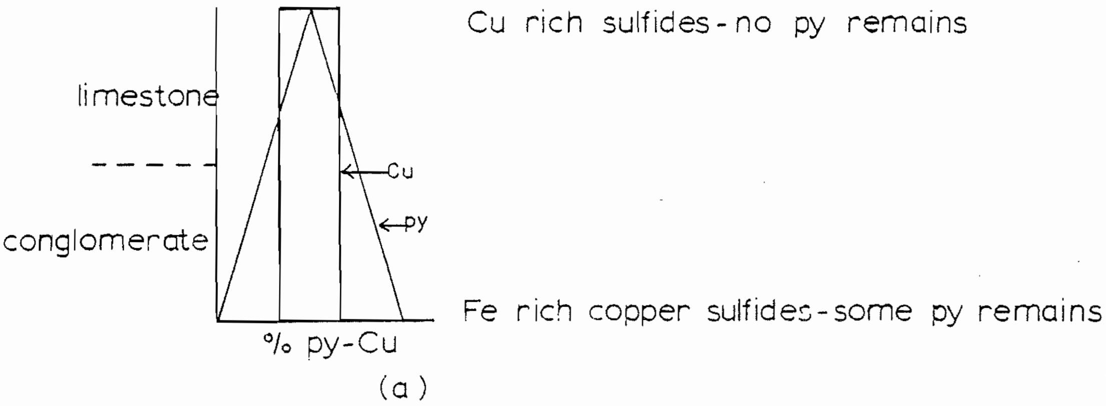


Figure V-10 Diagram illustrating how an upwardly decreasing pyrite content could result in the apparent Ohio-Sylvan Glen mineral zonation after copper replacement of pyrite.

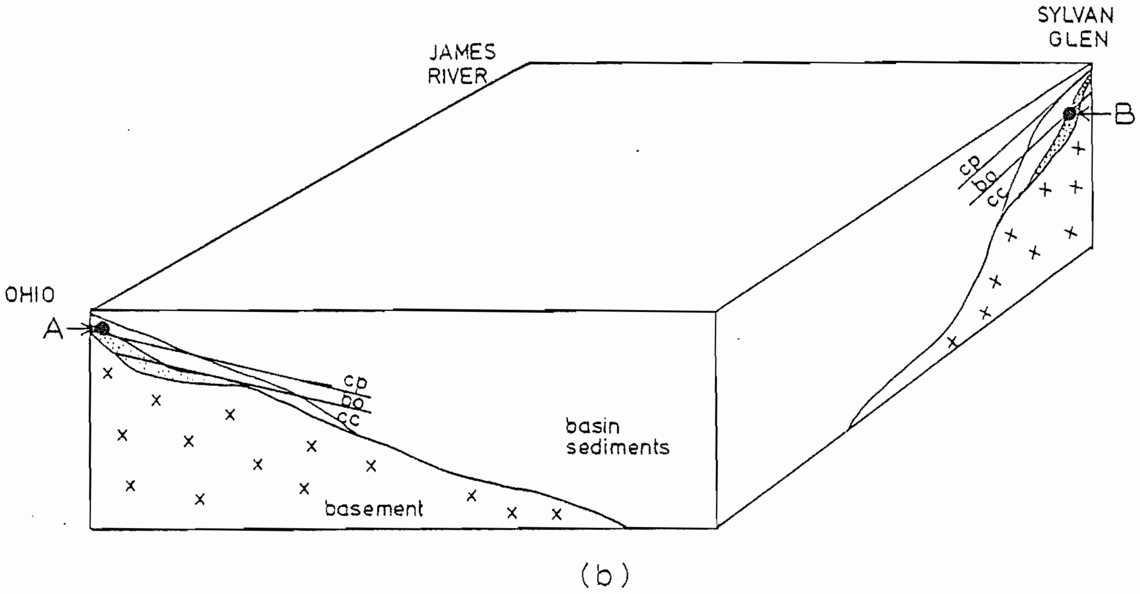


Figure V-10 Diagrammatic block section of the Ohio-Sylvan Glen Region showing possible location of sample areas with respect to the structural basin. Mineral zonation is that of White Pine and the Kupferschiefer. Sample locations A and B are located on the conglomerate (stippled) - limestone contact in the chalcopyrite and bornite - chalcocite zones, respectively, explaining the apparent reverse zonation found in the map area.

The vertical sulfide zonation of the Adeline Island Formation in Labrador shows an analogous trend to that of White Pine (Gandhi and Brown 1975). Copper-rich sulfides (bornite and chalcocite) predominate in the lower sediments while iron-rich sulfides (chalcopyrite and pyrite) occur higher in the stratigraphic succession.

Sulfide paragenesis in the Triassic sandstones of Sierra Nacimiento in New Mexico has been established with some certainty as being pyrite, bornite, chalcocite and covellite with decreasing age (Woodward et al 1974).

Renfro (1974) suggests a chalcocite-bornite-chalcopyrite-pyrite zonation from landward to seaward as a general model for evaporite-associated metalliferous deposits, such as the Kupferschiefer and Zambian Copper belt. This sequence would also be reflected vertically in a transgressive sequence (Fig. V-10b).

Comparisons of Ohio with other deposits establishes strong similarities in sedimentary environment and nearly identical mineralization including paragenesis, texture, and zonation of minerals. Experimental evidence, and models concerning the ore genesis of these deposits may thus be applied to the genesis of the Ohio Stratiform Copper Deposit.

2- Ore Genesis

a) Source of Metals

The source of the metals is unlikely to have been the overlying evaporite sequences since this would involve descending solutions which would produce a reversed copper-lead zonation to that found at Ohio (Renfro 1974).

No local volcanic activity occurred immediately prior to the deposition of the host lithologies. Thus, the derivation of ore solutions from volcanic sources (Stanton 1972, Dunham 1964) is not possible. Volcanic extrusives which comprise the basement lithologies were generated at least 200 million years before the Carboniferous sediments were deposited (Keppie 1978, Murphy and Keppie 1979).

Magmatic hydrothermal solutions (Stanton 1972) are unlikely sources of metals as no high temperature alteration of the Ohio host rocks is evident.

Seawater has been shown by Wedepohl (1964) in Jung and Knitzshke (1967) to be an unsuitable source of metal ions for the deposition of economic ore deposits and would also involve obsolete(?) syngenetic processes of ore formation. The very low content of copper in seawater (.003 ppm) (Krauskopf 1967) indicates that the sea is a highly unlikely candidate as a copper source (Stanton 1972). Fluid inclusion data also preclude a seawater source (Roedder 1967) for stratiform ore deposits.

Derivation of copper by pore space solution of K-feldspar in buried clastic sediments or possibly in fractured basement volcanics is suitable for lead (Helgeson 1967) but is unsuitable for the derivation of copper, since copper is relatively absent in igneous rocks (Goldschmidt 1958).

The only remaining logical source of metal ions is the underlying basinal clastic sediments (Stanton 1972, Brown 1971, Beales & Jackson 1968). Their metal content may be derived from local continental drainage (Stanton 1972) or by accumulation from several sources including seawater (Beales & Jackson 1968) and continental waters. Brown (1971) concludes that underlying extrusives and/or sediments are the source of copper at White Pine and that compaction (White and Wright 1966) mobilized the copper bearing solutions. June and Knitzschke (1976) conclude that the source of copper for the Kupferschiefer is the intraformational waters of the sedimentary molasse pile which lies adjacent to the Zechstein basin. Fleischer et al (1976) postulates a similar source, with the addition of seawater, for copper in the Zambian ore deposits. Davies (1954) advances several possible sources, including leeched basement rocks, for the Zambian ore deposits.

Binney (1975) and Kirkham (1978) postulate that the underlying red Horton sediments were the most likely source of metals in the Carboniferous basins of Nova Scotia. Kirkham (1978) also points out that unreplaced pyrite above the copper zone precludes a descending mode of entry for the copper-bearing solutions. Barren pyrite above the copper zone at Ohio also precludes such an origin.

b) Transportation of Metals

Pyrite forms the initial sulfide phase in the Ohio deposit. This has been established from the paragenetic sequence derived by textural relationships and the comparison of these with other deposits.

A source of iron poses no problems as the volcanic rocks from which the sediments are derived are rich (up to 25%) in hematite, magnetite and pyrite (see section II-a-2a). The deep red colouration of the lower sediments reflects the abundance of an iron oxide matrix, transported with the sediments. Thus, the main source of iron is undoubtedly of terrestrial origin, although some may have been carried to the site of deposition suspended in seawater, since the solubility of iron oxide products is negligable under normal geological weathering processes (Stanton 1972).

The most likely mode of transport of the iron would be as oxides and hydroxides (Lemoalle and Dupont 1973) suspended in the waters carrying the clastic sediments to the site of deposition. This is further supported by the observation of iron oxide coatings on pebbles in the conglomerates (Stanton 1972).

The transport of copper, however, is not as easily explained as the transport of iron. Since the abundance of copper in igneous rocks is negligible (Goldschmidt 1958, Turekian and Wedepohl 1961), transport in suspension by waters from the sediment source is highly unlikely.

The problem of extremely low sulfide solubility to transport of the sulfides is a widely recognized problem (Barton 1959, Czamanske 1959, Krauskopf 1967, Helgenson 1964, Barnes and Czamanske 1967). Experimental solution of sulfides in quantities sufficient for ore deposition has led to the formulation of very restrictive geological environments (Barnes and Czamanske 1967, Anderson 1973, Helgenson 1964) such as those of submarine volcanic regions. However, the environment of ore deposition in stratiform ore deposits probably involve solutions which do not vary appreciably in pH, Eh, composition and temperature from those of near surface geological environments (Roedder 1967a, b, Rose 1976).

Studies on complexes of copper, lead and zinc has established these as an extremely valid mode of dissolving such metals in various waters of near-natural composition, Eh, pH and temperature (Krauskopf 1967, Helgeson 1964, Vaughan 1976, Anderson 1973, Barnes 1960, Barton 1959 and Rose 1976). This work has shown that copper, lead and zinc may be transported at low temperatures (up to about 100°C) under the conditions postulated for the origin of "red bed" deposits. Because of the general presence of NaCl in ore-forming fluid inclusions (Roedder 1967a, b) and the availability of chloride from evaporites (Rose 1976) and seawater in sedimentary deposits, chloride complexes are probably the most likely forms of dissolved metal compounds. Rose (1976) has calculated solubilities of copper yielding copper contents of about 100 ppm in waters of pH 7.0, intermediate Eh and a temperature of 25°C. This is sufficient for deposition of an economic grade of ore (Helgeson 1967).

The detailed chemical parameters of this chloride complexing system, its' intricate interdependance on a multitude of other constituents of the environment, and the environmental implications of these systems (Garrels 1960, Garrels and Christ 1965), are beyond the scope of this paper.

Near shore accumulation of copper and zinc has been shown by White and Northcote (1962) to be a process which is proceeding at the present time. Fraser (1961a, b) reports copper accumulation in a present day euxinic environment. Thus, the availability of copper and zinc for solution in a near shore environment is adequately demonstrated.

Rose (1976) concludes that circulating chloride-rich groundwaters may accumulate sufficient quantities of copper for ore deposition. It is therefore plausible that pore fluids, comprising terrestial and/or marine waters rich in chloride derived from overlying and nearer shore evaporites, could accumulate a sufficient metal content to produce the sub-economic ore deposit at Ohio. The permiability of the lower red conglomerate is sufficient (see Appendix I) to allow for the circulation and transport of ore forming solutions.

Brown (1971) invokes chloride complexing to explain the solubility and transport of copper in the White Pine deposit. Using data from Garrels and Christ (1965), Brown outlines the probable Eh-pH conditions of the White Pine source and depositional beds. As the two deposits are similar, these generalizations may also be applicable to the respective Ohio source and depositional beds. Brown (1971) further shows that the copper content of ore fluids at White Pine could have been greater than 60 ppm, sufficient to account for ore deposition in about 879,000 years. This time span implies that ore deposition could have been completed before compaction of the ore horizon reduced the permiability to prohbitively low values (Brown 1971).

Gandhi and Brown (1975) suggest a similar origin for copper in the Adeline Island Formation, Labrador.

In addition, Rose (1976) suggests similar processes may have operated on at least some of the mineralization found in the Kupferschiefer and the Zambian Copper Belt.

Once the metals have been dissolved, a mode of transport from source to "trap" must be invoked. The obvious and most likely mechanism is compaction of sediments with resultant squeezing out of pore fluids (Carpenter et al 1974). This is akin to the processes of migration of petroliferous fluids in a basin (Levorsen 1967, Hobson and Tiratsoo 1975). Receptor surfaces for base metal adsorption become vastly reduced during compaction, and at least some of these ions will be released to the interstitial fluids (Beales and Jackson 1968, Krauskopf 1967). Beales and Jackson have postulated a compaction model of fluid migration for Pine Point in the Northwest Territories.

Brown (1971) outlines a model of ore deposition based on compaction of the source conglomerate at White Pine. At Ohio, a maximum of 2,600 feet of Lower Carboniferous sediments with 8,000 feet of Canso Group and younger sediments overlying the Lower Carboniferous (Benson 1974), could produce similar pressure conditions as those at White Pine.

The expelled ore carrying fluids would migrate upwards through the permeable conglomerate unit. Volcanic basement rocks would act as a barrier to any descending migration.

Although this model may be applied to some areas of the Kupferschiefer and the Zambian deposits (Rose 1976), European thought has centred about a mechanical transportation of copper to the basin where changing geochemical conditions precipitates it syngenetically with the sediments (Jung and Knitzschke 1976, Fleischer et al 1976). These aspects will be dealt with in the section below.

c) Deposition and Timing of the Ore

Precipitation of metals in solution may be caused by various mechanisms depending on the nature of the mineralizing fluids (Helgeson 1964, 1970, Anderson 1973). Changes in temperature and pressure and reactions between solutions and environment causing changes in pH, Eh and composition may all contribute to the upsetting of the metals in equilibrium in solution.

Much recent work on precipitation of ore in stratiform "red bed" deposits concerns the production of a reducing environment by bacterial decomposition of organic matter. This would provide not only appropriate Eh conditions, but a supply of sulfur with which to form sulfides. Bastin (1933) proposed this mechanism for both "red bed" and Kupferschiefer (Mansfeld) type deposits. Because of the availability of algal material and/or sulfate in such an environment of deposition, this mechanism has been applied to all deposits studied in this thesis. Skinner (1967) also applies the mechanism to Mississippi Valley type deposits.

One very attractive aspect of this mechianism is that it allows high solubility of metals in solution by providing an alternate source of sulfur. Great difficulties arise in transporting metals and sulfur in one solution.

Evidence of an organic origin of the precipitation of pyrite at Ohio is found as framboids of pyrite (Park and MacDiarmid 1970). Schouten (19~~64~~46) indicated a high favorability for the syngenetic precipitation of pyrite by sulfate-reducing bacteria. Experimental studies by Baas Becking and Moore (1961) provided quantitative evidence of sulfide precipitation by biological methods. Love (1962) concluded that framboidal pyrite found in the Kupferschiefer represented the remains of micro-organisms that caused the authigenic precipitation of pyrite in the seidments. Although framboids have been synthesized inorganically, Berner (1969) concludes that most framboidal pyrite is formed through biogenic hydrogen sulfide production.

Temple (1964) outlines the quantitative aspects of biological precipitation and concludes that the process is a satisfactory mechanism for syngenetic sulfide deposition.

The physico-chemical parameters in which these bacteria may survive, as outlined by ZoBell (1958), encompass the

Eh, pH, pressure, temperature and salinity conditions of most sedimentary environments (Trudinger et al 1972).

Trudinger (1976) provides a process whereby dissimilatory sulfate reducing bacteria which are found in environments akin to that outlined by Brown (1971), utilize the oxidation of organic compounds coupled with the reduction of sulfate to provide the energy for growth. During this process, Hydrogen sulfide (H_2S) is given off as a by-product. The bacteria are remarkably tolerant to H_2S and thus to very low Eh limits (Trudinger et al 1972). The requirement that H_2S be oxidized for formation of pyrite may be met by other bacteria in the environment (Trudinger 1976).

Thus the environment, organic matter (see section II-A), sulfate and supply of iron are all available constituents for the bacterial precipitation of pyrite at Ohio.

The reducing environment was probably initiated at the onset of the Windsor transgression and restriction (Kirkham 1978) and extended into the Horton to a depth equivalent to the penetration of the conglomerate by the Windsor sea as in Renfro's (1974) transgressive model. This area, marked by a green coloration, is the lower limite of pyrite formation.

Syngenetic-diagenetic pyrite (Love 1967) precipitation thus provided an environment for subsequent copper mineralization from below, by fluids which were squeezed out during compaction of the sediments. Copper sulfide replacement of pyrite is well established at Ohio, as well as in all the documented deposits used for comparison. Brown (1971) postulates an upward advancing front of copper bearing solutions which reacts with pyrite and replaces iron with copper to produce copper sulfides. Since the copper mineral zonation varies upward from iron-deficient (chalcocite) to iron-rich (chalcopyrite), Brown hypothesized that continued interaction of iron sulfides with copper solutions produced copper rich sulfides at the base of the unit where interaction had continued the longest. The time of interaction decreased upwards and is reflected by the progressive upward decrease in copper content of the sulfides. Since this mineral zonation appears to be reversed at Ohio, an identical mechanism could not have operated here. The White Pine zonation depends on a considerable and continuous supply of copper bearing solutions to complete a step by step replacement of pyrite with progressively more copper-rich sulfides. This abundant supply is no doubt the reason why the copper concentrations are of economic grade. However, in a subeconomic situation, such as Ohio, copper supply was probably not as abundant. The White Pine zonation probably also reflects a relatively homogeneous supply of pyrite throughout the mineralized stratigraphic column.

Since production of copper-iron sulfides depends on the relative supply of copper and iron ions, an upward decrease in iron (pyrite) availability should produce a zoning in reverse to that of White Pine. An upward decrease in iron may conceivably have been the case at Ohio. Examination of Fig. V-7 shows an upward, present day, decrease in iron content. With abundant pyrite at the base of this formation and limited copper supply, the sulfides produced could be iron rich. As the pyrite content decreases, the availability of iron also decreases and the sulfides should become more copper rich (Fig. V-10a).

However, if the change in mineralogy at Ohio reflects a lateral change in facies, such as the zonation of various levels of the Kupferschiefer and Zambian ore (Fig. V-10b), then the apparent reverse zonation would only reflect White Pine-like zonation observed at different levels in the structural basin. Within this Carboniferous Basin, the limestone-conglomerate contact, at the sites of chalcocite mineralization, are landward of the limestone-conglomerate contact where chalcopyrite mineralization predominates. A detailed paleo-environmental reconstruction of the area would be necessary to solve the problem, since, mineralogically, both ore sequences are known to occur in these deposits. Unfortunately, the scarcity of outcrop in the area does not allow resolution of this problem.

Available evidence therefore suggests that ore forming processes involving sedimentary transport of copper to a basin (Fleischer et al 1976, Malan 1964, Garlic 1964) with sulfide production dependant on a decreasing Eh potential downward in the basin (Jung and Knitzschke 1976, Fleischer et al 1976), are not valid for the Ohio area.

A sabkha process of mineralization (Renfro 1974) has been refuted by Rose (1976) for the origin of the Zambian copper ores on the basis that terrestrially derived solutions would not have the capacity to dissolve copper unless they were very saline. Whether or not the solutions could obtain chloride ions from the evaporites in a sabkha was not investigated by Rose. However, it would be unlikely that fluids moving relatively rapidly in a sabkha environment would have the time to obtain enough copper in solution from the onset of the late introduction of chloride to the nearby site of precipitation.

Other characteristics of the Ohio deposit preclude a sabkha origin. The sabkha sediments do not rest directly on terrigenous desert clastics. At Ohio, an evaporite sequence lies above the carbonate unit. It is therefore unlikely that solution mobilization due to high evaporation rates in a sabkha could account for the mineralization which lies below the carbonate unit. Furthermore, no mineral zoning across transgressive-regressive sabkha cycles is evident at Ohio. Kirkham (1978) invalidates a sabkha model for the Cape Breton deposits on this environmental basis.

It is unknown whether the lead mineralization higher in the carbonate unit is related to the copper (zinc-lead) mineralization or if it forms another phase. Since copper mineralization is restricted to the lowermost 25 cm of limestone, it is possible that the limestone was impermiable to fluids above this level. Barren pyrite zones above the copper mineralization support this contention. If this is the case, then the upper lead mineralization is related to another phase of mineralization requiring processes akin to those discussed by Jackson and Beales (1968) for Mississippi Valley type deposits. However, this cannot be evaluated until such time as the Reigle mineralization is found in outcrop or in drill core.

Calcite vein mineralization in the lower limestone may reflect the final phases of mineralization when fracturing developed (Brown 1971).

d) Summary

Rentzsche's (1974) comparison of the Kupferschiefer with the Zambian copper belt, indicates that Ohio is morphologically a Kupferschiefer type deposit. However, this does not imply a similar ore genesis for the two deposits.

A sequence of events leading to the Ohio copper prospect is summarized from the preceeding discussion, as follows:

1. Deposition of the Horton conglomerates in oxidizing conditions, probably as a scree deposit on basement volcanics, was followed by flooding of the Carboniferous basin and the abrupt deposition of carbonates over the clastics. The units represent a typical transgressive sequence. Overlying evaporites and intercalated siltstones represent subsequent regressive processes.

2. Syn-diagenetic pyrite was formed in the transgressive sequence, from terrestrial iron influx and production of H_2S by sulfate reducing bacteria.

3. Copper bearing intraformational solutions were expelled from the lower red Horton conglomerates upon compaction.

4. Upward migration of these solutions cause precipitation and replacement of encountered pyrite by copper. The relative abundances of iron and copper ions determined the type and intergrowth of copper mineralization. The upward decrease in pyrite content may have allowed for an upward increase of more copper-rich sulfides. Alternatively the zonation may appear reversed because of position of outcrop in the basin. If this is the case, then Brown's (1971) model for mineralization at White Pine would apply to Ohio. Here, an ascending, continuous supply of copper solution replaced pyrite in decreasing amounts upwards thereby

causing an upward decrease in copper rich sulfides.

Chalcopyrite (-chalcocite?) exsolution in sulfur-rich bornite indicates a temperature of formation between 75° and ?200°C.

Late stage mineralizing fluids permiated fractures in the lower conglomerate producing minor calcite vein copper mineralization.

6. Indications of a still later phase of mineralization is found in the Mississippi Valley type lead accumulations in diagenetic cavity fillings in the upper part of the lower limestone.

Addendum - Fluid Inclusion Geothermometry

Fluid inclusion geothermometry was carried out on primary fluid inclusions according to the principles and techniques of Roedder (1962, 1963a, b, 1967a, b, 1974, 1977). The fluid inclusions used were those of the calcite matrix containing the copper mineralization. An extensive petrographic study, accompanied by several heating stage experiments, indicate a relatively low temperature (approximately 100°C ±20°C) of deposition. This temperature estimate probably reflects conditions which existed during the precipitation of the pyrite. Since copper mineralization occurred subsequent to pyrite deposition, this temperature derived from fluid inclusions is not relevant to copper mineralization. However, secondary fluid inclusions may be related to the fluids involved in the copper mineralization. Rare secondary inclusions larger than 5u show bubble to fluid ratios comparable to those of the primary fluid inclusions (i.e. in the low temperature range). However, the vast majority of the plentiful secondary inclusions are <5u in diameter; too small for visual ratio estimates.

Other problems concerning the use of secondary inclusions, which usually are found by the thousands along cleavage planes, are:

1) It is not known whether the secondary inclusions are actually related to the fluids involved in the phase of copper mineralization.

2) If the fluids were related, the timing of the mechanism of deposition is not specifically known, thus the lithostatic pressure at the time of mineralization is not known. Temperature estimates of these inclusions could only derive a minimum temperature of formation. Actual temperature could only be inferred by guesstimating the total lithostatic load at the time of deposition.

CHAPTER VI

PLATE TECTONIC FRAMEWORK AND METALLOGENIC SETTING OF THE ANTIGONISH AREA

I INTRODUCTION - REGIONAL TECTONIC SETTING

The Appalachian Region has been the focus of intensive study concerning tectonics and mineralization. The history of the Appalachian Geosynclinal Belt has been relatively well defined and described by Bird and Dewey (1970), Schenk (1971, 1978) and Williams (1979). Only a very brief account of present day thinking will be presented in this chapter.

As early as 1961 several tectonic zones were defined in the Appalachian Belt (Neale et al 1961). Culmination of vast amounts of data and models is found in Williams (1979). Williams divides the Appalachian Orogen into five zones (Fig. VI-1). The westernmost zone is designated the Humber Zone. It records the development and destruction of the ancient continental margin of Eastern North America, which lay to the west of the proto-Atlantic Ocean (the Iapetus Ocean). The Humber Zone, which was initiated by rifting of the crystalline Grenvillian Basement in the Late Precambrian, consists of thick clastic sequences, mafic volcanics and mafic dike intrusions. Uppermost slices of allochthonous sequences consist of thick ophiolite suits showing that the

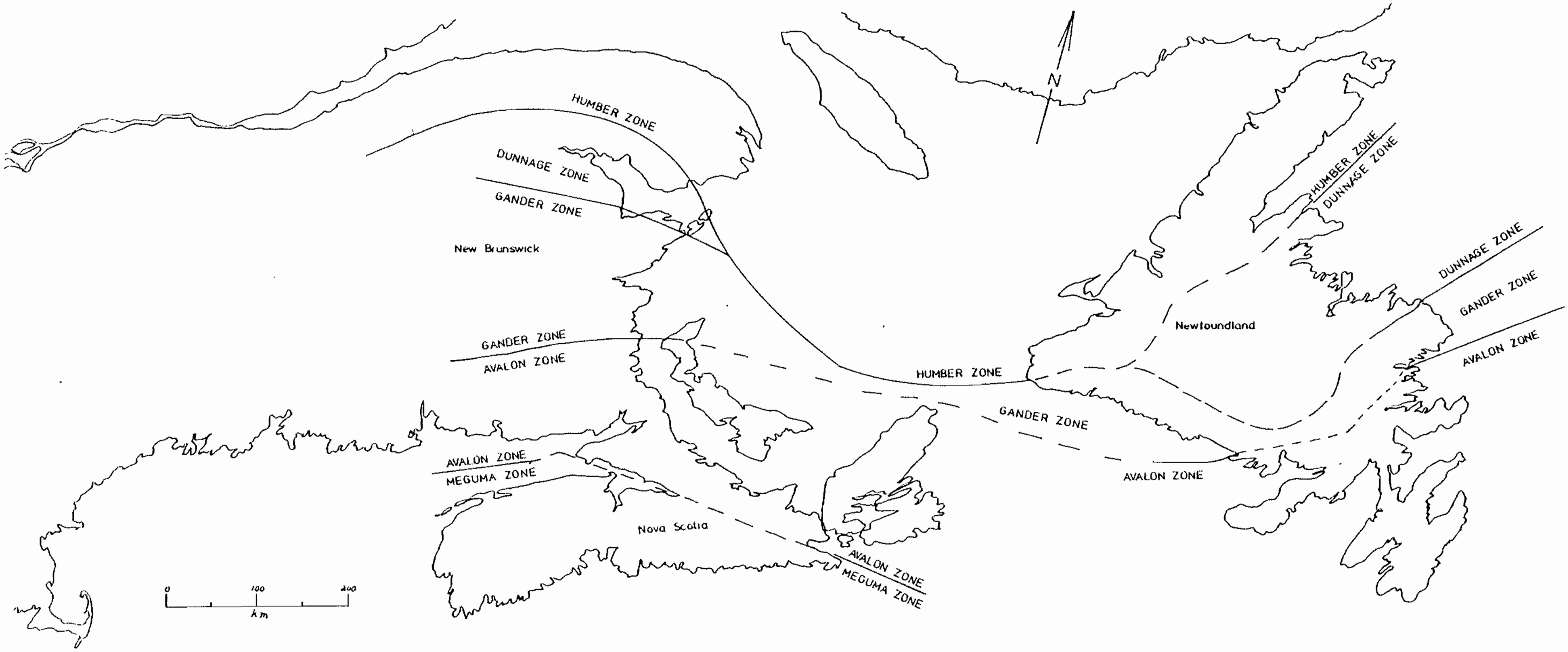


Figure VI-1 Tectonic zones of the Northern Appalachians (after Williams 1979) See text for explanation of zones. Broken lines indicate approximate boundaries.

Appalachian system evolved during oceanic growth and destruction. Destruction of the ancient margin began towards the end of the early Ordovician Period.

The Dunnage Zone represents remnants of a subduction zone and trench on the western margin of the Iapetus Ocean. The typical island arc rock assemblages include dominantly mafic volcanics and associated marine sediments. The age of the volcanism of the Dunnage Zone indicates island arc growth east of the Humber Zone during emplacement of the Humber zone allochthons.

The Gander Zone consists of a prism of pre-Middle Ordovician, polydeformed, arenaceous sediments built up parallel to an existing shoreline on the eastern margin of the Iapetus Ocean. It thus resembles clastic rock sequences on the east margin of the Humber Zone to the opposite side of Iapetus. Earliest deformation of this zone is interpreted as Early Ordovician in Newfoundland. In some areas volcanism was initiated upon the clastic prism of the eastern margin of Iapetus.

The Avalon Zone in Newfoundland consists of: 1) a basal assemblage of subaerial volcanic rocks with some sedimentary units; 2) a middle sequence of marine slates and greywackes with local volcanic interlayers; and, 3) an upper assemblage of mainly sedimentary rocks which, in places, includes a thick volcanic unit near its base; (sediments include arkose, red sandstone and conglomerate of shallow water continental origin). Elsewhere in the Appalachians the Avalon Zone resembles this succession of late Pre-Cambrian volcanic and sedimentary rocks. The rocks of this zone are relatively unmetamorphosed. In some areas, these rocks pass conformably upwards into Cambrian and Lower Ordovician shales and sandstones. Murphy et al (1979) and Keppie (1978, 1979) correlate the Antigonish Highlands with the Avalon Zone. The nature of the Avalon Zone in the Appalachian tectonic framework is as yet undetermined.

The Meguma Zone consists of Cambro-Ordovician greywacke and shale, possibly deposited in a faulted trough that developed within the Avalon Zone. In this respect, the Meguma Zone represents another continental margin which existed between the Avalon Zone and the Meguma Zone. Its presence in the Appalachian system is fortuitous and does not imply involvement in the Appalachian Orogen.

II ANTIGONISH HIGHLANDS - TECTONIC SETTING

Benson (1974) considered the Antigonish Highlands an island arc sequence, probably related to phases of the opening and closing of the ancient Iapetus Ocean. Keppie (1978, 1979) interprets its stratigraphic succession of volcanic and sedimentary rocks as part of William's (1979)

Avalon Zone. However, many problems concerning the tectonic setting of this zone are unsolved. Since the Avalon Zone is separated from the Dunnage Zone by the Gander Zone, then the Avalon Zone probably did not abut the Iapetus Ocean. The Avalon Zone also acted as a stable platform during the Cambrian period and locally during the Ordovician Period when the generation and destruction of Iapetus was most active (Williams 1979).

Many tectonic settings of the Avalon Zone are possible. The zone may represent 1) a volcanic arc system related to subduction during a cycle which pre-dated the opening of Iapetus; 2) island arc volcanism at an early Iapetus margin; 3) rifting and initiation of Iapetus; or 4) a cycle completely unrelated to the Appalachian-Iapetus system. Clearly, this zone does not fit well into the Appalachian Orogen and much work is required before any conclusive evidence concerning it's tectonic setting is found.

Classification of the Antigonish Highlands is ambiguous at the present time. Keppie (1979a) postulates the tectonic setting of the Antigonish Highlands as a marginal basin. An intra-arc environment is also possible. Volcanism is prevalent and many sedimentary sources are available in this environment and could adequately account for the Highland rock assemblage. However, mineral deposits of this regime are poorly understood (Strong 1974). The submarine volcanics denoted by Keppie (1979a) do not conform (descriptively) to the predominantly subaerial volcanics of the Avalon Zone, nor do the subdivisions of Benson (1974) correspond to the typical Avalon Zone assemblage. However, reclassification of the Browns Mountain Group in the Antigonish Highlands by Murphy et al (1979) (Fig. VI-2) shows lithological and stratigraphic similarities to the succession of the Avalon Zone and also corresponds to the early phases in the development of a geosynclinal belt (Bilibin 1968, McCartney and Potter 1962). Thus the mineralization of the Antigonish Highlands will be treated as belonging to early and intermediate phases in the development of a geosyncline, although the tectonic setting of the geosyncline is not known.

III METALLOGENIC FRAMEWORK OF ANTIGONISH HIGHLANDS

It is clear that the "geotectonic cycle" as described by Bilibin (1968) and followers has been rejected as a deterministic model since the development of Plate Tectonic theories. Furthermore, the area of the Antigonish Highlands can hardly be compared in size with the "geosynclines" or mobile belts of continental size. However, the models described by Bilibin (1968) and McCartney and Potter (1962) were based on empirical observations and can be used as a reference framework to analysis the metallogenic development of the study area, no matter what the fundamental mechanism responsible for the evolution of the mobile belt.

	IRON BROOK GROUP		SUGARLOAF GROUP	
ORDOVICIAN	Tramway Formation	Felsic crystal tuff 6m. Green siltstones & slates (F) 108m	Arbuckle Formation	Mafic volcanic rocks Rhyolite, crystal tuff Felsic ash & calcareous horizons 500m. Mafic tuff with fossiliferous limestone fragment, red slate & siltstone, & felsic tuff. Massive felsic tuff & conglomerate
	Ferrona Formation	Quartzites & ironstones (F) 15m Calcareous tuffs 12m.		
CAMBRIAN	Little Hollow Formation	Red slates & thin fossiliferous F Limestones, some green & black slates & one quartzite 200m.		
	Black John Formation	Red conglomerate, breccia Sandstone & siltstone 10m.	Malignant Cove Formation	Red conglomerate, breccia, sandstone & slate 250m.
	~ Fault ~	~ ~ ~ Fault ~ ~ ~ ~	~ Fault ~	~ ~ ~ Fault ~ ~ ~ ~ ~ ~
	UNNAMED GROUP		GEORGEVILLE GROUP	
LATE PRE-CAMBRIAN	Banded mudstones, slates & wackes		Livingstone Cove Formation	Green conglomerates, black (F) mudstones & thin siltstone, chert & limestone
			Morar Brook Formation	Black mudstone, thin siltstone. chert & limestone
			Chisholm Brook Formation	Mafic flows & pyroclastic rocks marble & mudstone Mafic volcanic rocks & dykes. Browns Brook Formation

Figure VI-2 Pre-Silurian stratigraphy of the northern Antigonish Highlands (after Murphy et. al. 1979).

Typical stratigraphic sequences formed during the initial phases of geosynclinal development consist of basaltic-andesitic volcanism usually accompanied by variable amounts of greywacke and ferruginous cherts. Ultrabasic and basic rocks intrude the assemblage. An eugeosynclinal sequence such as this may underlie the exposed rocks of the Antigonish Highlands (Keppie 1979a).

Following this is a reduction in volcanic activity and cherty sedimentation. Terrigenous sedimentation increases as a result of formation of considerable elevations in relief following first phase folding. Folding deforms the sediments and superimposes a second deformation on the earlier assemblages. Intrusive rocks include a broad range of basic magma differentiates from gabbro to granosyenites.

These initial phases of orogenesis probably began in late Precambrian and continued into the Middle Ordovician and locally into the Mid-Devonian (Acadian).

The development of the geosyncline is later predominated by terrigenous formations such as sandstone, shales and conglomerates. Volcanic activity is greatly reduced and occurs only as minor thin, intermediate to acid flows found sporadically in both space and time. The termination of this usually occurs as a third major phase of deformation and transformation of the geosyncline into a folded belt above sea level. Granitoid intrusions characterize plutonic activity in this stage. Events of this time were probably initiated in the Silurian, reached their climax during the Mid-Devonian and were terminated prior to Carboniferous time.

A post-orogenic period include crustal adjustments and continental and fresh water sedimentation, in some areas covered by marine transgressive sequences, represented in the Appalachians by Upper Devonian and Mississippian rocks and by Pennsylvanian and Triassic rocks.

Some mineral deposits related to these particular stages in geosynclinal development are found in the Antigonish Highlands; some others, which have as yet not been recognized in the Highlands hold potential for being present. These deposits are outlined below. Work on this aspect of the tectonic evolution of the Appalachians has been carried out by McCartney and Potter (1962), Potter (1970) and Strong (1974).

Massive, polymetallic sulfide deposits are associated with the volcanic-sedimentary eugeosynclinal (flysch) assemblages. The basic volcanics at the base of the Antigonish Highlands sequence (Murphy et al 1979) may at least be, in part, submarine (Keppie 1979a) and show potential for these deposits. However, no indication of any massive sulfide deposit in the Antigonish Highlands is known. This information supports the view that the Antigonish Highlands was not part of the Appalachian eugeosynclinal regime which generated the sulfide deposits of Bathurst, N.B. and Buchans, Nfld. The absence of massive sulfide deposits in the Highlands further demonstrates the non-typical nature of the development of this geosynclinal assemblage. Marginal basin or inter-arc regimes, which have also been invoked as possible depositional environments for the Antigonish Highlands (Keppie 1979a), would likewise leave many questions pending, since base metal deposition here would also be expected (Strong 1974). Conversely, the sheer magnitude of the sulfide rich Dunnage Zone (including Buchans, Nfld.) in respect to the very limited surficial extent of the Antigonish Highlands (Fig. VI-2) would indicate proportionately smaller possibilities of generating these deposits, if indeed their process of origins were similar.

The ferrigenous wacke beds of the Browns Mountain Group may indicate an exogenous deposit far removed from the mobile zone. If so, then a marginal basin origin of the Highlands is very plausable.

The post-orogenic developments were by far the most productive in the Antigonish Highlands, as far as mineralization is concerned. Mineralization consists exclusively of exogenous copper and lead deposits and bear no relationship to magmatic rocks. Calcite veins containing galena, barite and fluorite in Lower Carboniferous rocks in the Antigonish Basin form very late phase mineralization. This mineralization is unrelated to magmatic activity and is probably the result of diagenetic sedimentary processes. These same diagenetic processes probably produced the Lower Carboniferous Copperbelt (Group A, Chapter III) on the border of the Antigonish Highlands and Basin (Chapter V). Galena occurrences in diagenetic cavity fillings (Group B, Chapter III) in Lower Carboniferous lithologies in the Antigonish Basin are contemporaneous with or occur soon after deposition of the copperbelt.

The latest mineralization phase is the copper mineralization of Upper Carboniferous sandstones (Group F, Chapter III). This mineralization phase is likewise unrelated to magmatic activity and is due completely to sedimentary processes.

IV CONCLUSIONS

The unusual nature of the tectonic setting of the Antigonish Highlands and its probable foreign relation to the Appalachian Orogen lends doubt as to its interpretation as an island arc or rift valley system. A nearly complete absence of typical island-arc mineralization in the Browns Mountain Group and the Silurian lithologies also indicate that island arc processes were probably not responsible for the constitution of the Antigonish Highlands. Furthermore, the Wabana-like sedimentary iron deposits of the Browns Mountain Group may support a marginal basin interpretation (Keppie 1979) of the Highlands. Sedimentary copper and lead deposits of the Carboniferous may also be related to basin sedimentation removed from the late stage deformed belt (McCartney and Potter 1962).

CHAPTER VII

SUMMARY AND CONCLUSIONS

The most substantial mineralization of the Antigonish Highlands and Basin occurred during the final stages of geosynclinal and/or marginal basin development of a system probably unrelated to the Appalachian Orogen. The mineral deposits are related to sedimentary processes which were prevalent during the Carboniferous Period.

The mineralization is confined to clastic and carbonate sediments of the Lower Carboniferous Period and clastic sediments belonging to the Upper Carboniferous Period. Fluids responsible for the deposits were probably expelled from sediments during compaction and precipitated in favourable horizons.

Thus, although the Antigonish Highlands holds some potential for mineralization, the author is of the opinion that there is little indication of a large ore deposit in the Highlands.

However, more field mapping to determine the tectonic framework of the Antigonish Highlands must be carried out before generalizations of the mineral potential of the area may be drawn. If the Highlands does indeed represent vestiges of an island arc system, then some mineral potential as outlined in Chapter 6, may be yet realized.

Until such time, proposals for future work should be oriented about the sedimentary copper and lead mineralization of the basinal areas of the map area. The following proposals are mainly directed at the Ohio-Sylvan Glen Copperbelt and are generally applicable to all deposits of Carboniferous sediments.

A) A much more detailed study of the stratigraphy of the areas is needed to assess the sedimentary history and to outline, specifically, the mineral zonation pattern inferred from this study.

B) Sulfur isotopes of the pyrite, which probably formed during the sedimentation process, could substantiate the proposition that the pyrite is indeed a product of bacterial processes. In this respect, the pyrite should show an enrichment in ^{32}S (Faure 1977). However, trends between sedimentary and igneous sulfides overlap and must be used with great caution (Stanton 1972, Faure 1977).

A study of the sulfur isotopes of the copper sulfides should show a different trend than the pyrite, since presumably the copper sulfides are not products of bacterial action associated with the deposition of the sediments. The copper sulfides should show an enrichment of ^{34}S with respect to that of pyrite.

Problems concerning sulfur isotope studies include the dependance of sulfur fractionation trends on pH, and oxygen fugacity. Fluid inclusion studies would help quantify and clarify this aspect of a sulfur isotope study, if fluid inclusions could be related to copper mineralization. Another problem involves the separation of intimately intergrown sulfide phases in the minute grains.

C) A detailed elemental study of Cu, Pb, and S across the mineralized zone and higher into the stratigraphic column may resolve the problem of replacement of pyrite by copper during upward migration of fluids expelled during sediment compaction. If the Ohio - Sylvan Glen Copperbelt was deposited by upwardly migrating solutions, as other copperbelts most likely were, then a deficiency of sulfur in the copper zone with respect to the inferred pyrite zone lying above the copper zone, should be present. This is most likely due to the loss of sulfur during pyrite replacement by copper bearing solutions (Brown 1971).

Another possible elemental study to delineate a replacement model, such as that proposed in Chapter V, would entail a comparison of CO_2 to SiO_2 and/or Al_2O_3 in both unmineralized and mineralized host rock. If introduction of copper sulfides resulted in displacement of carbonate matrix by sulfides then SiO_2 and Al_2O_3 vs. CO_2 content in the mineralized zone should increase with respect to SiO_2 and Al_2O_3 vs. CO_2 in the unmineralized host (Stanton 1972).

Finally, the proposed source beds of the copper may be depleted in copper with respect to average values for similar beds not involved in a copper deposit.

REFERENCES

Abelson, P.H., 1959. Researches in Geochemistry. John Wiley & Sons, Inc.

A.C.A. Howe International Ltd., 1967. N.S.D.M. Open Assess. File #11E8C, 13-M-02.

Amax Exploration, Inc., 1974a. Some Notes on James River Station Gravity Data. N.S.D.M. Open Assess. File #11E9A, 42-B-14.

Amax Exploration, Inc., 1974b. Diamond Drill Record. N.S.D.M. Open Assess. File #11E8D, 40-B-19.

Ami, H.M., 1892. Catalogue of Silurian fossils from Arisaig, Nova Scotia. Trans. N.S. Inst. Sci., Ser. 2, No. 1, pp. 185-192.

Ami, H.M., 1900. Summary report by G.M. Dawson, Geol. Surv. Can. Ann. Rept., 1900, pp. 179A-180A.

Ami, H.M., 1901. The Knoydart Formation of Nova Scotia. Geol. Soc. Amer. Bull., 12, pp. 301-312.

Anderle, J., 1974. Diamond Drill Logs James River Area for Quebec Uranium Mining Corp. N.S.D.M. Open Assess. File #11E9A, 40B14(01).

Anderson, G.M., 1973. The Hydrothermal Transport and Deposition of Galena and Sphalerite Near 100°C. Econ. Geol., 68, pp. 480-492.

Anderson, G.M., 1975. Precipitation of Mississippi Valey-Type Ores. Econ. Geol., 70, pp. 937-942.

Anderson, Alfred L., 1951. Metallogenic Epochs in Idaho. Econ. Geol., 46, pp. 592-607.

Baas Becking, L.G.M. and More, D., 1961. Biogenic Sulfides. Econ. Geol., 56, pp. 259-272.

Bailey, Sturges W. & Cameron, Eugene N., 1951. Temperatures of Mineral Formation in Bottom-Run Lead-Zinc Deposits of the Upper Mississippi Valley, As Indicated by Liquid Inclusions. Econ. Geol., 46, pp. 626-651.

Barnes, H.L., 1960. Sphalerite Solubilities in Sulfide Solutions (abst.). G.S.A. Bull., 71, p. 1821.

Barnes, H.L., 1963. Ore Solution Chemistry 1. Experimental Determination of Mineral Solubilities. Econ. Geol, 58, p. 1054.

Barnes, H.L., 1967. Sphalerite Solubility in Ore Solutions of the Ilinois-Wisconsin District. Econ. Geol. Monograph 3, pp. 326-332.

Barnes, H.L., and Czamanske, G.K., 1967. Solubilities and Transport of Ore Minerals in Barnes, H.L. (Ed.) Geochemistry of Hydrothermal Ore Deposits. Holt, Rinehart and Winston Inc.

Barton, P.D., 1959. The Chemical Environment of Ore Deposition and the Problem of Low-Temperature Ore Transport. In Researches in Geochemistry, Abelson, P.H. (ed.) pp. 279-300. John Wiley & Sons Inc.

Barton, P.B., 1967. Possible Roll of Organic Matter in the Precipitation of the Mississippi Valley Ores. Econ. Gol. Monograph 3, pp. 371-378. Genesis of Stratiform Lead-Zinc-Barite-Fluorite Deposits in Carbonate Rocks (The So-Called Mississippi Valley Type Deposits).

Barton, P.B., 1970. Sulfide Petrology. Mineral. Soc. Amer. Spec. Pap. 3, pp. 187-198.

Barton, P.B., 1973. Solid Solutions in the System Cu-Fe-S Part I: The Cu-S and CuFe-S Joins. Econ. Geol., 68, pp. 455-465.

Barton, P.B., 1979. The System Cu-Fe-S. In Barnes, H.L. (ed.) Geochemistry of Hydrothermal Ore Deposits, second ed., in preparation.

Barton, P.B., & Skinner, B.J., 1967. Sulfide Mineral Stabilities. In: Barnes, H.L. (ed.) Geochemistry of Hydrothermal Ore Deposits. Holt, Rinehart and Windston, Inc.

Barton, P.B., Berthke, P.M., Toulmin, P., 1963. Equilibrium in Ore Deposits. Mineralogical Society of America, Special Paper 1, pp. 171-185.

Bateman, A.M., 1930. The Ores of the Northern Rhodesia Copper Belt. Econ. Geol., 25, pp. 365-418.

Beales, F.W., 1975. Precipitation Mechanisms for Mississippi Valley-Type Ore Deposits. Econ. Geol., 70, pp. 943-948.

Bell, J.M., 1931. The Genesis of the Lead-Zinc Deposits at Pine Point, Great Slave Lake. Econ. Geol., 26, pp. 661-624.

Bell, W.A., 1926. Carboniferous formations of Northumberland Strait, Nova Scotia. Geol. Surv. Can., Sum. Rept., 1924, pt. C, pp. 142-180.

Bell, W.A., 1927. Outline of Carboniferous stratigraphy and geologic history of the Maritime Provinces of Canada. Trans. Roy. Soc. Can., Vol. XXI, Sect. 4, pp. 75-108.

Bell, W.A., 1929. Horton-Windsor district, Nova Scotia. Geol. Suv. Can., Memoir 155.

Bell, W.A., 1940. The Pictou coalfield, Nova Scotia, Geol. Surv. Can., Memoir 225.

Bell, W.A., 1944. Carboniferous rocks and fossil floras of northern Nova Scotia. Geol. Surv. Can., Memoir 238.

Bell, W.A., 1958. Possibilities for occurrence of petroleum reservoirs in Nova Scotia. Nova Scotia Dept. Mines.

Bell, W.A., 1960. Mississippian Horton Group of type Windsor-Horton district, Nova Scotia. Geol. Surv. Can., Memoir 314.

Benson, D.G., 1961. Geology Map of Guysborough, Nova Scotia. G.S.C. Map 27-1961, Preliminary Series.

Benson, D.G., 1970. Notes to Accompany Geological Maps of Antigonish and Cape George Map-Areas, Nova Scotia. Geol. Surv. Can., Paper 70-8 and 70-9.

Benson, D.G., 1974. Geology of the Antigonish Highlands, Nova Scotia. Geol. Surv. Can., Memoir 376.

Berce, B., 1967. The Stratiform Lead-Zinc Deposits Bordering the Eastern Alps and Their Genetic Elements. Econ. Geol. Monograph 3, pp. 126-132.

Berner, R.A., 1969. The Synthesis of Framboidal Pyrite. Econ. Geol., <u>64</u>, pp. 383-384.

Berry, L.G. and Mason, B., 1959. Mineralogy, Concepts Descriptions Determinations, 630 p. W.H. Freeman and Co.

Bilibin, Yu. A., 1968. Metallogenic Provinces and Metallogenic Epochs, Geological Bulletin, Dept. of Geology, Queens College. Queens College Press, Flushing, New York.

Binney, W.P., 1975(a). Lower Carboniferous Stratigraphy and Base-Metal Mineralization, Lake Enon, N.S. Unpubl. M.Sc. thesis, Queen's University, Kingston, Ontario, 94 p.

Binney, W.P., 1975(b). Copper Occurrences in Lower Carboniferous Sedimentary Rocks of the Maritime Provinces. Geol. Surv. Can., Open File 281.

Binney, W.P. and Kirkham, R.V., 1974. A Study of Copper Mineralization in Mississippian Rocks of Nova Scotia. Geol. Surv. Can., Paper 74-1, Part A, pp. 129-130.

Binnery, W.P. and Kirkham, R.V., 1975. A Study of Copper Mineralization in Mississippian Rocks of the Atlantic Provinces. Geol. Surv. Can., Paper 75-1, Part A, pp. 245-248.

Bird, J.M. and Dewey, J.F., 1970. Lithosphere Plate-Continental Margin Tectonics and the Evolution of the Appalachian Orogen. Geol. Soc. Amer. Bull., 81, pp. 1031-1060.

Bishop, D.G. and Wright, J.D., 1974. Geology and Trace Element Studies of Manganese Occurrences in Nova Scotia. N.S.D.M. Econ. Geol. Series 74-1.

Black, D., 1979. Base Metal Potential of the Antigonish Basin for: Cuvier Mines Ltd. N.S.D.M. Confidential Assessment File.

Boehner, R.C., 1978(a). Geology of the Windsor Group NOrthern and Western Antigonish Basin, Nova Scotia. Preliminary Unpublished report, N.S.D.M.

Boehner, R.C., 1978(b). Assessment of Salt Deposits in Nova Scotia - Antigonish - Mabou Area. Preliminary, Unpublished report, N.S.D.M.

Boehner, R.C., 1978(c). Stratigraphy of the Wilkie Brook Formation, Cape George, Antigonish County, Nova Scotia (Abst.). N.S.D.M. Mineral Resources Division Report of Activities 1977, Rept. 78-1, p. 84.

Boehner, R.C. and Giles, P.S., 1976. Carboniferous Basin Study, The Lower Carboniferous Stratigraphy of the Musquodoboit Valley, Nova Scotia. N.S.D.M. Min. Res. Div. Rept. of Act. 1975, Rept. 76-2, pp. 99-100.

Bogdanov, Y.U., and Kutyrev, E.I., 1973. Classification of Stratified Copper and Lead-Zinc Deposits and the Regularities of their Distribution. In: Ores in Sediments, Amstutz, G.C. and Bernard, A.J. (Eds.) pp. 59-63. Springer-Verlag.

Boucot, A.J. et al, 1974. Geology of the Arisaig Area, G.S.A., Special Paper 139.

Bourque, P.D., 1979a. Metallogenesis and Mineral Deposits of Antigonish Highlands. N.S.D.M. Min. Res. Div. Rept. of Act. 1978, Rept. 79-1, pp. 65-78.

Bourque, P.D., 1979b. Assessment of Mineral Occurrences in the Antigonish Highlands. N.S.D.M. Open File Report No. 383.

Brett, P.R., 1961-62(c). Heating Experiments on Natural Bornites. Car. Inst. Wash. Year Book, 61, pp. 159-160.

Brett, P.R., 1961-62(b). Chalcocite-Chalcopyrite Assemblages. Car. Inst. Wash. Year Book, 61, pp. 157-159.

Brett, P.R., 1961-62(a). Exsolution Textures and Rates in Solid Solutions Involving Bornite. Carnegie Inst. Wash. Year Book, 61, pp. 155-157.

Brett, Robin, 1964. Experimental Data From the System Cu-Fe-S and Their Bearing On Exsolution Textures in Ores. Econ. Geol., 59, Part 2, pp. 1241-1269.

Brett, R. and Yund, R.A., 1964. Sulfur-Rich Bornites. American Mineralogist, 49, pp. 1084-1098.

Bridger, J.R., 1953. N.S.D.M. Open Assessment File #11E16A, 13-B-13.

British Newfoundland Corporation, 1954. N.S.D.M. Open Assessment File #11E16A, 13-B-13.

Brown, A.C., 1971. Zoning in the White Pine Copper Deposit, Antonagon County, Michigan. Econ. Geol., 66, pp. 543-573.

Brown, J.S., ed, 1966. Genesis of Stratiform Lead-Zinc-Barite-Fluorite Deposits (Mississippi Valley Type Deposits), A Symposium. Econ. Geol. Monograph 3.

Burton, W., 1974. Report on Diamond Drilling Ohio Copper Property, Antigonish Co., Nova Scotia, Oct. 1974 by Imperial Oil Ltd. N.S.D.M. Open Assessment File #13B23(02).

Callahan, W.H., 1967. Some Spatial and Temporal Aspects of the Localization of Mississippi Valley-Appalachian Type Ore Deposits. Econ. Geol. Monograph 3, pp. 14-19.

Cameron, E.N., 1961. Ore Microscopy, 293 p. John Wiley and Sons Inc.

Campbell, C.D., 1947. Brief Description of localities in Nova Scotia at which barytes occur in Nova Scotia for Maritime Explorations Ltd. N.S.D.M. Assessment File #11E9D-06B08.

Carpenter, A.B., Trout, M.S., and Pickett, E.E., 1974. Preliminary Report on the Origin and Chemical Evolution of Lead- and Zinc-Rich Oil Field Brines in Central Mississippi. Econ. Geol. 69, pp. 1191-1206.

Cheriton, C.G., 1960. N.S.D.M. Open Asses File #11F13B, 13-B-10.

Clarke, F.W., 1924. The Data of Geochemistry. Dept. of the Interior; U.S.G.S., Bulletin 770, 841 p.

Craig, J.R. and Scott, S.D., 1974. Sulfide Phase Equiligria (The Cu-Fe-S System - Craig). In Sulfide Mineralogy. Min. Soc. Amer., Short Course Notes, 1.

Cuthbert, M.E., 1962. Formation of Bornite at Atmospheric Temperature and Pressure. Econ. Geol., 57, pp. 38-41.

Czamanske, G.K., 1959. Sulfide Solubility in Aqueous Solutions. Econ. Geol., 54, pp. 57-63.

Davidson, D.M., 1931. The Geology and Ore Deposits of Chambishi, Northern Rhodesia, Econ. Geol., 26, pp. 131-152.

Davis, G.R., 1954. The Origin of the Roan Antelope Copper Deposit of Northern Rhodesia. Econ. Geo., 49, pp. 575-615

Dawson, J.W., 1843. On the Lower Carboniferous Rocks or Gypsiferous Formations of Nova Scotia. Proc. Geol. Soc., London, 4, pp. 272-281.

Dawson, J.W., 1845. On the new coal formation of the eastern part of Nova Scotia. Proc. Geol. Soc. pp. 322-330.

Dawson, J.W., 1847. The Gypsum of Nova Scotia. Acad. Nat. Sci., Philadelphia, Proc., 3, pp. 270-274.

Dawson, J.W., 1850. On the metamorphic and metalliferous rocks of eastern Nova Scotia. Quart. Jour. Geol. Soc. London, Vol. VI, pp. 347-364.

Dawson, J.W., 1855. Acadian Geology; an account of the geological structure of Nova Scotia and portions of the nieghbouring provinces of British America. Edinburg, 388 p.

Dawson, J.W., 1860. On the Silurian and Devonian rocks of Nova Scotia. Can. Natur. Geol. and Proc. Nat. Hist. Soc., Montreal, 5, pp. 132-143.

Dawson, J.W., 1863. Synopsis of the flora of the Carboniferous Period in Nova Scotia. Can. Nat., 8, pp. 431-457.

Dawson, J.W., 1874. On the geological relations of the iron ores of Nova Scotia. Can. Nat. N.S., 7, pp. 129-138.

Dawson, J.W., 1880. New facts respecting the geological relations and fossil remains of the Silurian Iron Ores of Pictou, Nova Scotia. Can. Nat. N.S., 9, pp. 313-314.

Dawson, J.W., 1881. Remarks on recent papers on the geology of Nova Scotia. Can. Naturalist,N. Ser., 9, pp. 1-16.

Dawson, J.W., 1891. Acadian geology, fourth ed. London. MacMilland and Co.

Douglas, G.V., Goodman, N.R., Milligan, G.C., 1946. On the Nature of Replacement. Econ. Geol., 41, pp. 546-553.

Dunham, K.C., 1964. Neptunist Concepts in Ore Genesis. Econ. Geol., 59, pp. 1-21.

Dunsmore, H.E., 1977. A New Genetic Model for Uranium-Copper Mineralization, Permo-Carboniferous Basin, Northern Nova Scotia. Geol. Surv. Can., Paper 77-1B, pp. 247-253.

Eastern-Northern Explorations, 1955. N.S.D.M. Open Asses. File #11E8C, CL10 and 15.

Ensign, C.O., White, W.D., Wright, J.C., Patrick, J.L., Leone, R.J., Hathaway, O.J., Trammells, J.W., Fritts, J.J., Wright, T.L., 1968. Copper Deposits in the Nonsuch Shale, White Pine, Michigan. In: Ore Deposits of the United States, 1933-1967. Granton - Sales Volume. Amer. Inst. of Mining, Metallogical and Petroleum Engineers Inc. (AIME)

Faure, G., 1977. Principles of Isotope Geology. John Wiley & Sons, 464 p.

Felderhof, G.W., 1978. Barite, Celestite and Fluorite in Nova Scotia. N.S.D.M. Bulletin No. 4.

Fetzer, W.G., 1946. Humic Acids and True Organic Acids as Solvents of Minerals. Econ. Geol., 41, pp. 47-56.

Finche, J.W., 1933. Sedimentary Copper Deposits of the Western States. In: Ore Deposits of the Western States, Lindgren Volume. A.I.M.E. Inc.

Fleischer, V.D., Garlick, W.G., and Haldane, R., 1976. Geology of the Zambian Copperbelt. In: Handbook of Strata-Bound and Stragiform Ore Deposits; Wolf, K.H. (ed.) 6, pp. 223-352. Elsevier Scientific Publishing Co.

Fletcher, H., 1887. Geological Surveys and explorations in the counties of Guysborough, Antigonish and Pictou, Nova Scotia. Geol. Surv. Can., Ann. Rept., VII, pt. P, pp. 5-128.

Fletcher, H., 1893. Geological Surveys and Explorations in the counties of Pictou and Colchester, Nova Scotia. Geol. Surv. Can., Ann. Rept. 1890-91, 5, part II, pp. 5-193.

Fraser, D.C., 1961. A Syngenetic Copper Deposit of Recent Age. Econ. Geol., 56, pp. 951-962.

Fraser, D.C., 1961. Organic Sequestration of Copper, Econ. Geol., 56, pp. 1063-1078.

Friedman, G.M. and Sanders, J.E., 1978. Principles of Sedimentology, 792 p. John Wiley & Sons.

Gandhi, S.S. and Brown, A.C., 1975. Cupriferous Shales of the Adeline Island Formation, Seal Lake Group, Labrador. Econ. Geol., 70, pp. 145-163.

Garlick, N.G., 1964. Association of Mineralization and Algal Reef Structures on Northern Rhodesian Copperbelt, Katanga and Australia. Econ. Geol., 59, pp. 416-427.

Garrels, R.M., 1960. Mineral Equilibria. Harper & Brothers, Publishers. 254 p.

Garrels, R.M. and Christ, C.L., 1965. Solutions, Minerals and Equilibria. Harper & Row Publishers. 450 p.

Garrels, R.M. and Dreyer, R.M., 1952. Mechanisms of Limestone Replacement at Low Temperatures and Pressures. Geol. Soc. Amer. Bull. 63.

Gary, M., McAfee, R., and Wolf, C.L., eds., 1974. Glossary of Geology. American Geological Institute.

Gesner, A., 1836. Remarks on the geology-mineralogy of Nova Scotia. Halifax, N.S., Gossig and Code.

Gesner, A., 1845. A geological map of Nova Scotia, with an accompanying memoir. Geol. Soc. London Proc., Vol. IV, pp. 186-190.

Giles, P.S., 1977. The Carboniferous Basin Study. N.S.D.M. Mineral Resources Division Report of Activities 1976, Rept. 77-1, pp. 115-123.

Giles, P.S., 1978. Windsor Group Stratigraphy. N.S.D.M., Mineral Resources Division, Report of Activities 1977, Rept. 78-1, pp. 77-80.

Giles, P.S. and Keppie, J.D., 1978. Redefinition of the McAras Brook Formation, Nova Scotia (Abstract). N.S.D.M., Mineral Resources Division Report of Activities 1977, Rept. 78-1, p. 83.

Giles, P.S. and Ryan, R.J., 1976. A Preliminary Report on the Stratigraphy of the Windsor Group in the Eastern Minas Sub-Basin - Nova Scotia. N.S.D.M. Mineral Resources Division Report of Activities 1975, Rept. 76-2, pp. 100-105.

Gillson, J.L., 1963. The Northern Rhodesian Copperbelt: Is It A Classic Example of Syngenetic Deposition. Econ. Geol., 58, pp. 375-390.

Goldschmidt, V.M., 1958. Geochemistry, 730 p. Oxford University Press.

Goudge, M.G., 1939. Coal seams of Merigomish Island?? N.S.D.M. Open Assessment File #11E9C, 09-M-17.

Goudge, M.G., 1940. Hefferman Mn. N.S.D.M. Assessment File #11F13B, 31-B-13.

Goudge, M.G., 1944. Potential of limestone for quarrying at Hillcrest. N.S.D.M. Open Assessment File #11E8D, 28-B-15.

Grace, K.A., 1966. Diamond Drill Logs, Antigonish, Nova Scotia for Kennco Explorations (Canada) Ltd. N.S.D.M. Open Assessment File #11F12B, 13-B-03.

Graves, M.C., 1976. The Formation of Gold-Bearing Quartz Veins in Nova Scotia; Hydraulic Fracturing Under Conditions of Greenschist Regional Metamorphism During Early Stages of Deformation. Unpubl. M.Sc. thesis, Dalhousie University, Halivas, N.S.

Gray, A., 1932. The Mufulira Copper Deposit, Northern Rhodesia. Econ. Geol, 27, pp. 380-387.

Great Horn Mining Syndicate, 1972. (M.J. Hooper). N.S.D.M. Open Assess. File #11E80, 13-B-19.

Greig, J.W., Jensen, E., and Merwin, H.E., 1955. The System Cu-Fe-S. Carnegie Inst. Washington, Year Book, 54, pp. 129-134.

Gustafson, L.B., 1963. Phase Equilibria in the System Cu-Fe-As-S. Econ. Geol., 58, p. 667.

Hannon, P., 1977. Diamond Drill Logs - Ohio Prospect for Imperial Oil Ltd. Imperial Oil Ltd. Confidential File.

Heathridge Mines Ltd., 1966. N.S.D.M. Open Assess. File #11E80, 13-B-19.

Helgeson, H.C., 1964. Complexing and Hydrothermal Ore Deposition, 128 p. The MacMillan Co.

Helgeson, H.C., 1967. Silicate Metamorphism in Sediments and the Genesis of Hydrothermal Ore Solutions. Econ. Geol. Monograph 3, pp. 333-342.

Helgeson, H.C., 1970. A Chemical and Thermodynamic Model of Ore Deposition in Hydrothermal Systems. Mineral Soc. Amer. Spec. Pap. 3, pp. 155-186.

Hewett, D.F., 1928. Dolomitization and Ore Deposition. Econ. Geol., 23, pp. 821-863.

Hobson, G.D. and Tiratsoo, E.N., 1975. Introduction to Petroleum Geology, 300 p. Scientific Press Ltd.

Honeyman, D., 1859. On the fossiliverous rocks of Arisaig. Trans. N.S. Lit. Sci. Soc., pp. 19-29.

Honeyman, D., 1860. On new localities of fossiliferous Silurian rocks in eastern Nova Scotia. Can. Natur. Geol., Vol. V, pp. 293-301.

Honeyman, D., 1864. On the geology of Arisaig, Nova Scotia. Quart. Jour. Geol. Soc. London, 20, pp. 333-345.

Honeyman, D., 1866. Geology of Antigonish County, Nova Scotia. Proc. Trans., N.S. Inst. Nat. Sci., 1, pt. 4, pp. 106-120.

Honeyman, D., 1870(a). Nova Scotian Geology. Proc. Trans., N.S. Inst. Nat. Sci., Vol. II, pp. 4-67.

Honeyman, D., 1870(b). Notes on iron deposits on East River in the County of Pictou, Nova Scotia. Proc. Trans., N.S. Inst. Nat. Sci., Vol. 2, pat. 4, pp. 67-73.

Honeyman, D., 1870(c). Notes on the geology of Arisaig, Nova Scotia. Quart. Jour. Geol. Soc. London, 26, pp. 490-492.

Honeyman, D., 1873. On the metamorphism of rocks in Nova Scotia and Cape Breton. Proc. Trans., N.S. Inst. Nat. Sci., 3, pp. 231-237.

Honeyman, D., 1874. Record of observations on the geology of Nova Scotia since 1855. N.S. Inst. Nat. Sci., Vol. III, pp. 31-40.

Honeyman, D., 1876. Nova Scotian Geology - Antigonish County. Proc. Trans., N.S. Inst. Nat. Sci., 4, pp. 47-79.

Honeyman, D., 1878. Nova Scotia geology, Precarboniferous, Lower Carboniferous, etc., retrospect to 1859. N.S. Inst. Nat. Sci., Vol. IV, pp. 439-487.

Honeyman, D., 1886(a). Polariscopic examination of crystalline rocks of Antigonish County. Proc. Trans., N.S. Inst. Nat. Sci., 6, pp. 299-301.

Honeyman, D., 1886(b). A revision of the geology of Antigonish County in Nova Scotia. Proc. Trans., N.S. Inst. Nat. Sci., 6, pp. 308-325.

Honeyman, D., 1890. Notes of examination by Prof. James Hall of the Silurian collection of the Provincial Museum. Proc. Trans., N.S. Inst. Nat. Sci., 7, pp. 14-17.

Hudgins, A., 1971. N.S.D.M. Open Assess File #11E9A, 13-B-23.

Imperial Oil Ltd., 1974. N.S.D.M. Open Assess. File #11F12C, 07-B-29.

Jackson, C.T. and Alger, F., 1828. A description of the mineralogy and geology of a part of Nova Scotia. Amer. Jour. Sci., 14, pp. 305-330.

Jackson, C.T. and Alger, F., 1829. Mineralogy and geology of a part of Nova Scotia. Amer. Jour. Sci., Vol. XV, pp. 132-160.

Jackson, G.C.A., 1932. The Ores of the Nchanga Mine and Extensions, Northern Rhodesia. Econ. Geol., 27, pp. 247-281.

Johnson, C.G., 1976. N.S.D.M. Open Assess. File #11E16, 13-B-13.

Johnson, D., 1972. Report on the Sylvan Glen Property for Cerro Mining Co. of Canada Ltd. N.S.D.M. Open Assess. File #11E9D, 13-B-26.

Johnson, D., 1973. Record of Diamond Drilling Sylvan Glen Antigonish Co., Nova Scotia for Imperial Oil Ltd. N.S.D.M. Open Assess. File #

Johnston, D., 1974. Diamond Drill Hole Logs, Sylvan Glen Property for Imperial Oil Ltd. In: Ward, M.C., 1974. Rept. of Exploration Gael-Sylvan Glen Property, Antigonish, Nova Scotia. N.S.D.M. Open Assess. File #11E9D, 13B26(02).

Jung, W. and Knitzschke, G., 1976. Kupferschiefer in the German Democratic Republic (GDR). With Special Reference to the Kupferschiefer Deposit in the Southeastern Harz Foreland, pp. 351-406. In: Handbook of Strata-Bound and Stratiform Ore Deposits, 6, Wolf, K.H. (ed.). Esevier Scientific Publishing Co.

Kautzsch, P., 1967. Genesis of Stratiform Lead-Zinc Deposits in Central Europe. Econ. Geol. Monograph 3, pp. 133-137

Keating, B.J., 1951. N.S.D.M. Open Assess. File #11E9A, 13-B-23.

Kennco Explorations (Canada) Ltd., 1966. Report on Antigonish Basin, Nova Scotia. N.S.D.M. Open Assess. File #11F12B, 13-B-03.

Keppie, J.D., 1976. Interpretation of P.P.I. Radar Imagery of Nova Scotia. N.S.D.M. Paper 76-3.

Keppie, J.D., 1978. Browns Mountain Group, Antigonish Highlands, Nova Scotia - Preliminary Reassessment. Geol. Soc. Amer., NE Section Abstracts.

Keppie, J.D., 1979a. Proterozoic Tectonics of Northern Nova Scotia (abstract). N.S.M., Mineral Resource Division Rept. of Activities, 1978. N.S.D.M. Report 79-1, p. 88.

Keppie, J.D., 1979b. Geological Map, the Province of Nova Scotia, Scale 1:500,000. Department of Mines and Energy, Nova Scotia.

Keppie, J.D., Giles, P.S. and Boehner, R.C., 1978. Some Middle Devonian to Lower Carboniferous Rocks of Cape Beorge, Nova Scotia. N.S.D.M. Paper 78-4.

Kerr, P.F., 1959. Optical Mineralogy, 442 p. McGraw-Hill Book Co.

Kirkham, R.V., 1971. Stratiform copper deposits in Mississippian rocks of Cape Breton Island and part of mainland Nova Scotia. Geol. Surv. Can., Paper 71-1, Part A, pp. 86-88.

Kirkham, R.V., 1973-74. Environments of Formation of Concordant and Peneconcordant Copper Deposits in Sedimentary Sequences. Canadian Mineralogist, 12, pp. 145-146.

Kirkham, R.V., 1978. Base Metal and Uranium Distribution Along the Windsor-Horton Contact, Central Cape Breton Island, Nova Scotia. Geol. Surv. Can., Paper 78-1B, pp. 121-135.

Klemm, D.D. and Schneider, H.J., ed., 1977. Time- and Strata-Bound Ore Deposits, 488 p. Springer-Verlag.

Knapp, T.S., 1959. N.S.D.M. Open Assess. File #11E9A, 39-B-23.

Kontak, D.J., 1976. The College Grant Copper Mine and Its Geologic Setting. Unpubl. B.Sc. Thesis, St. Francis Xavier University, Antigonish, Nova Scotia.

Krauskopf, K.B., 1967. Introduction to Geochemistry. McGraw-Hill. pp. 388-452.

Kullerud, G., 1955. Temperature of Deposition of Sulfide Ores. Carnegie Inst. Wash., Year Book, 54, pp. 99-100.

Kullerud, G., 1959. Sulfide Systems as Geological Thermometers. In: Researches in Geochemistry, Abelson, P.H., ed., pp. 301-333. John Wiley & Sons Inc.

Kullerud, G., 1967. Sulfide Studies: The Cu-Fe-S System. In: Researches in Geochemistry, 2, pp. 294-301. Abelson, P.H., ed. John Wiley & Sons Inc.

Kullerud, G., 1969. The Lead-Sulfur System. American Journal of Science, Schairer, 26, 7-A, pp. 233-256.

Kullerud, G., 1970. Sulfide Phase Relations. Mineral Soc. Amer., Spec. Pap. 3, pp. 199-210.

Lang, A.H., 1961. Metallogenic Maps. Econ. Geol., 56, pp. 1123-1132.

Lemoalle, J. and Dupont, B., 1973. Iron Bearing Oolites and the Present Conditions of Iron Sedimentation in Lake Chad (Africa). In: Ores in Sediments, Amstutz, G.C. and Bernard, A.J., eds. International Union of Geological Sciences, Lines A, No. 3, Springer-Verlag.

Levorsen, A.I., 1967. Geology of Petroleum. W.H. Freeman and Company, 723 p.

Love, L.G., 1962. Biogenic Primary Sulfide of the Permian Kupferschiefer and Marl Slate. Econ. Geol., 57, pp. 350-366.

Love, L.G., 1967. Diagenesis and the Origin of the Ores. Econ. Geol. Monograph 3, pp. 343-348.

Lovering, T.S., 1963. Epigenetic, Diplogenetic, Syngenetic and Lithogene Deposits. Econ. Geol., 58, pp. 315-331.

Lur'ye, A.M., 1975. Copper Deposits in Marine Sediments. International Geology Review, 17, pp. 1094-1102.

MacDonald, M.A., 1977. Petrology of the Malignant Cove Diorite Complex. Unpubl. B.Sc. Thesis, St. Francis Xavier University, Antigonish, N.S.

MacEachern, S.B. and Hannon, P., 1974. The Gays River Discovery - A Mississippi Valley Type Lead-Zinc Deposit in Nova Scotia. Can. Inst. Min. Bull. 67, No. 750, pp. 61-66.

MacIntyre Porcupine Mines Ltd., 1960. N.S.D.M. Open Assess. File #11E9A, 13-B-14.

MacKay, R.M. and Zentilli, M., 1976. Mineralogical Observations on the Copper-Uranium Occurrence at Black Brook, Nova Scotia. Geol. Surv. Can., Paper 76-1B, pp. 343-344.

MacLean, W.H., Cabri, L.J. and Gill, J.E., 1972. Exsolution Products in Heated Chalcopyrite. Can. Jour. Earth Sci., 9, No. 10, pp. 1305-1317.

MacLeod, J.L., 1978. Diamond Drill Logs, Ohio Prospect for Imperial Oil Ltd. Imperial Oil Ltd. Confidential File.

MacNeil, D.J., 1946. Geol. and Petroleum possibilities of Antigonish Harbour. N.S.D.M. Open Assess. File #11F12W, 39-B-40.

MacNeil, D.J., 1947. Petroleum potential, Antigonish Harbour. N.S.D.M. Open Assess. File #11F12W, 39-B-40.

MacNeil, D.J., 1948. Petroleum potential of Big Marsh. N.S.D.M. Open Assess. File #11E9D, 39-B-32.

MacNeil, D.J., 1952a. Oil and gas potential, Antigonish Harbour. N.S.D.M. Open Assessment File #11F12W, 39-B-40.

MacNeil, D.J., 1952b. N.S.D.M. Open Assess. File #11F2C, 42-B-05.

MacNeil, D.J., 1954. Followup of Sage ('52) work for Esso. N.S.D.M. Open Assess. File #11F12C, 39-B-05.

MacNeil, D.J., 1956. Petroleum possibilitiy for East.-North. Exploration. N.S.D.M. Open Assessment File #11F12C, 39-B-05.

MacNeil, D.J., 1959a. Report on the Carboniferous Basin for Lura Corp. N.S.D.M. Open Assess. File #11F12C, 39-B-05.

MacNeil, D.J., 1959b. N.S.D.M. Open Assess. File #11E9A, 39-B-23.

MacNeil, D.J., 1964. Pet. Potential, Antigonish Harbour for Eastern Petrol. Ltd. N.S.D.M. Open Assess. File #11F12C, 39-B-05.

Maehl, R.H., 1960. The Silurian of Pictou County, Nova Scotia. Mass. Inst. Tech., Unpubl. Ph.D. thesis.

Maehl, R.H., 1961. The older Palaeozoic of Pictou County, Nova Scotia. N.S.D.M., Memoir 4.

Malan, S.P., 1964. Stromatolites and Other Algal Structures at Mufulira, Northern Rhodesia. Econ. Geol. <u>59</u>, pp. 397-415.

Malcolm, W., 1976. Gold Fields of Nova Scotia. Geol. Surv. Can., Memoir 385 (originally published in 1929 as Memoir 156.).

Maritime Exploration Ltd., 1946. Browns Mountain Barite. N.S.D.M. Open Assess. File #11E9D, 06-B-08.

Maritime Rock Products Co., 1960. N.S.D.M. Open Assess. File #11E16A, 15-B-13.

Maucher, A. and Schneider, H.J., 1967. The Alpine Lead-Zinc Ores. Econ. Geol. Monograph 3, pp. 71-89.

McCartney, W.D. and Potter, R.R., 1962. Mineralization as Related to Structural Deformation, Igneous Activity and Sedimentation in Folded Geosynclines. Can. Mining Jour., <u>83</u>, pp. 83-87.

McCauley, J.F., 1958. Supergene Copper Uranium Deposits, Nova Scotia (A Discussion). Econ. Geol. <u>53</u>, pp. 1038-1049.

McCulloch, P.D., 1972. Report on Cera-Big Marsh Property, Big Marsh, Nova Scotia. N.S.D.M. Open Assess. File #11E9C, 06-B-32.

McKinstry, Hugh, 1959. Mineral Assemblages in Sulfide Ores: The System Cu-Fe-S-O. Econ. Geol., 54, pp. 975-1001.

McKinstry, Hugh, 1963. Mineral Assemblages in Sulfide Ores: The System Cu-Fe-As-S. Econ. Geol., 58, pp. 483-505.

McLearn, F.H., 1924. Palaeontology of the Silurian Rocks Of Arisiag, Nova Scotia. Gol. Surv. Can., Memoir 137.

Mendelsohn, F., 1961. The Geology of the Northern Rhodesian Copperbelt, 523 p. Waterlow & Sons Ltd.

Merwin, H.E. and Lombard, R.H., 1937. The System Cu-Fe-S. Econ. Geol., 32, pp. 203-284.

Messervey, J.P., 1929. Copper in Nova Scotia. N.S.D.M., Pamphlet No. 7.

Messervey, J.P., 1929. Lead and Zinc in Nova Scotia. N.S.D.M., Pamphlet No. 15.

Moh, G., 1963. Low Temperature Sulfide Synthesis. Carnegie Inst. Wash., 62, pp. 214-215.

Moore, R.G. and Ryan, R.J., 1976. Guide to the Invertebrate Fauna of the Windsor Group in Atlantic Canada. N.S.D.M. Paper 76-5.

Murphy, J.B., Keppie, J.D. and Hynes, A., 1979. Geology of the Northern Antigonish Highlands. N.S.D.M. Mineral Resources Division Rept. of Activities, 1978. N.S.D.M. Paper 79-1, pp. 105-107.

Murray, D.A., 1975. Limestones and Dolomites of Nova Scotia, Part II. N.S.D.M. Bulletin No. 2.

Neale, E.R.W., Beland, J., Potter, R.R., and Poole, W.H., 1961. A Preliminary Tectonic Map of the Canadian Appalachian Region Based on Age of Folding. Can. Inst. Mining Met. Bull., 54, pp. 687-694.

New Jersey Zinc Exploration Co. (Canada) Ltd., 1967, 1969, 1970. N.S.D.M. Open Assess. File #11E16A, 13-B-13.

Noranda Exploration Co., 1977. N.S.D.M. Open Assess. File #11E16A, 13-B-13.

Northcote, K.E. and White, Wm. H., 1962. Distribution of Metals in a Modern Marine Environment. Econ. Geol, 57, pp. 405-409.

Northern Minerals Ltd., 1966. N.S.D.M. Open Assess. File #11E8D, 13-B-19.

Nova Scotia Department of Mines, 1965. Geological Map of the Province of Nova Scotia.

Nova Scotia Department of Mines, 1959. Drilling Logs of Government Core Drills, 1958.

Nova Scotia Department of Mines, 1962. Drilling Logs of Government Core Drills, 1961.

Nova Scotia Department of Mines, 1964. Drilling Logs of Government Core Drills, 1963.

Nova Scotia Department of Mines, 1968. Drilling Logs of Government Core Drills, 1967.

Nova Scotia Department of Mines, 1970. Drilling Logs of Government Core Drills, 1969.

Nova Scotia Department of Mines, 1971. Drilling Logs of Government Core Drills, 1970.

Nova Scotia Department of Mines, 1976b. Drilling Logs of Government Core Drills, 1974, Rept. 76-1.

Nova Scotia Department of Mines, 1976c. Drilling Logs of Government Core Drills, 1975, Rept. 76-3.

Nova Scotia Department of Mines, 1977b. Drilling Logs of Government Core Drills, 1976, Rept. 77-3.

Nova Scotia Department of Mines, 1978b. Drilling Logs of Government Core Drills, 1977, Rept. 78-2.

Nova Scotia Department of Mines, 1976. Mineral Resources Division Report of Activities, 1975. N.S.D.M. Rept. 76-2.

Nova Scotia Department of Mines, 1977. Mineral Resources Division Report of Activities · 1976. N.S.D.M. Rept. 77-1.

Nova Scotia Department of Mines, 1978. Mineral Resources Division Report of Activities · 1977. N.S.D.M. Rept. 78-1.

Nova Scotia Dept. of Trade & Industry, 1952a. N.S.D.M. Open Assess. File #11F12C, 42-B-05.

Nova Scotia Dept. of Trade and Industry, 1952a. Magnetics and gravity of Antigonish Harbour. N.S.D.M. Open Assess. File #11F12C, 39-B-05.

Nova Scotia Research Foundation, 1958. N.S.D.M. Open Assess. File #11F12C, 39-B-05.

Nowlan, J.P., 1958. N.S.D.M. Open Assess. File #11E8C, CL10 and 15.

Ohle, Ernest L, 1951. The Influence of Permeability on Ore Distribution in Limestone and Dolomite. Part 1: Econ. Geol. 46, pp. 667-706. No. 7. Part 2: Econ. Geol., 46, pp. 871-908. No. 8.

Ohle, E.L., 1967. The Origin of Ore Deposits of the Mississippi Valley Type. Econ. Geol. Monograph 3, pp. 33-39.

Papenfus, E.B., 1931. "Red Bed" Copper Deposits in Nova Scotia and New Brunswick. Econ. Geol., 26, pp. 314-330.

Park, Charles F., Jr., 1931. Hydrothermal Experiments With Copper Compounds. Econ. Geol., 26, pp. 857-883.

Park, C.F., Jr. and MacDiarmid, R.A., 1970. Ore Deposits 522 p. W.H. Freeman and Company.

Potter, R.R., 1970. Metallogeny and Characteristics of Sulfide Deposits in the Appalachian Region. Summary Paper; presented at Toronto, April 1970, 72nd Annual Convention Meeting, Can. Inst. Miningy and Met.

Quebec Uranium, 1974. N.S.D.M. Open Assess. File #11E9A, 40-B-14.

Ramdohr, Paul, 1969. The Ore Minerals and Their Intergrowths, 1174 pp. Pergamon Press.

Renfro, A.R., 1974. Genesis of Evaporite-Associated Stratiform Metaliferous Deposits -- A Sabkha Process. Econ. Geol. 69, pp. 33-45.

Rentzsch, J., 1974. The Kupferschiefer in Comparison with the Deposits of the Zambian Copperbelt. Centenaine de la Societe Geologique de Belgique Gissments Stratiforms et Provinces Cupriferes, Liege. pp. 395-418.

Roberts, W.M.B., 1961. Formation of Chalcopyrite by Reaction Between Chalcocite and Pyrrhotite in Cold Solution. Nature, 191, pp. 560-562.

Roberts, W.M.B., 1963. The Low Temperature Synthesis in Aqueous Solution of Chalcopyrite and Bornite. Econ. Geol., 58, pp. 52-61.

Roedder, Edwin, 1962. Ancient Fluids in Crystals. Scientific Amer., 207, pp. 38-47.

Roedder, Edwin et al, 1963. Studies of Fluid INclusions III: Extraction and Quantitative Analysis of Inclusions the Milligram Range. Econ. Geol., 58, pp. 353-374.

Roedder, Edwin, 1963. Studies of Fluid Inclusions II: Freezing Data and Their Interpretation. Econ. Geol., 58, pp. 167-211.

Roedder, E., 1967. Environment of Deposition of Stratiform (Mississippi-Valley Type) Ore Deposits, From Studies of Fluid Inclusions. Econ. Geol. Monograph 3, pp. 349-362.

Roedder, Edwin, 1967. Fluid Inclusions as Samples of Ore Fluids in Barnes, H.L., Geochemistry of Hydrothermal Ore Deposits. Holt, Rinehart and Winston Inc.

Roedder, E., 1974. Fluid INclusion Evidence on the Genesis of Ores in Sedimentary and Volcanic Rocks. Prelim. paper for Ores in Sediments, Sedimentary and Volcanic Rocks. K.H. Wolf, ed., pp. 67-110.

Roedder, Edwin, 1977. Fluid Inclusions As Tools in Mineral Exploration. Econ. Geol., 72, pp. 503-525.

Rose, A.W., 1976. The Effect of Cuprous Chloride Complexes in the Origin of Ted-Bed Copper and Related Deposits. Econ. Geol., 71, pp. 1036-1048.

Ross, V., 1954. The Formation of Intermediate Sulfide Phases in the Solid State. Econ. Geol., 49, pp. 734-752.

Sage, N. McL., 1952. MIT field school assimilation of data. N.S.D.M. Open Assess. File #11F12W, 39-B-40.

Sage, N. McL., 1954. The Stratigraphy of the Windsor Group In the Antigonish Quadrangles and The Mahone Bay - St. Margaret Bay area, Nova Scotia. N.S.D.M. Memoir No. 3.

Sales, R.H., 1962. Hydrothermal versus Syngenetic Theories of Ore Deposition. Econ. Geol., 57, pp. 721-734.

Samonov, I.Z. and Pozharisky, I.F., 1977. Deposits of Copper. In: Ore Deposits of the USSR. Smirnov, V.I. ed., Vol. II, 424 pp. Pitman Publishing.

Schenk, P.E., 1967. The Significance of Algal Stromatolites To Palaeoenvironmental And Chronostratigraphic Interpretations of the Windsorian Stage (Mississippian) Maritime Provinces. Geol. Soc. Can., Spec. Paper 4, pp. 229-243.

Schenk, P.E., 1969. Carbonate-Sulfate Facies and cyclic Sedimentation of the Windsorian Stage (Middle Carboniferous). Maritime Provinces. Can. Jour. Earth Sci., 6, pp. 1037-1066.

Schenk, P.E., 1971. Southeastern Atlantic Canada, Northwestern Africa, and Continental Drift. Can. J. Earth Sci., 8, pp. 1218-1251.

Schenk, P.E., 1978. Synthesis of the Canadian Appalachians. In: Caledonian-Appalachian Orogen of the North Atlantic Region. Geol. Surv. Can., Paper 78-13, pp. 111-136.

Schenk, P.E., 1975. Windsorian Stage (Middle Carboniferous) Antigonish Basin. Unpublished Report.

Schenk, P.E. and Hatt, B.L., 1979. Depositional Environment of the Gays River Reef, Nova Scotia, Canada. Report in preparation.

Schmitt, H.D., ed., 1962. Equilibrium Diagrams for Minerals 199 pp. Geological Club of Harvard.

Schouten, C., 1934. Structures and Textures of Synthetic Replacements in "Open Space". Econ. Geol., 29, pp. 611-658.

Schouten, C., 1946. Synthetic Replacements as an Aid to Ore-Genetic Studies. Econ. Geol., 41, pp. 659-667.

Schouten, C., 1946. The Role of Sulphur Bacteria in the Formation of the So-Called Sedimentary Copper Ores and Pyritic Ore Bodies. Econ. Geol., 41, pp. 517-538.

Schwartz, G.M., 1928. Experiments Bearing on Bornite-Chalcocite Intergrowths. Econ. Geol., 23, pp. 381-397.

Schwartz, G.M., 1931. Textures Due to Unmixing of Solid Solutions. Econ. Geol., 26, pp. 739-763.

Schwartz, G.M., 1931. Intergrowths of Bornite and Chalcopyrite. Econ. Geol., 26, pp. 186-201.

Schwartz, G.M., 1939. Significance of Bornite-Chalcocite Microtextures. Econ. Geol., 34, pp. 399-418.

Schwartz, G.M., 1951. Classification and Definitions of Textures and Mineral Structures in Ores. Econ. Geol., 46, pp. 578-591.

Shaw, A.B., 1964. Time in Stratigraphy. McGraw-Hill Book Co.

Short, M.N., 1940. Microscopic Determination of the Ore Minerals. U.S. Dept. of the Interior. Geol. Surv. Bull. 914.

Skinner, B.J., 1967. Precipitation of Mississippi Valley-Type Ores: A Possible Mechamism. Econ. Geol. Monograph 3, pp. 363-370.

Snyder, F.G., 1967. Criteria for Origin of Stratiform Ore Bodies with Application to Southeast Missouri. Econ. Geol. Monograph 3, pp. 1-13.

Stanton, R.L., 1972. Ore Petrology (McGraw-Hill), pp. 386-398.

Strong, D.F., 1974. Plate Tectonic Setting of Newfoundland Mineral Deposits. Geoscience Canada, 1, pp. 20-30.

Sugaki, A., Shima, H., Kitakaze, A., Harada, H., 1975. Isothermal Phase Relations in the System Cu-Fe-S Under Hydrothermal Conditions at 350°C and 300°C. Econ. Geol., 70, pp. 806-823.

Taupitz, K.C., 1967. Textures in Some Stratiform Lead-Zinc Deposits. Econ. Geol. Monograph 3, pp. 90-107.

Temple, K.L., 1964. Syngenesis of Sulfide Ores: An Evaluation of Biochemical Aspects. Econ. Geol., 59, Part 2, pp. 1473-1491.

Terry, R.D. and Chilingar, G.V., 1955. Comparison Chart for Estimating Percentage Composition. Jour Sed. Pet., 25, pp. 229-234.

Transterre Explorations Ltd., 1966. N.S.D.M. Open Assess. File #11E16A, 27-B-20.

Trudinger, P.A., 1976. Microbiological Processes in Relation to Ore Genesis. In: Handbook of Strata-Bound and Stratiform Ores Deposits, 2, Wolf, K.H., ed. Elsivier Scientific Publishing Co.

Trudinger, P.A., Lambert, I.B. and Skyring, G.W., 1972. Biogenic Sulfide Ores: A Feasibility Study. Econ. Geol., 67, pp. 1114-1127.

Turekian, K.K. and Wedepohl, K.H., 1961. Distribution of the Elements in Some Major Units of the Earth's Crust. Geol. Soc. Amer. Bull., 72, Part 1, pp. 175-191.

Twenhofel, W.H., 1909. The Silurian section at Arisaig, Nova Scotia. Amer. Jour. Sci., 4, No. 28, pp. 143-169.

Uytenbogaarot, W. and Burke, E.A.J., 1971. Tables For Microscopic Identification of Ore Minerals, 430 pp. Elsevier Publishing Co.

Van Eden, J.G., 1974. Depositional and Diagenetic Environment Related to Sulfide Mineralization, Mufulira, Zambia. Econ. Geol., 69, pp. 59-79.

Vaughan, D.J., 1976. Sedimentary Geochemistry and Mineralogy of the Sulfides of Lead, Zinc, Copper and Iron and Their Occurrence in Sedimentary Ore Deposits. In: Handbook of Strata-Bound and Stratiform Ore Deposts, 2, Wolf, K.H., ed. Elsevier Scientific Publishing Co.

Vokes, F.M., 1969. A Review of the Metamorphism of Sulfide Deposits. Earth Sci. Reviews, 5, pp. 99-143.

Ward, M.C., 1974a. Report on Exploration Gael-Sylvan Glen Property, Antigonish, Nova Scotia, 1973-1974 for Imperial Oil Limited. N.S.D.M. Open Assess. File #11E9D, 13B26(02).

Ward, M.C., 1974b. Report on Field Work in Antigonish Basin Area, Nova Scotia, 1973 by Imperial Oil Ltd. N.S.D.M. Open Assess. File #11F12W, 07-B-04.

Ward, M.C., 1974c. Preliminary Report on Geological, Geochemical and Geophysical Surveys, Ohio Copper Property, Antigonish Co., Nova Scotia by Imperial Oil Ltd. N.S.D.M. Open Assess. File #11E9A, 13-B-23.

Ward, M.C., 1974d. Report on Geochemical Surveys, Ohio Copper Property, Antigonish Co., Nova Scotia by Imperial Oil Ltd. N.S.D.M. Open Assess. File #11E9A, 13-B-23.

Ward, M.C., 1975a. Report on Geological and Geochemical Surveys, Pitchers Farm Area, Antigonish Co., Nova Scotia by Imperial Oil Ltd. N.S.D.M. Open Assess. File #11F12B, 13-B-30.

Ward, M.C., 1975b. Report on Geophysical Surveys, Stewart Lake Area, Antigonish Co., Nova Scotia by Imperial Oil Ltd. N.S.D.M. Open Assess File #11E8D, 07-B-33.

Ward, M.C., 1975c. Report on Geochemical Surveys, Ohio Area, Antigonish Co., Nova Scotia by Imperial Oil Ltd. N.S.D.M. Open Assess. File #11E9A, 13-B-23.

Ward, M.C., 1975d. Summary Report on Diamond Drilling, Gael, Potash, Addington Forks Area, Antigonish Co., Nova Scotia by Imperial Oil Ltd. N.S.D.M. Open Assess. File #11E9A, 40-B-08.

Ward, M.C., 1976. Summary Report on Drilling Stewart Lake Area, Antigonish Co., Nova Scotia by Imperial Oil Ltd. N.S.D.M. Open Assess. File #11E8D, 07-B-33.

West, D.M., 1944. Geology of Merigomish Island. N.S.D.M. Open Assess. File #11E9C, 39-M-17.

White, D.E., 1967. Outline of Thermal and Mineral Waters as Related to Origin of Mississippi Valley Ore Deposits. Econ. Geol. Monograph 3, pp. 379-382.

White, W.S., 1971. A Paleohydrologic Model for Mineralization of the White Pine Copper Deposit, Northern Michigan. Econ. Geol., 66, pp. 1-13.

White, W.S. and Wright, J.C., 1954. The White Pine Copper Deposit, Ontonagon County, Michigan. Econ. Geol. 49, pp. 675-716.

White, W.S. and Wright, J.C., 1966. Sulfide-Mineral Zoning in the Basal Nonesuch Shale, Northern Michigan. Econ. Geol., 61, pp. 1171-1190.

Whitehead, W.L., 1944. Petroleum potential of Antigonish Harbour Area. N.S.D.M. Open Assess. File #11F12W, 39-B-00.

Williams, H., 1979. Appalachian Orogen in Canada. Can. Jour. Earth Sci., 16, pp. 792-807.

Williams, H. and Stevens, R.K., 1974. Zaconic Orogeny and the development of the Ancient Continental Margin of Eastern North America in Newfoundland. Geoscience Canada, 1, pp. 31-33.

Williams, H., Turner, F.J. and Gilbert, C.M., 1954. Petrography, An Introduction to the Study of Rocks in Thin Sections, 406 pp. W.H. Freeman and Co.

Williams, H., Turner, F.J., Gilbert, C.M., 1954. Petrography, An Introduction to the Study of Rocks in Thin Sections. W.H. Freeman and Co.

Williams, M.Y., 1914. Arisaig-Antigonish District, Nova Scotia. Geol. Surv. Can., Memoir 60.

Wolf, K.H., ed., 1976. Handbook of Strata-Bound and Stratiform Ore Deposits. Elsevier Scientific Publishing Co.

Woodman, J.E., 1909. N.S.D.M. Open Assess. File #11-E-16A, 25-B-06.

Woodward, L.E., Kaufman, W.H., Schumacher, O.L. and Talbott, L.W., 1974. Strata-Bound Copper Deposits in Triassic Sandstone of Sierra Nacimiento, New Mexico. Econ. Geol., 69, pp. 108-120.

Wright, J.D., 1966. Metallic Mineral Occurrences recorded in the Province of Nova Scotia. N.S.D.M. Accompaniment to Mineral Map of Nova Scotia.

Wright, J.D., 1975. Iron Deposits of Nova Scotia. N.S.D.M. Econ. Geol. Seris, 75-1.

Yund, R.A. and Kullerud, G., 1966. Thermal Stability of Assemblages in the Cu-Fe-S System. Jour. Petrology, 7, pp. 454-488.

Zajic, J.E., 1969. Sulfate reductions and sulfides, in Microbial biogeochemistry: pp. 1-345. New York, Academic Press.

Zentilli, M., 1977. Evolution of Metallogenic Domains in Nova Scotia. Abstract. Can. Inst. Mining Met. Bull. 70, p. 69.

Zobell, C.E., 1958. Ecology of sulfate-reducing bacteria. Producers Monthly, 22, pp. 12-19.

APPENDIX 1

Geological Descriptions of Mineral Occurrences in the Antigonish Area

1- ARISAIG LEAD OCCURRENCE 11E16

	U.T.M. GRID
Lat. 45° 45' 52"	5068000 Northing
Long. 62° 08' 48"	566380 Easting

This location is found on McGillivray Brook, 1400 feet (490 m) south from Hwy. 245.

No lead was found in the fine grained, micaceous grewacke with a well developed cleavage.

2- TELFORD LEAD-ZINC OCCURRENCE 11E9W

Several locations between Telford and Sutherlands River settlement, as indicated on N.S.D.M. Mineral Occurrence file, were checked.

Bensen (1970) reports two lead-zinc locations in this area in a preliminary report. The locations are not found in Benson (1974).

These localities consist of fine to medium-grained, red and grey, micaceous and silty sandstones of the Canso Group. One location contained an interbedded grey conglomerate unit. However, no metallic mineralization was found in any of the locations.

3- ANTIGONISH HARBOUR LEAD OCCURENCE

			11F12W U.T.M. Grid
(1)	Lat.	45° 38' 02"	5053660 N
	Long.	61° 56' 01"	583120 E
(2)	Lat.	45° 36' 35"	5050980 N
	Long.	61° 54' 20"	585300 E
(3)	Lat.	45° 38' 12"	5054060 N
	Long.	61° 51' 51"	588520 E

No lead was found at coordinate (1), which is located at the north end of the Williams Point road.

Location (2) lies 1400 feet (470 m) southeast of the South Side Harbour Road, along the railroad track at South River Station. No outcrop was found in the stream at this location or along the railroad track east to the Taylor Road.

Location (3) is found on the property of C.E. Giles, 2000 feet (890 m) west along the Cove Road, approximately one mile (1.6 km) north of Pomquet.

Traces of galena associated mainly with calcite cavity fillings are found in the brownish grey Windsor dolomite. This outcrop has been noted by Murray (1975) to be upper E-subzone Windsor Group.

Galena was also found in limestone and dolomite in several drill holes in the Pomquet, Monk Head and Williams Point areas (Murray 1975) (see Maps 1 and 2).

4- GEORGEVILLE-HEFFERNAN MANGANESE OCCURRENCE

		11F13W
		U.T.M. GRID
Lat.	45° 47' 35"	5071320 N
Long.	61° 59' 33"	578580 E

Heffernan's occurrence is located on a farm at the west end of North Lake, approximately 3 miles (4.8 km) south of Georgeville.

Bog manganese and/or iron was found as orange and black oxide layers on the surface of compacted soil in the swamp and stream on the property. In addition, scattered boulders of compact, sandy, grey pebble conglomerate show minor manganese staining.

Very extensive swamps are present in this area and the possibility exists that bog manganese is being formed presently.

Bishop and Wright (1974) consider the occurrence uneconomic.

5- AFTON MANGANESE OCCURRENCE 11F12W

		U.T.M. GRID
Lat.	45° 35' 36"	5049310 N
Long.	61° 46' 07"	596120 E

This reported occurrence is 2500 feet (830 m) east of Hwy. 104, along Hwy. 4, just east of Heatherton.

No manganese was found at this location.

6- POMQUET RIVER MANGANESE OCCURRENCE

11F12W

		U.T.M. GRID
Lat.	45° 34' 18"	5046860 N
Long.	61° 50' 26"	590520 E

No evidence of bog manganese was found on this farm, two miles (3.2 km) southwest of Pomquet Forks.

7- HILLCREST MANGANESE OCCURRENCE 11E8E

		U.T.M. GRID
Lat.	45° 27' 21"	5033800 N
Long.	62° 03' 30"	573620 E

Float on the property of D. McInnis, one mile (1.6 km) south of Cross Roads Ohio, is reported to have contained pyrolusite (N.S.D.M. Mineral occurrence File).

Examination of the reported occurrence showed no outcrop nor any boulders. The small stream adjacent the property was similarly devoid of showings.

8- GREENVALE GOLD OCCURRENCE 11E9

	U.T.M. GRID
Lat. 45° 30' 10"	5038700 N
Long. 62° 29' 03"	540260 E

This reported gold occurrence has been worked to a limited extent in the past. The trench is located on the east side of a logging road approximately 2100 feet (700 m) south of the southern loop of the "S" turn at Greenvale. The logging road follows the Sutherlands river.

A 12 foot (4 m) long, 3-1/2 (1 m) foot wide and 5-1/2 foot (1.8 m) deep trench has been cut parallel to the nearly vertical slatey cleavage and following three 8 cm wide quartz veins that cut greenish-grey slatey quartzwackes, of the Browns Mountain Group. The quartz veins commonly contain chlorite and although no gold was found, traces of chalcopyrite were noted.

Although no records of gold production exist (Malcolm 1976, Graves 1976), these Cambro-Ordovician quartzwackes bear lithological resemblance to the Lower Ordovician gold-bearing Meguma Group. This area, therefore, warrants further investigation.

9-GEORGEVILLE URANIUM AND BERYLLIUM OCCURRENCE

	11E16
	U.T.M. GRID
Lat. 45° 49' 55"	5075560 N
Long. 62° 01' 43"	575440 E

Coordinates cited are found at the mouth of McInnes Brook, along the Georgeville coast. This is situated approximately in the centre of the alaskite. A pegmatite, which forms a prominent point, is found approximately 1000 feet (330 m) northeast of this location.

Locations plotted on N.S.D.M. Mineral Occurrence Data File were examined. Background scintallometer readings (20-40 c.p.s.) were obtained in the Browns Mountain argillites of McInnes Brook. Slightly higher than background readings (80-120 c.p.s.) were recorded in the alaskite on the Georgeville coast. Pegmatite areas of the alaskite also show readings slightly above background.

Trace amounts of thorium may be found in chloritic rich areas on fracture surfaces (Nance, person. comm., 1979).

No beryl crystals were found, although green amazonite is quite common.

10- MOOSE RIVER COPPER OCCURRENCE

		11E8
		U.T.M. GRID
Lat.	45° 26' 42"	5032405 N
Long.	62° 19' 45"	552440 E

This occurrence appears to have been worked to a very limited extent. It is located approximately 300 feet (100 m) west of Hwy. 347 along a small stream which crosses Hwy. 347, 1.3 miles (2.1 km) north of the church at Garden of Eden.

Chalcopyrite and minor malachite in quantities of about 0.5% are found in large 10 cm. discontinuous calcite veins lying within a 20 foot (6.7 m) wide siliceous shear zone. The host rock is a grey quartz-feldspar welded crystalline tuff of the Browns Mountain Group, which displays a cleavage that is deflected around the quartz and feldspar phenocrysts. Pyrite and pyrrhotite grains, generally with a preferred orientation, are disseminated in the host.

Quartz grains in the shear zone have been granulated and strained. Fragmented blocks of sheared host are incorporated within some calcite veins.

11- KNOYDART POINT COPPER OCCURRENCE

	11E9
	U.T.M. GRID
Lat. 45° 43' 12"	5063255 N
Long. 62" 14' 10"	559460 E

The Knoydart Point copper occurrence is located along the shore approximately 2700 feet (900 m) east of Knoydart Point, just west of the Antigonish-Pictou County line. Access may be gained to the shore through the fields north of Hwy. 245. Fletcher (1886) also reports a copper occurrence approximately 3000 (1000 m) from the shore, along Knoydart Brook. No copper was found in this area.

In the Knoydart Point area, grey oolitic limestones of the Windsor Group are overlain by the Lismore Formation which comprises sandstone redbeds of the Canso Group. Primary sedimentary structures indicate that both units are right way up.

The laminated, fine to medium grained, red and grey sandstone of the Lismore Formation forms a very thick sequence which concordantly overlies the Windsor limestone. Small coal seams up to 1 cm thick occur concordantly in the sandstones, while carbonaceous fossil horizons may be 3 cm thick. These are always found within the grey-green reduced sandstones.

One copper occurrence is located in a fossil layer, 4300 feet (1430 m) west of the prominent Windsor limestone point, near Knoydart Point. Here, malachite is disseminated throughout the matrix of the sandstone as well as occurring on small surfaces. Very minor "replacement" of the fossils with malachite is likely to represent void-filling in weathered fossil fragments.

Such relationships suggest that the decaying organic matter originally provided a reducing environment which allowed for the later precipitation of the copper.

This environment is also condusive to uranium precipitation such as the Colorado Plateau copper-uranium deposits and other copper-uranium deposits of Northern Nova Scotia (Dunsmore 1977). One annomalous uranium stream value in a small brook at Knoydart Point was obtained by the Nova Scotia Department of Mines (1977). The possibility of uranium potential of this area should be investigated along with that of copper.

12- GEORGEVILLE COPPER OCCURRENCE 11E16E

			U.T.M. GRID
(1)	Lat.	45° 48' 49"	5073600 N
	Long.	62° 02' 24"	574618 E
(2)	Lat.	45° 49' 50"	5075460 N
	Long.	62° 01' 52"	575280 E

Plate A-I-1

a Sphalerite (medium grey) and chalcopyrite (light grey) in mutual boundary intergrowth. Georgeville Copper Occurrence #2. Reflected light. Sphalerite is amber to rust red in transmitted light.

Plate A-I-1

b Intergrowth of sphalerite (medium grey), chalcopyrite (light grey) and galena (white). Chalcopyrite is found as traces on right edge of left galena grain, and bottom of right galena grain. Georgeville Copper Occurrence #1. Reflected light.

c Transmitted light of Plate A-I-2b. Sphalerite is rust red in colour.

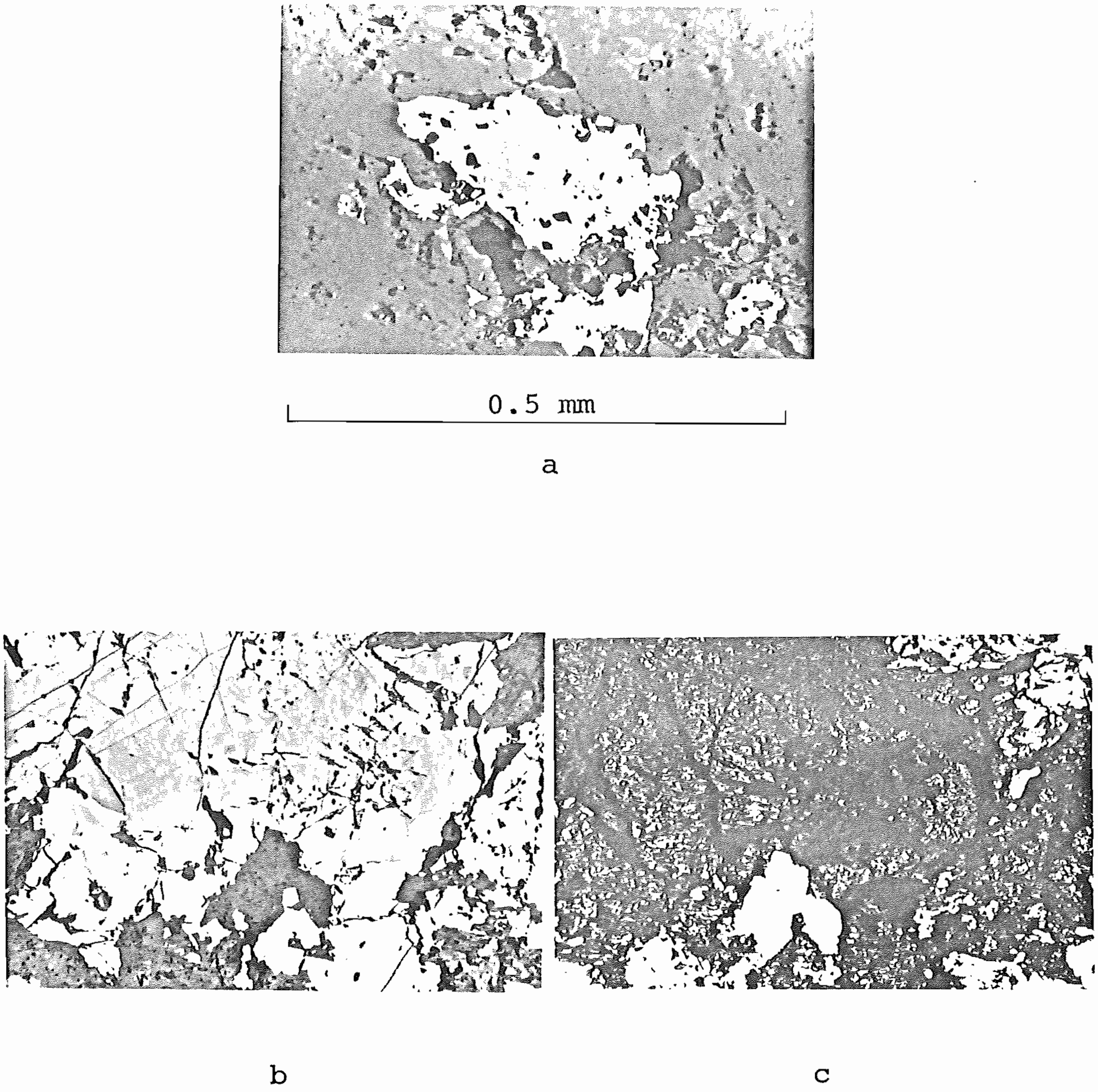


Plate A-I-1

1 mm Scale unless otherwise indicated

(1) This occurrence is located on the east side of Hwy. 337, adjacent to the road to the Maritime Rock Quarry at Georgeville. A small outcrop of very altered, fine grained diorite/gabbro, with galena, sphalerite, pyrite and pyrrhotite disseminated and found in small veinlets, is situated 100 feet (330 m) south of a medium-grained relatively unaltered Cambro-Ordovician diorite (MacDonald 1977). The visible galena and sphalerite, appear to be restricted to this small (20 cm by 20 cm) buried outcrop of fine-grained diorite, and were not observed in the medium to coarse-grained diorite. Total sulphides constitute up to about 25% of some parts of the diorite.

Sphalerite with minor galena and chalcopyrite form mutual boundary intergrowths (Plate A-I-1). Some evidence of chalcopyrite-galena infilling of spaces in sphalerite is present (Appendix II-C). These minerals occur discretely as well as in intergrowth, as anhedral, 0.05-1 mm grains. Pyrite and pyrrhotite occur as anhedral to euhedral, very corroded, 0.02-1 mm grains in some cases intergrown. Pyrrhotite may show mutual boundary intergrowth with chalcopyrite, and is often found intergrown around many diorite crystals. Ilmenite and rutile occur in trace amounts throughout the studied area.

Sphalerite forms approximately 3% of this lithology while chalcopyrite, galena and pyrrhotite may each constitute up to 25% of some parts of the rock. See Appendix II-B for individual slide descriptions. Microprobe analysis of the red sphalerite show iron content of approximately 1-3%.

The sulfides in the diorite may have acted as a source for subsequent (contemporaneous?) mineralization of the host argillite (hornfels). Some mineralization may have concentrated in the volatile phase (found in the northeast of the diorite (MacDonald 1977), and have been expelled along fault zones. Further work in the area is necessary in order to demonstrate this.

Alteration of the diorite, both fine and coarse-grained, is extremely complex, and varies over distances of a few centimeters. A geochemical study may provide some insight as to the origin of the concentration of the sulfides.

(2) This copper occurrence is located along the shore near Georgeville, 6000 feet (2000 m) northeast of the breakwater point at the Maritime Rock Quarry.

Chalcopyrite, up to about 0.5%, occurs in black, aphanitic argillites (hornfels) of the Browns Mountain Group. Pyrite, in quantities up to 25%, occurs throughout the compact argillites from the quarry to beyond the occurrence. However, copper mineralization is limited to a three-foot-wide shear zone within the argillite unit. Calcite, which also occurs in the shear zone is intimately associated with the chalcopyrite and serves as an infilling between the broken up, 0.5 to 5 cm blocks of argillite.

Chalcopyrite regularly shows mutual boundary intergrowth with sphalerite, forming 0.2-0.5 mm, anhedral grain aggregates (Plate A-I-1). Zircon forms rare mutual boundary intergrowth with chalcopyrite. Chalcopyrite and pyrite also occur as discrete, 0.01-0.1 mm, anhedral grains. Covellite replaces some chalcopyrite to a small degree, while chalcocite (tennantite?) rims chalcopyrite rarely. Pyrrhotite occurs discretely in trace amounts.

Rutile (and anatase?) and ilmenite occur as 0.02-0.03 mm, anhedral grains disseminated throughout the argillite.

The chalcopyrite and sphalerite occur in approximately equal portions, constituting 0.5-1% of the shear zones. The sulfides, in nearly all cases, are associated with small (1/10 mm) calcite stringers in the argillite unit.

The sphalerite varies from nearly transparent to amber to red in transmitted light. Microprobe analysis place iron contents between 0% and 3% respectively.

See Appendix II for individual slide descriptions.

(3) Black, aphanitic, compact, in some areas banded, argillites (hornfels) of the Browns Mountain Group occur along the Georgeville coast and extend from the Maritime Rock Quarry to approximately 11,000 feet (3670 m) to the northeast. An alaskite granite intrudes the argillites sporadically along the coast.

A very high geochemical zinc anomaly, with stream sediment values averaging approximately 600 p.p.m. and up to 900 p.p.m. (background 70 p.p.m.), is present on Browns, Georgeville and McInnes Brooks, in the area.

Sphalerite occurs as 0.01-1 mm grains anhedral to subhedral grains found predominently as 0.05-0.2 mm veinlets and alligned grains. Anhedral, pyrite may constitute 10-25% of the argillite, and show a strong lineation of grains. Rare sulfide intergrowths as described in section 12(2) are found in some areas.

The sulfide mineralization probably comprises less than .25-0.5% of the argillites, although individual slides may show approximately 0.5%. Estimates of sphalerite content are ambiguous due to the presence of small disseminated grains of rutile throughout.

13- BALANTYNES COVE COPPER OCCURRENCE

	11F13W
	U.T.M. GRID
Lat. 45° 51' 40"	5078950 N
Long. 61° 55' 06"	584190 E

Horton conglomerate, greywacke and amygdaloidal basalts of interest in this area, are located approximately 1200 feet (400 m) northeast of the inland end of the pier, along the coast at Ballantynes Cove. Access to the shore may be gained near the pier.

Interbedded cobble conglomerate, greywacke and amygdaloidal basalts outcrop along the coast north and south of the pier. No Windsor units outcrop at this location.

A two-metre-thick bank of fine to medium-grained greywacke within the conglomerate unit contains some traces of malachite on fracture surfaces. This copper mineralization is confined to a 15 cm band of dark grey compacted greywacke. Covellite which is disseminated evenly throughout the matrix of the sediment, forms much less than 1% of the rock.

Pyrite forms 0.01-0.05 mm, anhedral to subhedral grains disseminated evenly throughout the matrix, constituting approximately 5% of the volume. Some covellite is present in fractures in the pyrite.

Some rutile is found in the sediments.

This unit also outcrops approximately 4000 feet (1300 m) southwest of the area described above and 2000 feet (670 m) inland, along a small stream. However, no copper mineralization is visible here although this location appears on Fletchers' map as a copper occurrence. A coastal study at this location was not made, although Binney (1975) reports a mineralized Horton-Windsor contact here.

14- COLLEGE GRANT COPPER OCCURRENCE

			11E8 U.T.M. GRID
(1)	Lat.	45° 24' 00"	5027640 N
	Long.	62° 03' 38"	573520 E
(2)	Lat.	45° 23' 39"	5027000 N
	Long.	62° 05' 09"	571560 E

The following are detailed instructions on reaching the above locations. Their purpose is to simplify access to these areas, since the name Collge Grant no longer appears on the National Topographic Series of maps, and since the said areas are rapidly being overgrown.

(1) The large College Grant pit may be reached from the South Lochaber turnoff, as follows:

1) 3500 feet (1170 m) north along the West

Lochaber road then turn west;

2) 4500 feet (1500 m) west along an old College Grant road; then turn north;
3) 2800 feet (930 m) north along an old road then turn west;
4) 700 feet (230 m) west along an overgrown path.

(2) The reported location of the College Grant shaft may be reached from the South Lochaber turnoff, as follows:

1) 3500 feet (1170 m) southeast, towards Two Mile Lake, then turn west;
2) 2.2 miles (3.5 km) west along a road to Hwy. 347, then turn north;
3) 4300 feet (1430 m) north along the old College Grant road;
4) the shaft is on the farm property on the west side of the road at this point.

Small scale mining was carried out at College Grant during the late 1800's.

The shaft was not found at location (2), however, scattered boulders of malachite-chalcopyrite and specularite bearing quartz veins in sheared diorite are found in the bushes southeast of the old farmhouse.

According to Fletcher (1886) the mineralization consists of specular hematite, siderite, pyrite and chalcopyrite in large (1-2 m wide) quartz veins which cut the diorite and host Devonian sediments. The veins are apparently associated with the intrusive diorite-diabase. The Copper Lake siderite vein is very similar in mineralization and environment to the College Grant mineralization (Fletcher 1886).

Kontak (1976) shows widespread occurrence of copper in the area in several lithological hosts including the diorite, Devonian limestones and red beds of the Knoydart Formation (Lower Devonian). The mineralization is mainly restricted to the quartz veins cutting the country rocks, although some mineralization is disseminated throughout the rocks. Work done by Kontak suggests subsequent infilling and mineralization of pre-existing fractures which may have been related to the Acadian Orogeny. Source beds of the copper are proposed by Kontak to be the diorite and/or the red beds. The mechanism of mineralization is interpreted as compaction and dewatering of the rocks (Kontak 1976) rather than a magmatic-hydrothermal model related to the diorite intrusion. The latter model would invoke contemporaneous fracture formation and infilling. It would also not explain the widespread occurrence of copper in the sediments away from the intrusion.

One outcrop of unsheared diorite is found along the road, 1000 feet (330 m) north of the farmhouse.

The pit, (1), contains much rubble of grey quartzite, believed to be the host rock of the diorite intrusive. Traces of malachite and quantities of specular hematite up to about 30% occur throughout the rubble.

15- JAMES RIVER COPPER OCCURRENCE 11E9E

			U.T.M. GRID
(1)	Lat.	45° 34' 37"	5047340 N
	Long.	62° 07' 24"	568490 E
(2)	Lat.	45° 34' 49"	5047750 N
	Long.	62° 07' 12"	568790 E

The two James River copper occurrences are located on two small streams which cross Hwy. 4, approximately 4000 and 5200 feet (1300-1700 m) northeast of the turnoff to the Trans Canada Highway at James River. The Horton-Windsor contacts occur approximately 700 and 900 feet (230-300 m) upstream, respectively.

James River is one of numerous copper occurrences found along the Horton-Windsor contact and has been known since at least 1886.

Dark grey, laminated basal Windsor limestone conformably overlies fairly well rounded and consolidated

Horton, cobble conglomerate interbedded with fossiliferous, fine to medium grained, grey sandstones. Malachite up to about 0.5% occurs throughout the conglomerate and sandstones near the topmost 20 to 40 cm of Horton. Absence of most of the carbonate matrix in the conglomerate allows speculation only, concerning the mineralization in this unit. No copper mineralization is found below the reduced grey-green conglomerate, where a red, oxidized conglomerate occurs. Pyrite, chalcocite, bornite, covellite, malachite and traces of chalcopyrite are found in the lowermost parts of the limestone.

The James River Occurrence is unique in the copper belt which forms between Ohio and Sylvan Glen in that the conglomerate unit contains mineralized, interbedded fossiliferous layers. These provide a restricted Colorado Plateau type of environment within a predominently marine type of environment. In this way, James River shows an analogy to the Knoydart Point Copper Occurrence (No. 11) and to other copper occurrences reported in Northern Nova Scotia (Dunsmore 1977).

16- BRIERLY BROOK COPPER OCCURRENCE

		11E9
		U.T.M. GRID
(1) Lat.	45° 36' 39"	5051000 N
Long.	62° 04' 07"	572620 E

(2)	Lat.	45° 36' 22"	5050450 N
	Long.	62° 04' 39"	571920 E
(3)	Lat.	45° 36' 15"	5050260 N
	Long.	62° 04' 48"	571740 E

These three copper occurrences are found 700-1000 feet (230-330 m) northwest (upstream) of the Brierly Brook road, along small streams at Brierly Brook settlement. The streams cross the Brierly Brook road respectively, 9600 feet (3200 m), 7600 feet (2530 m) and 6500 feet (2170 m) northeast of the westernmost turnoff of the Brierly Brook road from Hwy. 4 (Map 3).

The Brierly Brook copper occurrences form three of the many reported copper showings along the Horton-Windsor contact. The mineralization and rock types conform to descriptions given for the James River copper occurrences, with the exception of the interbedded fossiliferous sandstone layers found only at James River.

Dark grey, laminated basal Windsor limestone conformably overlies grey and red, Horton cobble conglomerate. Total copper mineralization averages about 0.5%, and consists of chalcocite, bornite, covellite, malachite and traces of chalcopyrite. Traces of malachite are also found in the small calcite veins in the lowermost limestone.

17- SYLVAN GLEN COPPER OCCURRENCE

			11E9E U.T.M. GRID
(1)	Lat.	45° 38' 05"	5053680 N
	Long.	62° 01' 10"	576460 E
(2)	Lat.	45° 37' 47"	5053140 N
	Long.	62° 02' 18"	575040 E
(3)	Lat.	45° 37' 19"	5052260 N
	Long.	62° 03' 15"	573725 E
(4)	Lat.	45° 38' 04"	5053660 N
	Long.	62° 00' 24"	577440 E

Four copper occurrences were examined in this area.

Location (1) is situated on the South Rights River near its intersection with Hwy. 245.

Location (2) is also found on the South Rights River near its intersection with the CNR track, approximately 1.0 mile (1.6 km) southwest of Hwy. 245. Access to this occurrence may be gained 1.5 miles (2.4 km) west of Antigonish, along the Sylvan Valley - Brierly Brook road.

Location (3) is found approximately 1500 feet (500 m) west of the Brierly Brook road, along a small tributary of the South Rights River, at Sylvan Valley settlement.

Location (4) is situated on the Rights River, approximately 1500 feet (500 m) northeast of the MacDonald Trailer Park in Antigonish town (Map 3).

Mineralization along the Sylvan Valley is associated with the Horton-Windsor contact.

Copper, mainly malachite with some chalcopyrite, chalcocite, bornite and covellite is found in the matrix of the uppermost 15 to 30 cm of the Horton conglomerate. The Horton in this area is a grey-green pebble conglomerate with clasts averaging one to two centimetres, and ranging up to four cms. Away from the contact, the conglomerate is red with cobbles up to 12 cm. No copper mineralization is found within this lower oxidized environment; it is restricted to the uppermost reduced sediments. The copper mineralization is found in quantities of approximately 0.5%.

Some copper is found along fractures in the laminated basal Windsor limestone which is in conformable contact with the underlying Horton. Copper mineralization in the limestone is dominantly chalcocite, with minor bornite, covellite and traces of chalcopyrite.

Near the contact at location (1), associated traces of bornite and/or chalcocite are found as cubes and masses up to 2-3 mm across. These are associated with discontinuous calcite veins and smeared out on surfaces in the Windsor limestone. Traces of barite also occur in these calcite veins.

At locations (2) and (3), a fine-grained, light-grey, limy sandstone containing subangular quartz clasts and malachite on fracture surfaces, marks a 4 cm thick transition between Horton and Windsor. Quartz and carbonate occur in approximately equal proportions within this unit. Copper mineralization within the uppermost Horton occurs as at location (1).

Mineralization at location (4) is as described for the previous three locations. However, here, a 6 cm thick limestone with much slickensliding lies two metres above the Horton-Windsor contact. Above this limestone unit, lies a one metre thick unit of light brownish, porous laminated limestone. Both these units appear as conformable Windsor sediments.

Also at location (4), at the north end of the outcrop, there appears to be a fault contact of Horton-Windsor units. No copper mineralization occurs in the uppermost conglomerate here.

Basal Windsor mineralization was initiated during the onset of a reducing depositional environment at the beginning of Windsorian times. Other workers have found a mineral distribution along the Horton-Windsor contact similar to that of the Kupferschiefer (Kirkham 1978).

18- SAINT JOSEPH - OHIO COPPER REGION

(1) Ohio-MacLean Showing		11E9E
		U.T.M. GRID
	Lat. 45° 30' 44"	5040000 N
	Long. 62° 04' 40"	572000 E

Access to the MacLean showing is through the rear of the property of Ron MacLean, which is situated on the west side of the Ohio River, approximately 3000 feet (1000 m) south of the bridge at Ohio.

This location comprises one of several copper showings lying on a north-south trending ridge from St. Joseph to Cross Roads Ohio, a distance of approximately 3.5 miles (5.6 km). The ridge forms the boundary between Cambro-Ordovician, Browns Mountain volcanics and the Lower Carboniferous Windsor carbonates.

The MacLean showing has been worked to a limited extent in the past, as is evident by a small shaft and a trench. Recently, mining companies have shown interest in the property, in conducting exploration programs over the area (Ward 1975). The trench follows a fault contact between the Windsor limestone and a basal Windsor breccia. The breccia overlies Browns Mountain porphyry rhyodacite. Discontinuous calcite veins and cavity fillings with associated chalcopyrite, malachite and minor bornite, barite and azurite, exist in the shear zone.

Chalcopyrite and malachite are found to a lesser degree in the dark grey unbrecciated limestone.

The bulk of the copper mineralization, constituting about 0.5%, is found in the breccia unit and consists exclusively of chalcopyrite. Small 10 cm, interbedded layers of limestone within the breccia show the unit to be bedded nearly perpendicular to the fault zone. The breccia consists of angular, pebble to cobble size porphyry fragments of rhyodacite to latite volcanics, probably of the Browns Mountain Group, and is compact, grey in colour with much carbonate in the matrix. It grades upward from a light grey lithology with minor carbonate in the matrix and abundant volcanic fragments to a limy unit with minor volcanic fragments.

A vertical shaft, 50 feet (17 m) south of the breccia, has been driven into the unmineralized volcanics. Its purpose was apparently to extend northward at depth in order to reach the breccia. The shaft is flooded and it is unknown to what extent it reaches.

(2) Ohio Iron Occurrence

	11E8
	U.T.M. GRID
Lat. 45° 31' 03"	5040630 N
Long. 62° 05' 06"	571450 E

This property is listed as an iron occurrence in the N.S.D.M. Mineral Occurrence File. It is actually a northerly continuation of the "MacLean breccia".

It is found 2500 feet (830 m) southwest of a road, along the north branch of MacIsaacs Brook. The brook, which is on the west side of the Ohio River, crosses the road approximately 1500 feet (500 m) north of the bridge at Ohio.

The Browns Mountain - Windsor contact, as described above, is found at this location, which lies 2800 feet (930 m) northwest of the MacLean showing. Copper mineralization similar to the MacLean showing is present at this location. Some pyrrhotite is associated with the Browns Mountain volcanics.

(3) Ohio - Pinkietown (St. Joseph) Copper Occurrence

11E9

			U.T.M. GRID
(1)	Lat.	45° 32' 03"	5042440 N
	Long.	62° 05' 38"	570750 E
(2)	Lat.	45° 32' 34"	5043420 N
	Long.	62° 05' 54"	570420 E

(1) This occurrence, lying west of St. Joseph Lake, is located 1000 feet (330 m) southwest of a road, along the south branch of Frasers Brook.

The Browns Mountain - Windsor contact was again found at this location which lies approximately 1.7 miles (2.7 km) northwest of the MacLean showing. However, here Windsor limestone appears to conformably overlie basal Windsor breccia. Copper mineralization, as at the MacLean showing, is evident.

(2) This location marks the southerly extent of the Horton - Windsor contact. It is located 1600 feet (530 m) west of a road along a stream which crosses the road 3500 feet (1170 m) north of the bridge across the Ohio River at St. Joseph.

The Horton-Windsor contact which is exposed here, 3000 feet (1000 m) northwest of occurrence (1), contains copper mineralization as found at James River - Brierly Brook. Basal Windsor limestone conformably overlies grey-green, Upper Horton cobble conglomerate containing about 0.5% malachite, chalcopyrite and traces of azurite, bornite and chalcocite. This unit grades downward into a red, muddy, cobble conglomerate devoid of copper mineralization.

The location is indicated by Benson to be a Browns Mountain - Windsor contact. A new boundary for these units is thus proposed in Map 3.

(4) Ohio - Reigle Showing	11E9E
	U.T.M. GRID
Lat. 45° 30' 13"	5039130 N
Long. 62° 04' 30"	572250 E

The Reigle Showing is located at the Reigle farm, on the west side of the Ohio River, approximately one mile south of the bridge at Ohio. The showing lies on the "MacLean breccia ridge", approximately 0.6 miles (1 km) southeast of the MacLean Occurrence.

Although no outcrop is present at this location, several boulders of dark grey limestone, containing approximately 1% galena and traces of chalcopyrite, were found.

Galena is found in cubes averaging about 0.5 to 1.0 mm and is usually associated with small stringers and cavity infillings of calcite.

19- CROSS ROADS OHIO LEAD OCCURRENCE

	11E8E
	U.T.M. GRID
Lat. 45° 29' 18"	5037410 N
Long. 62" 04' 24"	572360 E

This occurrence is located part way up a ridge, at the rear of an abandoned farm property. The farm is located west of a road, on the west side of the Ohio River, 4000 feet (1330 m) north of the crossroads near Cross Roads Ohio.

Although this occurrence is contained wholly within rocks of the Browns Mountain Group, its proximity to the Windsor - Browns Mountain contact, its "on-strike" character with the Ohio-St. Joseph copper ridge and the association of copper mineralization with calcium carbonate, suggest it may be related to the Ohio copper.

This occurrence is filed as a lead occurrence in the N.S.D.M. Mineral Occurrence File, however, no mineralization was found at the location indicated. An old copper shaft, however, was located near the filed lead occurrence.

The adit-type shaft, approximately 35 feet (12 m) long, has been cut into the side of the ridge. About 20,000 cubic feet (6670 m^3) of loose rubble has been dumped on the side of the ridge.

The host rock is a very dense and compact, grey-green lapilli tuff with an acid composition. Fragments are subangular to subrounded and vary between 2 mm and 15 mm. At least three prominent sets of joints cut the volcanics into large blocks.

The copper mineralization is confined to a 10 foot (3.3 m) wide, mildly sheared zone within the volcanics. The shearing has fragmented the volcanics into approximately 20 cm square blocks. The shaft appears to have followed the shear zone. Large 15 cm, discontinuous calcite veins are associated with the shear zone. Chalcopyrite and malachite, constituting about 0.5% of the shear zone material, occur in the calcite and also form discontinuous veinlets up to 0.5 cm thick along fracture surfaces in the volcanics.

This ridge would form a 3.5 mile (5.6 km) long onlap of Windsor on Browns Mountain, a relationship that may be essential in the exploration of Kupferschiefer-type mineralization in this area.

The initiation of Windsor deposition has provided a mechanism for mineralization in underlying strata by changing the depositional environment. The change from oxidizing to reducing conditions at the onset of Windsor times appears to have provided an environment for copper precipitation. In this way, the St. Joseph-Ohio (Cross Roads Ohio?) copper mineralization may be related to Horton-Windsor contact mineralization in the James River - Brierly Brook area.

20- PITCHERS FARM COPPER OCCURRENCE

		11F12W
		U.T.M. GRID
Lat.	45° 31' 56"	5042430 N
Long.	61° 57' 12"	581821 E

Access to the Pitchers Farm copper occurrence is gained approximately 7800 feet (2600 m) upstream along a main tributory of the South River, west of the Dunmore Road. An old farm road provides access to the initial 3000 feet (1000 m) of stream bed from the Dunmore Road.

The area consists of brown to red or grey, fine to medium-grained, subangular Canso age sandstones and quartzites with approximately five percent mafic clasts and 10 percent weathered feldspars constituting the matrix.

Specular hematite occurs in reddish sandstones in trace amounts. Traces of chalcopyrite are disseminated in a grey quartzite unit. Traces of pyrite cubes appear throughout the sandstones.

Upper Carboniferous sediments (Canso and Pictou Groups) provide an ideal environment for copper and uranium precipitation and many copper occurrences in these sediments in Northern Nova Scotia have been documented (Occurrence No. 11, Dunsmore 1977, Fletcher 1893).

21- McARRAS BROOK COPPER OCCURRENCE

	11E9
	U.T.M. GRID
Lat. 45° 43' 57"	5064460 N
Long. 62° 12' 34"	561520 E

Both McArras and McPherson Brooks, which are located northwest of Hwy. 245, approximately 3 miles (4.8 km) south of Arisaig, at McArras Brook settlement, were examined for copper showings. However, no copper was found in either the predominantly red, muddy, fine grained, micaceous quartzwacke or the minor grey micaceous siltstones.

22- SUNNYBRAE COPPER OCCURRENCE 11E8W

A one and one half mile (2.4 km) section of the Blanchard Road, from the Sunnybrae turnoff, northward, was examined for a reported copper showing. However, no copper mineralization among the Browns Mountain volcanics and argillites was found.

Local inhabitants expressed no knowledge of any previously known or worked copper occurrences.

However, a small diorite intrusive contains up to 15% disseminated pyrrhotite.

23- BLUE MOUNTAIN COPPER OCCURRENCE

		11E9
		U.T.M. GRID
Lat.	45° 30' 06"	5038540 N
Long.	62° 26' 18"	543880 E

Access to this occurrence may be gained approximately 3350 feet (1117 m) east (upstream) from the rear of a private property on Hwy. 347, by way of a stream lying 2500 feet (830 m) south of the turnoff to North Bloomfield. This stream flows westerly into the French River.

The area consists of folded green to grey chlorite phyllites and minor muscovite schists, black argillites and one unit of feldspar porphyry latite, of the Lower Silurian, Beechhill Cove Formation. The schistosity which exists in all sediment units is crenulated.

Quartz veining is common throughout the units, ranging from one to ten cm across. Some pyrite, chlorite and ankerite mineralization is associated with the quartz veins.

In one area of the argillites, up to about 0.1% chalcopyrite is found in small (1 cm) quartz veins that parallel the slatey cleavage. Fragments of argillite are sporatically incorporated in the quartz veins.

Pyrite commonly concentrates in the argillite, on the argillite-quartz vein boundaries, decreasing in abundance away from the veins. It is found as framboids, indicating a syngenetic, bacterial origin. Some evidence of chalcopyrite replacement of pyrite is present in the quartz veins.

Some crosscutting quartz veins, younger in age, are devoid of metallic mineralization.

24- LOCHABER COPPER OCCURRENCE

	11E8E
	U.T.M. GRID
Lat. 45° 24' 18"	5028250 N
Long. 62° 03' 31"	573860 E

Lochaber diamond drill hole No. 14, is located 800 feet (270 m) east along a drill road which runs eastward from the north end of the Ireland Road.

Diamond drill hole "14" of Great Horn Mining Syndicate was located and examined. Approximately 40 core boxes, totalling just over 1000 feet (330 m) of core, were present on the drill site.

N.S.D.M. Mineral Occurrence and Open Assessment File descriptions of the drill core were confirmed. Approximately 750 feet (250 m) of argillaceous limestone, with the basal 250 feet (80 m) averaging approximately 0.35% copper, is overlain and underlain by muddy red, sandy shales and siltstones. Production plans for an open pit of the over 2 million ton ore body were not executed.

Pyrite, chalcopyrite, bornite and minor fluorite, galena and sphalerite, occur both disseminated and in bedding-parallel veinlets. The ore is apparently stratiform and lies approximately 3 km away from any known Devonian intrusive. Its mode of occurrence contrasts with that of other copper occurrences in the area (i.e. College Grant, Copper Lake) which are found in quartz-siderite-specularite veins in or near diorite intrusions. However, the mineralization of the area, including the vein occurrences, may be accommodated in a compaction mineralizing solution expulsion hypothesis (Kontak 1976) (see Occurrence No. 14). It is, at least, more plausible than the fault theory (Cameron 1952) based on an allignment of several copper occurrences.

In this way, all the Devonian(?) lithologies in this area may have acted as a source and/or trap for mineralizing fluids during compaction of the rocks. This would indicate excellent copper potential over the entire extent of Devonian lithologies in the area.

25- CAPE GEORGE COPPER OCCURRENCE

			11F13W U.T.M. GRID
(1)	Lat.	45° 50' 55"	5077580 N
	Long.	61° 59' 09"	578878 E
(2)	Lat.	45° 50' 25"	5076600 N
	Long.	61° 59' 50"	577880 E

Although the above locations refer to the Cape George Copper Occurrence, only one trace of possible copper mineralization was found, however, pyrite mineralization is fairly abundant, visibly constituting approximately 5% of the rock.

These areas are found approximately 500 to 1000 feet (160-330 m) southeast (upstream) from Hwy. 337 on Morar Brook, and approximately 400 feet (130 m) southeast (upstream) from Hwy. 337 on Horseshoe Turn Brook, respectively.

Dense, dark grey to black, fine grained argillites (hornfels) of the Browns Mountain Group have undergone at least two deformations seen as two distinct cleavages in hand specimen. Pyrite is disseminated in the argillites, and also fills fracture surfaces, cleavage planes and joints. Traces of possible chalcocite and sphalerite in one confined area of location (2) were evident.

Pyrite constitutes 1-5% of the argillite and occurs as tiny grains forming small intersecting stringers. Chalcopyrite is found in trace amounts replacing pyrite and in rare mutual boundary intergrowth with sphalerite.

The argillite becomes extremely brecciated shoreward along Horseshoe Turn Brook. Benson (1974) indicates a fault nearly paralleling the brook. This shear zone is a probable conduit for the copper bearing solutions (see also Occurrence No. 12-2).

26- LAKEVALE BARIUM OCCURRENCE 11F13W

	U.T.M. GRID
Lat. 45° 47' 12"	5070750 N
Long. 61° 54' 36"	584660 E

The Lakevale barium occurrence is located along the shore, on the south side of a prominent point, at Lakevale.

Light grey, medium- to coarse-grained, poorly sorted, subangular to subrounded Horton sandstones grade into red, medium to coarse-grained, micaceous Horton sandstone with variable amounts of carbonate in the matrix. The units are lying right way up. Minor barite occurs in calcite veins associated with a shear zone.

Horton sandstones grade into a loose, grey pebble conglomerate with a carbonate-rich matrix, that forms a transition into Windsor rocks, as marked by grey laminated limestone. No obvious copper mineralization was observed along this Horton-Windsor contact.

Barite-calcite veins are found in shear zones nearly parallel to bedding, and on joint sufraces, in the limestone. Barite is found as white to pinkish-red crystals and massive aggregates. Veins vary from 0.5 cm to 3 cm and have a frequency of about 3 per metre. Barite may constitute up to 30% of the vein.

Other mineralization includes brecciated pyrite grains in the Horton sediments and pyrite framboids and traces of chalcopyrite in the overlying Windsor limestone. See Felderhof (1978) for more data concerning this occurrence.

27- BRIERLY BROOK BARIUM OCCURRENCE

	11E9E
	U.T.M. GRID
Lat. 45° 36' 39"	5051000 N
Long. 62° 04' 07"	572620 E

The Brierly Brook barium occurrence is found along a stream flowing through the MacDonald farm, 700 feet (230 m) north of the Brierly Brook road. The stream crosses the road 9600 feet (3200 m) northeast of the westernmost turnoff of the Brierly Brook road from Hwy. 4. This is the same location as one of the Brierly Brook copper occurrences.

Contact relations between Horton and Windsor at this location are described under BRIERLY BROOK COPPER (Occurrence No. 16).

White and pink barite is found in the 1 cm calcite veins which cut the Macumber Windsor limestone. Traces of malachite associated with the veins, are found at the extreme base of the limestone. The barite is a minor constituent of the calcite veins.

The frequency of the near vertical veins is approximately two per meter. The veins do not penetrate the upper Horton conglomerate. See Felderhof (1978) for further details of this occurrence.

28- BROWNS MOUNTAIN BARIUM AND IRON OCCURRENCES

11E9

			U.T.M. GRID
(1)	Lat.	45° 38' 28"	5054320 N
	Long.	62° 09' 30"	565580 E
(2)	Lat.	45° 39' 03"	5055380 N
	Long.	62° 08' 53"	566380 E
(3)	Lat.	45° 39' 05"	5055440 N
	Long.	62° 09' 15"	565880 E

The above coordinates refer to locations described by N.S.D.M. Mineral Occurrence File, the N.S.D.M. Open assessment File and N.S.D.M. Metallic Mineral Occurrences Report.

Both the iron (3) and one barium (2) locations are found in a very large swamp with no rock outcroppings. Furthermore, no outcrop was found at location (1). Felderhof (1978) also failed to find the occurrence.

One outcrop, 4000 feet (1330 m) southeast of locations (2) and (3) showed visible pyrrhotite in Browns Mountain volcanics.

29- BIG MARSH BARIUM OCCURRENCE 11E9E

		U.T.M. GRID
Lat.	45° 44' 05"	5064850 N
Long.	62° 00' 48"	576840 E

This occurrence is located on the west side of the road at Big Marsh, 50 feet (17 m) north of the pond on Wallace Brook. Debris of the old Big Marsh School marks the location.

Grey, laminated, folded, basal Windsor limestone outcrops at this location. The limestone is brecciated in places and contains lenses of granulated calcite. Although no barite is associated with these small discontinuous calcite veins and lenses, abundant, large pieces of massive barite float are scattered around old test pits. Further digging of one pit revealed a possible outcrop of a one foot wide barite vein cutting across the limestone bedding. The vein, however, is continuous over only two feet (0.7 m). This exposed barite is stable to the depth dug, but is easily broken up and thus may be within the C-soil horizon (zone of "rotten rock"). Thus the "vein" may or may not represent an actual outcropping of a continuous vein at depth.

Pyrite occurs in the limestone in quantities of about 1% in some places. It is found as tiny, corroded grains concentrated mainly along the limestone laminations.

30- ARISAIG POINT BARIUM OCCURRENCE

	11E16E
	U.T.M. GRID
Lat. 45° 45' 45"	5067720 N
Long. 62° 10' 22"	564340 E

Arisaig point is located northwest of Arisaig settlement, along route 245. The occurrence is found on the extreme northwest of the point, about 40 feet (13 m) south of the high tide mark.

Barite occurs as discontinuous veins, 2-4 cm thick, in pink, flow-banded rhyolite of Upper Ordovician age. Quartz veins from 0.5 cm to 8 cm truncate the earlier barite veins.

Agalmatolite is sometimes associated with the barite which occurs as pink to white crystals and crystalline masses. The barite veining is of limited extent. See Felderhof (1978) for details of this occurrence.

31- McARAAS BROOK BARIUM OCCURRENCE

11E9

Although time in the field season did not allow for a study of the known barite occurrence, the area, 5500 feet (1830 m) south of Hwy. 245, along Knoydart Brook was examined. Canso, Windsor and Horton lithologies are exposed along this brook. No barite was found in any of the units. Also, no Horton-Windsor contact is exposed.

According to Benson, these units continue northward to the coast, where the McAraas Brook barium occurrence lies. Felderhof (1978) describes two stratigraphically controlled beds of barite in shales and siltstones of the Martin Road

Formation (Lower Carboniferous).

32- McISAAC POINT BARIUM OCCURRENCE

	11E12W
	U.T.M. GRID
Lat. 45° 44' 09"	5065070 N
Long. 61° 53' 24"	586320 E

This occurrence is located on the shore at McIsaac Point, approximately 2 miles (3.2 km) north of Jimtown, on on Hwy. 337.

Basal Windsor limestone overlies red Horton sandstone at this location. The limestone is grey, laminated, highly folded and probably recrystallized. In some areas a cataclastic "crush breccia" overlies folded limestone. The breccia consists of small 5 cm blocks of unoriented, laminated limestone in a re-worked featureless limestone matrix. Calcite crystals are granulated and veins are discontinuous within the breccia.

Calcite veins in the laminated limestone are frequently cut by en echelon tension fractures. Pinkish-red barite is associated with some of the veins. Marcasite in globular structures is associated with calcite and barite in the tension gashed veins in one area. Veins vary from 0.5 cm to 2 cm in thickness and show a frequency average of one vein per metre. Limestone in this location shows much iron oxide including minor hematite and limonite. Pyrite occurs as 0.01-0.05 mm, anhedral, brecciated grains commonly disseminated parallel to the limestone laminations. No other sulfides were observed at this occurrence.

An unfiled lead occurrence (Boehner, pers. comm.) approximately 4000 feet (1330 m) south of the barite occurrence, along the shore, was examined. Traces of galena and pyrite are associated with small (0.05 cm) discontinuous calcite stringers and cavities (1-7 cm diameter) in an impure, mylonated limestone. Foreign pebbles and terrestrial mud are contained in the limestone which lies adjacent to nearly vertical units of intercalated recrystallized gypsum and black lime mud.

Chalcocite forms approximately 0.03 mm grains, disseminated throughout the limestone which is adjacent to the gypsum. The chalcocite, usually rimmed with a bluish (chalcocite?) translucent halo, forms up to 2% of the slide studied. Traces of bornite with minor chalcopyrite mutual boundary intergrowth as well as chalcocite - pyrite intergrowths are observed in the limestone. Pyrite framboids forming up to 2% of the rock are disseminated evenly throughout.

Comparison of the ore mineralogy with areas in the Ohio - Sylvan Glen copperbelt, indicate that the limestone is probably Lower Windsor.

33- ARISAIG AGALMATOLITE OCCURRENCE

11E16E

		U.T.M. GRID
Lat.	45° 45' 42"	5067690 N
Long.	62° 10' 10"	564580 E

The Arisaig agalmatolite quarry is found on the easternmost exposure of rhyolite at Arisaig Point in Arisaig.

Agalmatolite, sometimes loosely referred to as soapstone, is actually fine-grained pyrophyllite. It is used extensively in decorative carvings.

The soft, green, massive agalmatolite forms thin veneers along fractures and also small (1-4 cm) lenses in the flow banded rhyolite. The pods of agalmatolite are usually associated with chert and/or barite. Flow bands deflect around the chert and agalmatolite lenses.

34- PIEDMONT MANGANESE OCCURRENCE 11E9W

		U.T.M. GRID
Lat.	45° 35' 54"	5049400 N
Long.	62° 22' 45"	548450 E

This occurrence is located on a small tributary of the East French River, approximately 6000 feet (2000 m) southwest of Piedmont.

No outcrop is present on the stream; however, boulders of a well rounded, grey-green, compact, pebble to cobble conglomerate with manganese staining on fracture surfaces, are abundant.

35- PIEDMONT IRON OCCURRENCE 11E9W

		U.T.M. GRID
Lat.	45° 35' 57"	5049500 N
Long.	62° 21' 16"	550360 E

No iron mineralization was found in the greenish-grey, silicious siltstones of the Browns Mountain Group that occur along the gorge south of Piedmont. Quartz veining occurs throughout the sediments and contains some iron oxides.

Wright (1975) describes the iron bed as consisting of a hematite matrix with much detrital quartz clasts occurring concordantly in meta-sediments of the Cambro-Ordovician Browns Mountain Group. In these respects the occurrence may be related to the Browns Mountain iron beds southeast of Arisaig (Occurrence No. 37).

36- ARISAIG BROOK IRON OCCURRENCE 11E9E

		U.T.M. GRID
Lat.	45° 44' 42"	5066140 N
Long.	62° 10' 09"	564670 E

See Chapter IV for occurrence summary.

37- ARISAIG IRON DISTRICT, IRON OCCURRENCES

			11E16E	
			U.T.M. GRID	
(1)	Lat.	45° 45' 55"	5068120 N	
	Long.	62° 06' 46"	568980 E	
(2)	Lat.	45° 45' 50"	5067950 N	
	Long.	62° 06' 44"	569020 E	
(3)	Lat.	45° 45' 40"	5067670 N	
	Long.	62° 06' 54"	568800 E	
(4)	Lat.	45° 45' 04"	5066530 N	
	Long.	62° 07' 55"	567525 E	
(5)	Lat.	45° 44' 55"	5066300 N	11E9E
	Long.	62° 07' 54"	567540 E	

See Chapter IV for occurrence summaries.

38- TELFORD IRON OCCURRENCE

		11E9W
		U.T.M. GRID
Lat.	45° 34' 14"	5046240 N
Long.	62° 28' 34"	540840 E

The above coordinates refer to two old pits in the vicinity of the reported iron occurrence. No old mine workings were found where indicated or in the surrounding area. The two pits are found along Hwy. 4, at Telford, 700 feet (230 m) south of the reported location of the McLaurins Iron Mine (Wright 1975). The pits, which are completely overgrown, have apparently been worked for iron (siderite ore) in the past, as reported by local inhabitants.

Drill holes intersected about a two foot (0.7 m) siderite bed hosted by red and green shales and calcareous shales.

Red, muddy, New Glasgow pebble conglomerate is found on a stream south of Telford, however, there is no associated iron.

39- MEIKLEFIELD IRON OCCURRENCE 11E9W

		U.T.M. GRID
Lat.	45° 31' 51"	5041840 N
Long.	62° 28' 15"	541260 E

The above coordinates refer to the recorded position of the old shaft. However, the former owner of the showing indicated the workings were no longer visible. The shaft intersected a four foot (1.3 m) wide bed of oolitic hematite (Wright 1979), probably hosted by sediments of the Arisaig Group.

Sediments in the surrounding area contain some oxidized iron and specular hematite on fracture surfaces.

Sediments include grey, aphanitic grewacke and medium-grained, reddish, subangular arkose, probably of the Lower Silurian, Beechhill Cove Formation.

40- WENTWORTH GRANT IRON OCCURRENCE

		11E8
		U.T.M. GRID
Lat.	45° 29' 36"	5037460 N
Long.	62° 29' 32"	539580 E

This reported occurrence is located at the end of a logging road, approximately 2.5 miles (4 km) west of Blue Mountain settlement. It extends north from another road, 0.8 miles (1.3 km) west of the Blanchard Road turnoff.

No outcrop was found at this location or in the area 1000 feet (330 m) east, where Fletcher indicates an iron occurrence.

41- GEORGEVILLE IRON OCCURRENCE

		11E16E
		U.T.M. GRID
Lat.	45° 49' 51"	5075500 N
Long.	62° 01' 42"	575480 E

This occurrence, reported by Fletcher in 1886, is found in Browns Mountain argillites (hornfels) near the mouth of McInnes Brook, north of Georgeville.

Pyrite is disseminated throughout the Baxter Brook Formation in this area, making up as much as 20% of the argillites. However, no discrete beds of iron were found. Pyrite textures are described under Occurrence No. 12.

42- BARNEYS RIVER STATION IRON OCCURRENCE

	11E9E U.T.M. GRID
Lat. 45° 35' 29"	5048700 N
Long. 62° 14' 38"	559000 E

This reported occurrence is located on the cliff north of Hwy. 104, one mile (1.6 km) east of Barneys River Station. However, no iron mineralization was found in either the green to reddish compact pebble conglomerate or the red, coarse-grain arkoses of the Browns Mountain Group, exposed here.

43- LOCHABER LAKE AREA IRON OCCURRENCES

		11E8E U.T.M. GRID
(1)	Lat. 45° 26' 11"	5031700 N
	Long. 62° 00' 29"	577600 E
(2)	Lat. 45° 24' 43"	5029080 N
	Long. 62° 00' 24"	577740 E
(3)	Lat. 45° 23' 24"	5036480 N
	Long. 62° 03' 11"	574120 E

Location (1) is situated on Hurlbert Brook, near the north end of a pond which is drained by Hurlbert Brook. The red, micaceous siltstones present here, have a prominent cleavage, but no iron mineralization.

No outcrop was found at the N.S.D.M. Mineral Occurrence File location which is 1000 feet (330 m) west-southwest of location (1).

No outcrop was found at location (2) which is situated one mile (1.6 km) east of Hwy. 7, on the southern Copper Lake road.

No outcrop was found at location (3) which is situated 2500 feet (830 m) west of the West Lochaber road, along a stream at the southern end of Lochaber Lake.

These occurrences were noted by Fletcher (1886) and consist only of minor hematite, usually found on fracture surfaces.

44- MOOSE RIVER IRON OCCURRENCE

	11E8W
	U.T.M. GRID
Lat. 45° 27' 42"	5034220 N
Long. 62° 20' 08"	551910 E

This occurrence is located 500 feet (170 m) east of the Moose River, along one of its small tributaries; 2.6 miles (4.2 km) southeast of the cemetary at Moose River settlement. The tributary joins the Moose River, 1300 feet (430 m) east of Hwy. 347.

Specular hematite, up to 3 mm thick, forms on fracture surfaces and is disseminated throughout the Browns Mountain quartz porphyry rhyodacites (Plate AI-2). The iron mineralization constitutes about 1% of the volcanics. The light greenish to reddish-grey volcanics show minor quartz veining.

A fine-grained diorite with minor specularite on fracture surfaces and about 15% disseminated magnetite and pyrrhotite,intrudes the volcanics. Traces of euhedral pyrite and chalcopyrite are found in the chloritic parts of the diorite.

45- BEAVER LAKE IRON OCCURRENCE 11E8W

			U.T.M. GRID
(1)	Lat.	45° 24' 20"	5028000 N
	Long.	62° 20' 38"	551320 E
(2)	Lat.	45° 25' 16"	5029730 N
	Long.	62° 20' 50"	551070 E

Location (1) is a contact of a medium-grained granodiorite and a fine- to medium-grained diorite. Some

Plate A-I-2

a Moose River Occurrence. Specular hematite lathes in volcanics. Reflected light.

Plate A-I-2

b Moose River Iron Occurrence. Pyrite (light grey) and chalcopyrite (medium grey, centre) in diorite.

Plate A-I-2

c Beaver Lake Iron Occurrence. Galena (white), sphalerite (medium grey, centre left of galena grain) and pyrrhotite (very light grey, just below sphalerite) in mutual boundary intergrowth about gangue grains (dark grey).

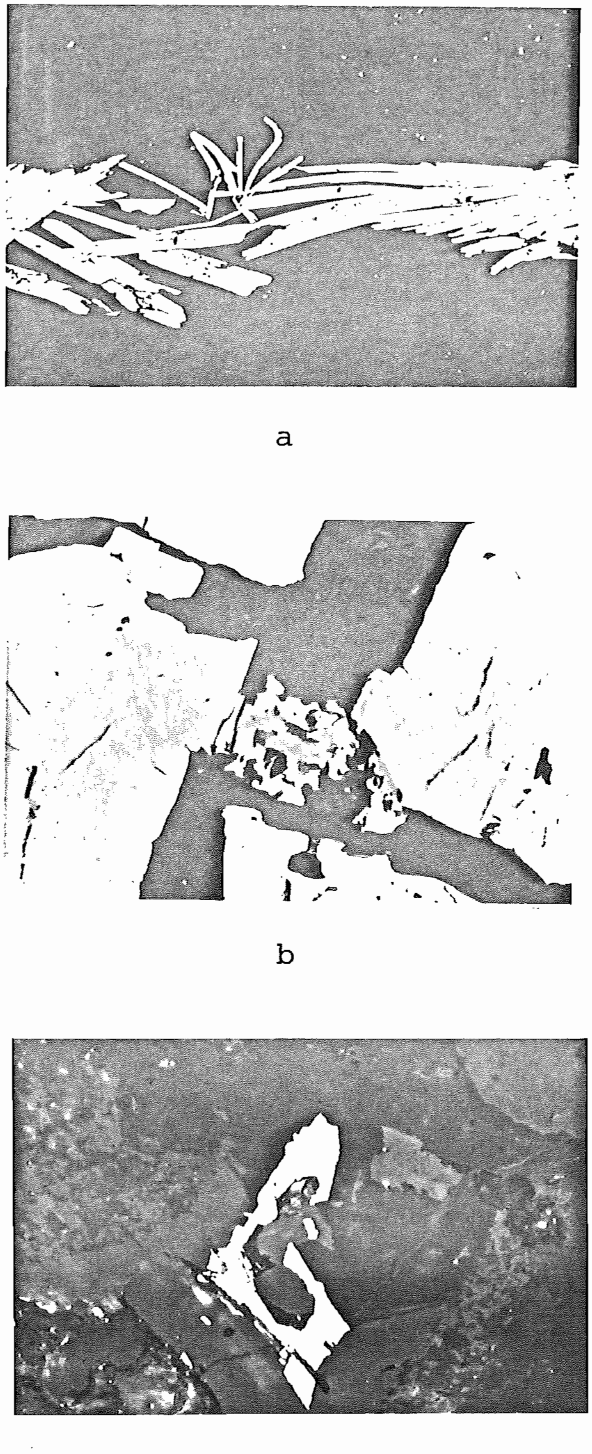


Plate A-I-2

1 mm Scale unless otherwise indicated

hematite is present on fracture surfaces in the diorite, while traces of specular hematite are evident near the contact in the granitic rock.

The diorite is magnetic due to the presence of pyrrhotite and magnetite. Traces of chalcopyrite, galena, sphalerite and pyrrhotite are found in diorite (Plate A-I-2).

Location (2) gives the coordinates of an iron occurrence noted by Fletcher in 1886. It is located on the east branch of the Kittle River, north of what is now known as Hunters Lake, but which was then known as Beaver Lake. The occurrence is probably very minor. The N.S.D.M. Mineral Occurrence File shows an occurrence of iron 2500 feet (830 m) north of Location (1), on a small stream. No traces of iron was found at that location.

A considerable geochemical iron anomaly, however, (up to 80,000 p.p.m. iron), exists on the Kittle River, although no examination of the area was made.

46- IRELAND (HILLCREST) IRON OCCURRENCE

	11E8E
	U.T.M. GRID
Lat. 45° 26' 42"	5032560 N
Long. 62° 05' 05"	571290 E

This reported occurrence is located on the Ohio River, approximately 1.5 miles (2.4 km) south of Hillcrest.

No evidence of iron mineralization was found in either the medium grained pink biotite granite or the two small basic volcanic dikes which intrude the granite, at the plotted location.

47- CAMPBELL BROOK IRON OCCURRENCE

		11E8E
		U.T.M. GRID
Lat.	45° 25' 03"	5029420 N
Long.	62° 14' 06"	559830 E

This occurrence is found along Campbell Brook, 8000 feet (270 m) north of Hwy. 347.

Slightly magnetic, dark grey, banded, cherty argillites are in contact with a dark green basic volcanic. Both units belong to the Browns Mountain Group. Pyrrhotite constitutes up to about 0.1% of the volcanics. No other iron mineralization was found, however, Fletcher (1886) reports minor specular hematite on fracture surfaces in the Cambro-Silurian sediments, in a nearby area.

48- SILVER MINE LEAD OCCURRENCE	11E9E
	U.T.M. GRID
Lat. 45° 39' 58"	5057150 N
Long. 62° 06' 32"	569420 E

This occurrence is situated on the South Rights River, approximately 2.5 miles (4 km) northwest of Clydesdale.

Although this locality was not examined, samples from the area were provided by William McLellen. Fletcher marks this occurrence with quartz veins and shafts. The samples provided were taken from the shaft area and along the South Rights River Valley. However, the location of the individual samples was not distinguished. Mr. McLellen indicated the shafts were probably no longer visible.

The samples consist of fine grained, pinkish grey, very compact quartzites with up to approximately 20% pyrite. The pyrite occurs in 0.5 to 1 mm cubes associated with highly silicified veinlets. Where this association is not apparent, the cubes have truncated quartz grains. Some pyrite occurs as tiny sulfide veinlets. The pyrite is thus, probably, epigenetic.

Analysis of the rocks shows an average of 5.8% pyrite, ranging from 1.3% to 18.5%. Copper and zinc show background values, while silver is consistently less than one p.p.m. However, three samples have anomalous lead values (up to 243 p.p.m.), indicating that further investigation of this occurrence is warranted.

The tailings of the old workings have been located by airplane (Terry St. George, pers. comm.) and appear to be inaccessable from the river valley floor. However, an old logging road provides access to a nearby point. A total of three tailing piles were located by St. George along the bank of the river valley. Samples from one pile, examined by the author, appear to be very similar to those samples analysed (above).

APPENDIX II

PETROGRAPHIC DESCRIPTIONS

APPENDIX II-A

Thin Section Description

Ohio - Sylvan Glen Region

1. CROSS ROADS OHIO

Sample 7286 Fragments, comprising approximately 40% of the rock, are subangular to subrounded and range between 2 and 20 mm. Fragments are aphanitic to porphyritic, felsic in composition and highly altered. Some areas of matrix contain aphanitic laths with approximately 10% chlorite and 10% opaque material. One large (2x2 cm) fragment contains 10% altered feldspar phenocrysts ranging from 1x2 mm to 2x4 mm. The matrix of the fragment, comprising 80% of the rock, consists mainly of aphanitic feldspar laths. Larger opaque grains (1 mm) constitute about 1% of the fragment while smaller (1/20 mm) opaque grains make up approximately 10%. Some of the larger brecciated quartz grains are bordered by opaque material. The overall texture of the fragment matrix is pilotaxitic.

The remaining 60% of the rock is made up of an aphanitic matrix, probably felsic in composition. Indistinct bands of chlorite and sericite form a flow texture in the matrix. Relict feldspar phenocrysts (1x2 mm) constitute approximately 10% of the matrix, while opaque material (1/20 mm) makes up 1 to 2%.

Rock Classification: Crystal, Lapilli Tuff

Sample 7289 Opaque material forms approximately 10% of the rock, distributed predominently in small (1/4 mm) discontinuous stringers which form a rock fabric defelcting around fragments. The stringers are made up of finely disseminated opaque microlites.

Fragments, which comprise 40% of the rock, are subangular to subrounded, averaging 2 to 4 mm and up to 1 cm. The fragments are aphanitic, felsic, contain approximately 10% chlorite and in many cases some feldspar laths. Boundaries of the fragments are very indistinct, and most are highly corroded.

An aphanitic matrix, constituting the remaining 60% of the rock, contains about 30% chlorite and sericite. The composition of the matrix is felsic.

Rock Classification: Crystal Lapilli Tuff

Sample 7291 Opaque material, probably hematite, makes up about 5-10% of the rock.

Rock fragments which represent about 70% of the total rock, averaging 2x8 mm and reach 2 cm. The fragments are made up of about 20% chlorite and sericite, 5% opaque material and about 75%, 1/16 x 1/8 mm feldspar laths constituting a trachitic texture. Feldspar phenocrysts, up to 1x1 mm in size are also present in the fragments in proportions of about 1%.

One large (2 cm) fragment consists of 10%, 1x2 mm feldspar phenocrysts, mainly plagioclase and about 90% matrix made up of 10% opaque (1/50 mm), 10% chlorite (1/50mm) and 80% feldspar laths showing a trachitic texture.

A felsic matrix, composed of approximately 1/16 mm grains, constitutes the remaining 30% of the rock. Up to 20% of the matrix is made up of a dark, semi-opaque material in very corroded masses around fragments. The masses are probably iron oxides.

Rock Classification: Fragments: Porphry Latite
Rock: Lapilli Tuff; Quartz Latite - Rhyodacite Composition

2. OHIO -- MacLEAN

Sample 7321A Grains of quartz, feldspar and minor chlorite, ranging from aphanitic to fine-medium constitute the matrix hosting subhedral quartz and feldspar phenocrysts up to 3 mm. Quartz shows evidence of moderate strain. The grain size is "equigradational" (i.e., having the same amount of each grain size, from aphanitic to medium). Quartz constitutes about 40% of the rock, while feldspar makes up to 60%.

Rock Classification: Rhyodacite or Rhyolite

Sample 7322 The rock is made up of angular fragments of rhyodacite cemented by calcite. Some fragments are more equigranular than the rhyodacite of Sample 7321A, averaging 1/4 mm grain size. The matrix is minor while subhedral feldspar laths are common, forming an intersertal texture. Other fragments contain quartz and feldspar phenocrysts up to 2 mm in an aphanitic matrix. The fragments are undoubtedly derived from adjacent volcanics (Sample 7321A).

Fragments form very sharp contacts with the calcite cement which forms 2 mm crystals.

Rock Classification: Fragments: Rhyodacite and Porphyritic
Rhyodacite
Rock: Breccia

Sample 7323 The matrix and fragments show intense granulation. Many fragments are microlitic, showing subparallel lath shaped crystals. The matrix shows eratic "flowage" texture around fragments.

Rock Classification: Sheared Breccia

Sample 7327 Relict phenocrysts of kaolinized feldspar with rare polysynthetic twinning visible, are found in an aphanitic, felsic matrix with some subangular rock fragments. Relict crystals are brecciated and altered. Iron oxide forms in subparallel fractures. The rock appears to be an extremely granulated and altered porphry rhyodacite.

Sample 7340 Quartz and feldspar phenocrysts form glomeroporphyriticly in the aphanitic groundmass. These form subangular, microlitic, rhyodacite fragments cemented by 2-3 mm calcite crystals. Calcite constitutes only a minor percentage of the rock.

Plagioclase composition of the fragments is An_{34}.

Rock Classification: Breccia

Sample 7341 Calcite is more predominent than in Sample 7340. The description of the fragments is the same as that for Sample 7340, with the exception of a reduction in the amount of fragments.

Rock Classification: Breccia

Sample 7345 Subangular, detrital quartz clasts make up approximately 1% of the micritic limestone. The clasts tend to be found along opaque pyrite material disseminated into small stringers (0.5%).

About 3% of the rock is made up of calcite (1 mm) infillings of cavities (5 mm).

Rock Classification: Micrite

3. OHIO -- IRON

Sample 7328 Rounded fragments of aphanitic, 2-8 mm, microlitic rhyodacite constitute approximately 50% of the rock. The remaining 50% is an aphanitic groundmass, containing 2-3% opaque (probably hematite) material. Rare, relict feldspar phenocrysts are visible.

Rock Classification: Lithic Lapilli Tuff

Sample 7329 The rock is predominently composed of angular to subangular fragments cemented by minor calcite. The fragments are sized above 10 mm and are generally quartz-feldspar porphyry rhyodacite or rhyolite. Phenocrysts of quartz and feldspar average 1-2 mm in an aphanitic matrix. Some fragments are made up entirely of aphanitic sized grains.

Calcite cement generally is 1-2 mm wide between fragments.

Rock Classification: Fragments: Porphyry Rhyodacite or
Rhyolite
Rock: Breccia

Sample 7330 Opaque material makes up about 1% of the rock. Subhedral, quartz and altered feldspar phenocrysts (1 mm) constitute approximately 2% and are set in an aphanitic matrix. Minor calcite fracture infillings are present.

Rock Classification: Porphyry Rhyodacite or Rhyolite

Sample 7330A The rock contains an abundance (35%) of very finely granulated calcite disseminated in the aphanitic matrix which contains anhedral quartz and feldspar phenocrysts (1 mm). Small quartz veinlets (1/10 mm) with 1/10 mm quartz grains are common as are 3 mm quartz pods. Calcite and calcite-quartz veinlets (1/10 - 1 mm) also permiate the rock. The veinlets do not have well defined borders.

Opaque material appears to replace brecciated quartz grains in some cases.

Rock Classification: Deformed porphyry rhyodacite or rhyolite

Sample 7332 Rounded rock fragments make up about 50% of the rock. Most are aphanitic, greyish-brown with some 1/15 mm feldspar laths. Some fragments contain feldspar phenocrysts as well as smaller feldspar laths forming a trachitic texture. Opaque material (hematite) may constitute up to 50% of some fragments.

The aphanitic matrix, making up the remainder of the rock, may contain up to 10% feldspar (1 x 2 mm) and minor quartz phenocrysts as well as finely disseminated opaque and semi-opaque material.

Quartz and minor calcite veinlets (1/10 mm) form a crosscutting texture throughout the rock.

Rock Classification: Lapilli Crystal Tuff

Sample 7333 A network of small (1/2 - 2 mm) quartz veinlets with unstrained quartz grains 1/4 to 1 mm, is found throughout the rock.

Subhedral, 1 x 2 mm to 2 x 4 mm, altered feldspar and minor quartz phenocrysts constitute about 5% of the rock. The remainder is an aphanitic matrix composed of 35-40% very dark, aphanitic, semi-opaque material. About 10% of the matrix is made up of tiny (1/20 mm) laths of, probably, sericite which forms indistinct stringers, in some cases bordering quartz veinlets and following iron oxide filled fractures.

Rock Classification: Quartz Latite -- Dacite

Sample 7334 Opaque material (less than 1%) is associated with chloritic rich areas of the rock. Chlorite forms anhedral, 1-2 mm grains and makes up about 1% of the matrix. The aphanitic, predominently felsic matrix itself makes up at least 80% of the rock. Very fine grained sericite and chlorite is disseminated throughout the matrix in quantities of 5-10%.

Feldspar phenocrysts (1 x 2 to 2 x 4 mm) constitute the remaining portion of the rock. The phenocrysts are subhedral and form glomeroporphyritically. Minor quartz phenocrysts (1 mm) are also present.

Minor amounts of silicification may be found in the form of quartz grains in blebs.

Rock Classification: Porphry Quartz Latite

Sample 7336 The major portion of the rock (80%) is made up of a holocrystalline, aphanitic matrix with predominently lath-shaped grains arranged in a trachitic texture. The laths (probably feldspar) form a "flow" pattern around phenocrysts.

Feldspar phenocrysts (1 x 2 mm) form up to 10% of the rocks and are found glomeroporphyritically. The clusters of feldspars average about 5 mm. Minor quartz phenocrysts are also present.

Quartz grains, however, form 3-4 mm pods, blebs and discontinuous veinlets throughout the rock. Opaque material is associated with the silicification in many cases.

Plagioclase composition was determined as An30.

Rock Classification: Porphyry Quartz Trachite

Sample 7337 The rock is predominently (97%) made up of aphanitic laths of feldspar and hornblende (and/or biotite) in approximately equal proportions.

Rare, relict phenocrysts of altered feldspar are present. Silicification is found in the form of elongated quartz blebs constituting up to 1% of the rock.

Rock Classification: Andesite

Sample 7338 Approsimately 40% of this rock is made up of rounded, corroded fragments (2-10 mm) of andesite (Sample 7337). The remaining 60% is composed of an aphanitic, felsic matrix with minor feldspar phenocrysts

(1 mm). This part of the rock is a lapilli tuff.

In sharp contact with the tuff is a porphyritic quartz trachite or latite as described for Sample 7336.

Sample 7339 Approximately 75-80% of the rock is an aphanitic, felsic matrix containing up to 25% chlorite and 5-10% opaque material associated only with the chlorite. The remainder of the matrix is composed of silicious microlites.

Subhedral feldspar phenocrysts (1-2 mm) constitute 15-20% of the rock. Chlorite occurring as 1/2 - 1 mm anhedral grains is found in quantities up to 5%. Opaque material is usually associated with the chlorite.

Plagioclase composition is An32.

Rock Classification: Porphyritic Latite

5. OHIO -- PINKIETOWN

Sample 7225 One fragment constitutes about 80% of this slide. Altered feldspar phenocrysts (2 x 3 mm) make up 40% of the fragment. The phenocrysts are subhedral and are altered to the extent that twinning is not visible in any grains. The remaining 60% of the rock is composed of a very silicious, aphanitic matrix with up to 30% chlorite. The rock fragment is a feldspar porphyry rhyolite.

One small andesite fragment is present. Other rock fragments are felsic and average greater than 5 mm.

Calcite forms the matrix between the subangular rock fragments, and constitutes about 10% of the rock.

Rock Classification: Breccia

Sample 7226 Approximately 80-85% of the rock is holocrystalline, aphanitic with some feldspar laths visible. Chlorite microlites constitute up to 10% of the bulk. This matrix appears very felsic.

Subhedral feldspar phenocrysts (1 x 2 mm) make up the remaining 15-20% of the rock. Plagioclase accounts for about 60% of the feldspar.

Aphanitic, opaque material accounts for 5-10% of the matrix and is disseminated evenly throughout.

Rock Classification: Prophyritic Latite

7. BRIERLY BROOK

Sample 7197 The rock is a greyish-brown, micritic limestone composed of 10-20%, 1/10 - 2 mm, oval peloids and up to 10%, 1/50 - 1/10 mm, subangular to subrounded quartz clasts, and 80-90% aphanitic calcium carbonate. The peloids are outlined by very fine strands of dark brown, semi-opaque material, possibly of organic origin. These strands also form fine, parallel laminations within the limestone with spacings on the average, of 1 mm. These laminations may be algal in origin.

This limestone is in sharp contact with a micrite containing at least 10% quartz clasts. This area marks a transition from Horton in Windsor sediments.

Sample 7198 This conglomerate consists of subrounded to angular, mainly quartzite, granules and pebbles. Much subangular, fine to medium grained quartz and feldspar detritus is also present. The fragments are cemented by a micritic calcium carbonate matrix which constitutes 10-20% of the rock. Very few volcanic fragments are present.

8. SYLVAN GLEN

Sample 7383 Micritic limestone conformable to description of Sample 7197 (Brierly Brook). Very faint lineation of quartz clasts parallel to bedding. Opaque material (chalcocite) appears to have preferential association with quartz rich laminations.

Sample 7384 This conglomerate is conformable to the conglomerate description of Sample 7198 (Brierly Brook). Opaque material is found replacing feldspar clasts and following fractures throughout grains and fragments.

Sample 7399 This slide is composed of approximately 50%, subangular, fine grained (1/10 mm), fairly well sorted sand clasts in a micritic calcium carbonate matrix. An indistinct layer of opaque material traverses the slide.

Samples 7401 and 7405 These samples conform to descriptions given for a Brierly Brook conglomerate (Sample 7198) with the exception of larger calcite crystals (1/10 mm) in some areas of the matrix and the presence of much more porphyry volcanic pebbles.

APPENDIX II-B

Thin Sections - Antigonish Highlands

8. GREENVALE GOLD OCCURRENCE

Sample 7207 The slide is 30% made up of fine grained subangular to subrounded, 1/2 - 3/4 mm quartz clasts. The quartz is generally unstrained to mildly strained. Anhedral feldspar grains show obscure relict twinning and compose 5-10% of the rock. Aphanitic, alligned chlorite flakes constitute 10-20% of the total. Aphanitic, 1/50 mm felsic grains constitute the matrix, total about 30% of the rock. Biotite occurs as alligned plates, making up about 5% of the slide.

The lineation of the grains is not strong but does tend around larger quartz and feldspar grains.

Rock Classification: Quartzwacke

Sample 7310 Opaque material is disseminated throughout and constitutes about 1% of the rock.

Subangular to subrounded, 1/10 - 1/20 mm quartz clasts constitute approximately 15% of the slide. The quartz is generally unstrained to mildly strained. Approximately 85% of the rock is made up of an aphanitic matrix, 50% of which is chlorite and 50% of which is silicious material. A well developed lineation of chlorite around larger quartz grains exists. The lineation has not reached schistose texture.

Rock Classification: Slatey Greywacke

10. MOOSE RIVER COPPER OCCURRENCE

Sample 7214 Opaque material makes up $<<1\%$ of the rock. Fine grained (1/10 mm) equigranular, subangular to subrounded quartz grains constitute 5 to 10 mm quartzite fragments. The quartz grains are slightly elongated and possess a preferred orientation. Areas between the fragments are composed of inequigranular, subangular to angular, 1/50 - 1/20 mm quartz grains which appear more strained than the quartz grains of the fragments. The fragments and quartz matrix constitutes about 80% of the rock.

Large, 2-3 mm calcite crystals fill interstitial areas, and make up about 10%.

The remaining 10% is an aphanitic chlorite and silicious matrix.

Perfect, isotropic, transparent hexagons occupy 1% of the calcite.

Rock Classification: Sheared Quartzite

Sample 7215 Opaque material accounts for 1-2% of the rock. Anhedral to (rarely) subhedral, 1-2 mm, quartz (35%) and feldspar (65%) phenocrysts constitute 25% of the rock. Quartz shows much strain. Twinning is seen only rarely in feldspar.

The remaining portion of rock is made up of an aphanitic matrix of muscovite-sericite (60%) and silicious matter (40%) forming a well developed cleavage flowing around phenocrysts. A vague cleavage is seen in hand specimen.

Small (1/2 mm) quartz veins are found in the slide.

Rock Classification: Welded Crystal Tuff (Rhyolite-
Rhyodacite composition)

Sample 7217 The entire rock is generally aphanitic. Anhedral calcite blebs (1/10 mm) are corroded and occur throughout. Biotite constitutes 10-20% of the slide. Opaque material accounts for 15-20% of the bulk and shows a lineation.

One, 1mm calcite-quartz-biotite vein with 1/2 mm grains cuts the rock.

The slide shows a somewhat regular banding of biotite and opaque material:

15% opaque 0.05 mm biotite 10%
20% opaque 1% biotite 0.02 mm } ~5% calcite
10% opaque 15% biotite 0.1-0.05 mm
15% opaque 1% biotite
10% opaque 20% calcite

Rock Classification: Altered Quartzite

23. BLUE MOUNTAIN COPPER OCCURRENCE

Sample 7184 Opaque material makes up <1%.

Platey minerals show a strong parallel lineation. Bands of micaceous minerals are 1/10 - 1/2 mm wide and show parallel extinction. Bands are made up of aphanitic grains of chlorite (20%) and quartz (80%) and alternate with bands made up of nearly all chlorite grains elongated in a preferred direction parallel to banding. Bands also contain a dark, nearly opaque, probably iron oxide product. Quartz is mildly strained.

Rock Classification: Chloritic Phyllite

Sample 7186 Opaque material grades from 10% content at 'botton' of slide to 5% content at 'top'.

A very strong, undeformed lineation of minerals showing indistinct light and dark bands is composed of aphanitic silicious and glassy material. The silicious bands are made up of elongated grains. Glass forms interstitial areas of grains.

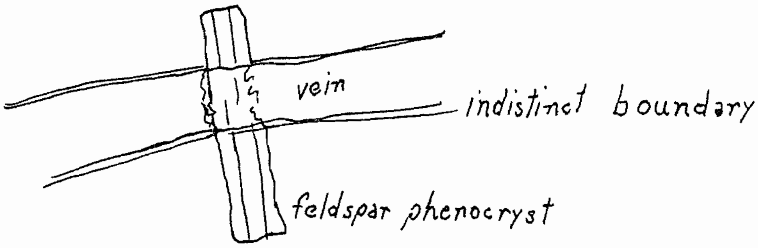
Composition of the rock is vague due to extremely fine grained nature of the minerals, however, subangular, 1/10 mm silicious clasts make up 10%; elongate grains constitute about 55% and glass composes 35% of the rock.

Sample 7187 Opaque material, probably pyrite, accounts for 10% of the slide.

Subhedral to euhedral, 1/4 x 1 mm, feldspar (mainly plagioclase) phenocrysts form a subparallel trachitic texture and constitute about 15% of the rock.

The remaining 85% of the slide is occupied by matrix material which is composed of feldspar laths, 1/10 mm (45%), anhedral, dark grey microlites (45%) and opaque material (10%). The microlites may be partially devitrified glass of corroded micaceous material.

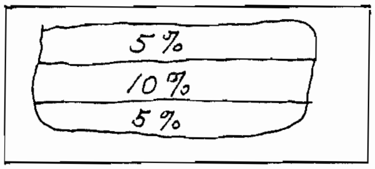
A network of 1 mm, branching quartz and quartz-feldspar veins containing 1/50 - 1/10 mm grains occurs throughout the slide. A lighter coloured halo (1/2 mm) surrounds the veins. The halos show distinctly less opaque material. The veins actually cut and displace some phenocrysts while most other veins appear to incorporate portions of the phenocryst within them.



The veins, for the most part, are probably not true hydrothermal veins but formed by migmatic or recrystallization processes.

Rock Classification: Feldspar Porphyry Latite

Sample 7190 Opaque material is banded in the slide in alternating layers:



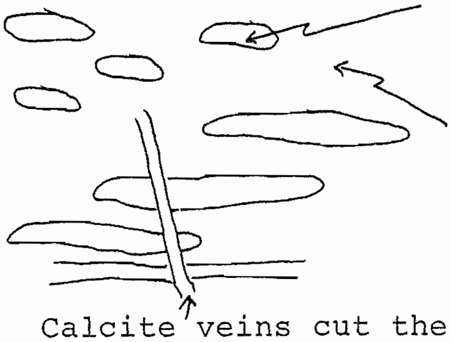
A very well developed schistosity is characterized by a lineation of biotite, muscovite and sericite. These minerals constitute 40% of the bulk in the 5% opaque areas and only 20% in the 10% opaque areas. Parallel extinction is shown by the grains. The micaceous minerals flow around anhedral quartz grains (1 mm) which make up 15-20% of the rock. The remainder of the rock (25%) is made up of aphanitic quartz in interstital areas of the micaceous minerals.

Rock Classification: Biotite-Muscovite Schist

26. LAKEVALE BARIUM OCCURRENCE

Sample 7255 No opaque material is present.

The limestone is micritic with dark laminations. Micritic areas, which constitute 50% of the slide, form as pods and elongated lenses within a crystalline (1/2 - 1 mm) limestone area. Crystalline limestone constitutes about 50% of the slide and may represent recrystallized micritic limestone.



micritic fragments and layers - presence of much nearly opaque material in some layers.

recrystallized, fine to medium grained crystalline limestone. 0.5 to 1 mm proportions micrite: crystalline 50:50

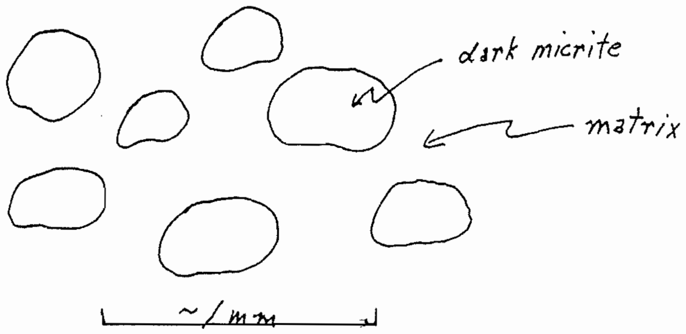
Calcite veins cut the laminations.

Sample 7261 Opaque material makes up 1-2% of the slide.

The rock contains predominently, 1 mm subrounded, mostly unstrained quartz clasts (40%) and anhedral, 1 mm, feldspar clasts and fragments (60%). The silicious clasts total about 70% of the rock. The remaining 30% is made up of an aphanitic, limy matrix.

Sample 7262 Featureless, dark grey-grown micritic limestone.

Sample 7263 Subangular, 1/10 mm, detrital quartz clasts constitute 1-5% of the limestone. Micritic areas are dark, spheroidal in shape (peloids) and make up about 50% of the slide. Interstital areas are formed by very fine grained (1/50 mm) calcium carbonate crystals, lighter in overall colour than the micrite.



29. BIG MARSH BARIUM OCCURRENCE

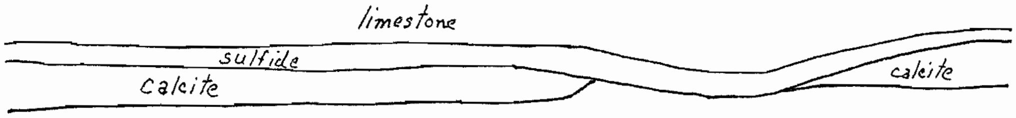
Sample 7276 Opaque material forms bands parallel to bedding in quantities of 1-2%.

Subangular, 1/10 - 1/20 mm quartz clasts form about

5% of the rock. The quartz forms in indistinct layers varying from 0-5% in content.

The limestone is laminated showing bands (1-2 mm) of light and darker material. The darker bands are completely micritic while the lighter bands are made up of 1/40 mm calcium carbonate grains. The darker material is apparently made up of tiny dark strands, possibly organic in origin. The laminated carbonate makes up at least 95% of the slide.

One 1/2 mm calcite vein is rimmed on one boundary by sulfide (<1/2 mm). The calcite, in places, pinches out, while the sulfide remains continuous.



Rock Classification: Laminated Micritic Limestone

Sample 7277 Opaque material constitutes about 5% of the rock and is disseminated mainly along one .5 mm layer parallel to laminations.

Subangular, 1/15 mm detrital quartz clasts account for about 1% of the slide. The remainder of the slide is composed of laminated micritic limestone. Laminations are found on a scale of 1 mm thickness. Darker layers are formed by indistinguishable grains while lighter layers are formed by 1/80 mm grains.

Calcite veins (1/4 - 1 mm grains) cut the laminations.

Rock Classification: Laminated Micritic Limestone

Sample 7279 Opaque material (5-10%) forms in indistinct, subparallel discontinuous layers.

Angular to subangular quartz clasts make up less than 1% of the rock.

More than 95% of the slide is laminated micritic limestone as described for Sample 7277.

Large (2 x 5 mm) lenses infilled by crystalline calcite grains (1 mm) are found in a few areas.

Open fractures (1 mm) (not filled) parallel to the laminations make up about 1% of the limestone.

Sample 7280 This reddish brown non-laminated limestone consists of crystalline calcium carbonate grains (1/2 - 1/4 mm). Abundant calcite (1 mm) filled pods (2-4 mm) are found throughout. Reddish-brown colour may be due to iron oxide.

Rock Classification: Crystalline Limestone

32. McISAAC POINT BARIUM OCCURRENCE

Sample 7266 Non-laminated, probably recrystallized limestone. Irregular micritic areas are dark grey-brown and constitute 80% of the slide. The remaining 20% is made up of 1/20 mm crystalline calcite.

Sample 7295 Approximately 80% of the slide is taken up by rounded fragments (2-8 mm) of micritic limestone. Mainly open space is found between the fragments, however subangular to subrounded, 1/2 - 1 mm strained quartz grains also occupy this space.

Rock Classification: Mylonated, Recrystallized Limestone

36. ARISAIG BROOK IRON OCCURRENCE

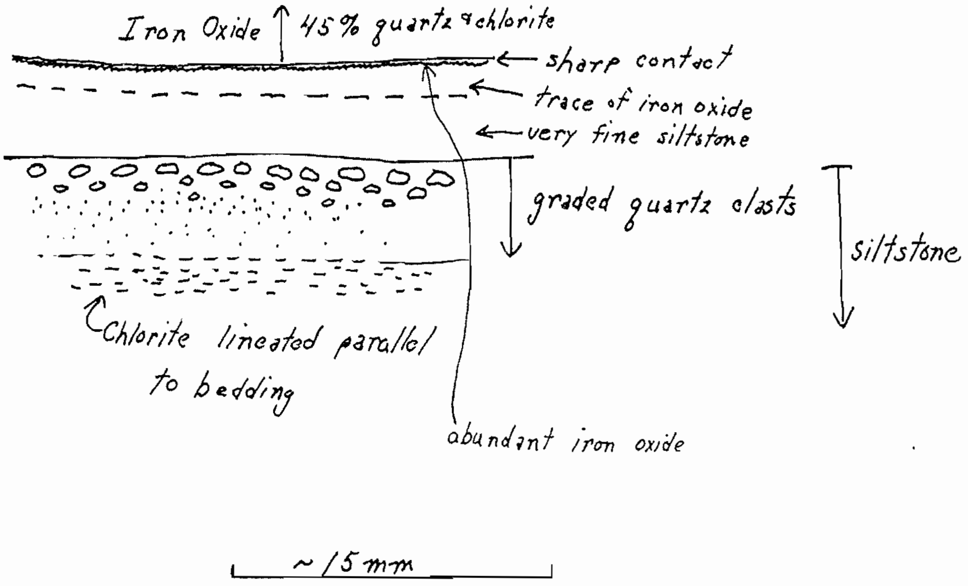
Sample 7410 The ironstone is made up of a fine grained hematite matrix occupying 60-75% of the slide.

Subangular to subrounded detrital quartz (1/5 - 1 mm) and chlorite (1/4 - 1/2 mm) clasts make up 25-40% of the ironstones. The quartz and chlorite are found in approximately equal proportions. The elongated clasts show a preferred, parallel orientation.

Sample 7411 Subangular, 1/10 mm well sorted, quartz clasts make up 70% of the slide. The remaining 30% is made up of chlorite and minor muscovite dispersed among the quartz clasts.

Rock Classification: Siltstone

Sample 7412 This slide contains the contact of the ironstone and host siltstone.



This sample clearly shows right way up in the sample and indicates the sequence of sediments is right way up towards the east.

Sample 7413 Hematite matrix makes up about 50% of the rock. Subrounded to rounded, 1/2 - 1 mm quartz clasts are evenly distributed throughout the matrix and constitute the remaining 50% of the slide.

37. ARISAIG IRON DISTRICT, IRON OCCURRENCES

Sample 7418 Subrounded quartz clasts constitute 50% (1/4 - 1/2 mm grains) of half the slide and make up 70% (1/4 - 1-1/2 mm grains) of the other half of the slide. The sharp gradation is probably parallel to original bedding.

Hematite makes up the matrix and constitutes 30-50% of the rock, clearly lower in iron content than the ironstones of Arisaig Brook. Many oolites of hematite about quartz and chlorite grains are present. Oolites constitute about 1% of the total bulk.

Sample 7419 Subangular to subrounded, well sorted, 1/6 mm interlocked quartz grains make up 80% of the rock. Chlorite grains make up the remaining 20% of the slide.

The grains show a preferred orientation parallel to bedding.

Rock Classification: Fine Grained Quartzite

Sample 7420 This slide was taken in the ironstone near the hematite-quartzite contact.

Subangular to subrounded, 1/8 - 1 mm poorly sorted quartz and minor chlorite clasts make up 60-80% of the slide. The quartz is unstrained to moderately strained.

Hematite constitutes the matrix in proportions of 10-30%. No oolites are present in the slide.

Sample 7421 Subangular to subrounded well sorted, 1/5 mm fairly clean, interlocked quartz grains form a fine grained quartzite.

Sample 7422 Subangular to subrounded, 1/6 - 1-1/2 mm quartz clasts make up 40% of the ironstone.

Microlaminated, 1 mm thick beds of chert are fragmented throughout the slide. Most of the beds are sub-parallel. Primary sedimentary structures may be seen in many of the beds (Plate IV-1).

Hematite occupies the interstital areas (forming the cement) and makes up 20-30% of the slide. No oolites are present.

Chlorite grains are present in amounts of 1-2%.

Sample 7425 Calcium carbonate forms 1/60 - 1/80 mm grains in the micritic, brownish red limestone. Calcite (1/4 - 1/2 mm grains) filled fossils form 20% of the rock.

Sample 7429 Subangular to subrounded, 1/6 - 1/2 mm interlocking quartz clasts form 85% of the slide. The remainder of the rock is made up of aphanitic chlorite grains.

Rock Classification: Quartzite

Sample 7431A Subrounded, 1/10 mm well sorted quartz grains make up 60-70% of the slide. The remaining area is taken up by an aphanitic matrix showing a preferred orientation.

Rock Classification: Quartzwacke

Sample 7417 The volcanic is 40% made up of 1/25 mm feldspar laths. Pyrrhotite or magnetite amounts of 15%, disseminated throughout. Mafic minerals are too fine grained for identification, although some chlorite is present.

Rock Classification: Basalt

44. MOOSE RIVER IRON

Sample 7348 Pyrrhotite or magnetite occur in 1/2 - 1 mm masses disseminated throughout and associated with the chlorite. These opaques constitute 15% of the slide. The chlorite is found as 1-3 mm anhedral masses disseminated throughout.

Anhedral to subhedral, in some cases fragmented, feldspar grains (1/2 x 1/2 mm to 1 x 2 mm) constitute 55% of the slide. Twinning is obscure but plagioclase to orthoclase ratio is about 60:40.

Rock Classification: Monzodiorite

Sample 7350 Hematite and hematite rimmed pyrite (1/50 - 1/10 mm) are disseminated throughout the matrix.

Phenocrysts constitute 30% of the slide and are made up of feldspar (80%) and quartz (20%). Twinning on feldspar is obscure. The quartz phenocrysts are strained and shattered and form 2-3 mm grains. Feldspar phenocrysts are also shattered, anhedral and vary from 2 to 3 mm in size.

The remaining 70% of the slide is taken up by aphanitic matrix. Opaque material makes up 5-10% of the matrix. Sericite and chlorite make up 15% and silicious material constitutes about 80% of the rock. The sericite and chlorite form as sub-parallel grains showing a "flow" texture.

Rock Classification: Quartz-Feldspar Porphyry Rhyodacite

Sample 7355   Aphanitic opaque material are disseminated throughout and make up 5% of the slide.

Anhedral, 1/15 x 1/8 mm, corroded feldspar laths show a trachitic texture and constitute about 50% of the slide. The feldspar laths are altered beyond identification as plagioclase or orthoclase. Aphanitic chlorite grains constitute about 35% of the slide. Sericite makes up about 10%.

Rock Classification: Andesite (Basalt)

Sample 7356   Opaque material makes up 5% of the slide. Rounded to subrounded volcanic fragments (1 x 2 mm) with a preferred orientation and acidic composition makes up at least 50% of the slide.

The remainder of the rock is aphanitic, interstital micaceous material forming a flow texture around fragments.

Rock Classification: Welded Lithic Tuff

Sample 7360   Opaque material constitutes 2-3% of the slide. Aphanitic muscovite and/or sericite showing a distinct lineation, makes up 10% of the rock. The remainder of the matrix is silicious. Relict feldspar phenocrysts are found in minor amounts throughout. Traces of calcite are found throughout.

Rock Classification: Schist (Welded)

45. BEAVER LAKE IRON OCCURRENCE

Sample 7363 Pyrrhotite is disseminated throughout and accounts for 15% of the rock. Hornblende and chlorite constitute 15-20% of the slide. Hornblende is clearly being altered to chlorite.

Feldspar is very altered and constitutes 70% of the rock. Twinning is obscured on the feldspars.

Texture is holocrystalline with grains averaging 1 mm.

Rock Classification: Diorite (Fine Grained)

Sample 7364 Texture of the rock is holocrystalline with grain size averaging 5 mm and up to 7-8 mm. Quartz is somewhat strained and constitutes 15-20% of the rock. Euhedral, altered (twinning obscured) feldspar crystals make up about 70% of the slide. Biotite which is being altered to chlorite constitutes about 10% of the rock.

Probable Rock Classification: Granodiorite (Medium Grained)

46. HILLCREST IRON OCCURRENCE

Sample 7408   Specular hematite or magnetite in quantities of <1% replace highly chloritized hornblende.

Inequigranular, 1/20 - 3 mm, very mildly strained quartz grains occupy 35% of the slide.

Altered 1 mm to 2 x 4 mm, predominently plagioclase feldspar, constitutes 60% of the rock.

Chloritized hornblende accounts for about 5% of the total.

Probable Rock Classification: Granodiorite

Sample 7409   Anhedral chlorite grains, 1/2 - 1 mm occurring in a variolitic texture makes up 35-40% of the slide.

Dark brown, non-pleochroic, 1/4 mm, nearly opaque material, possibly iron oxides with some chlorite and traces of calcite form the matrix which occupies about 15% of the rock. Altered feldspar laths (1/2 x 2 mm) form a trachitic texture and compose 45% of the slide.

Rock Classification: Diabase

MISCELLANEOUS RELATED OCCURRENCES

CAPE JACK

Sample 7437 Opaque material is found in trace amounts. Dark and light laminations are found on a 1 mm scale. Darker laminations are characterized by micritic limestone while the lighter bands are formed by 1/20 mm crystalline limestone grains.

Angular to subangular, 1/5 - 1/10 mm detrital quartz clasts form 1-5% of the rock. The clasts form quartz rich layers parallel to bedding. One large (4 mm) calcite vein (1 - 2 mm grains) cuts perpendicular to the laminations.

Sample 7438 Opaque material makes up 10% of the slide. Subangular, 1/10 - 1/4 mm quartz clasts make up 80% of the rock. Up to 10 % of the slide shows empty areas, most probably missing quartz clasts. Carbonate is found throughout in amounts of about 1%.

Rock Classification: Sandstone (Fine-Grained)

CAPE BLUE

Sample 7440 Opaque material (probably pyrite) constitutes about 3% of the rock and is found mainly along a preferred horizon (3 mm) parallel to laminations. The grains are shaped like corroded cubes (some grains are 1/2 - 3/4 mm while most are 1/10 mm). The limestone is laminated on a 1 mm scale and shows darker and lighter banding. The darker bands are made up of 1/80 mm, barely distinguishable grains while the lighter bands are composed of 1/10 mm crystalline grains.

Subangular, 1/10 mm quartz clasts make up 15-20% of the slide and are arranged preferentially in discrete layers.

Calcite veins (2 mm) cut perpendicular to laminations.

MONESTARY

Sample 7448 Traces of chalcopyrite are found disseminated throughout.

The crystalline limestone is made up of 1/2 mm calcite grains and many calcite replaced fossils. An overall brown colour of the limestone may be due to iron oxide material. No clastic material is present.

Sample 7449 Only traces of opaque material is evident. Subangular to subrounded, fine to medium grained quartz clasts form 75% of the slide. The remaining 25% is made up of a carbonate matrix.

Rare, anhedral grains of feldspar are found. One thin layer with 5-10% opaque material is found in the slide.

Rock Classification: Limy Sandstone (Grey)

APPENDIX II-C

Polished Section Descriptions

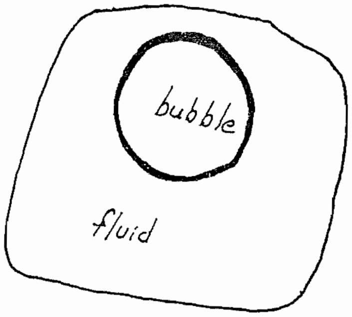
Antigonish Highlands

8. GREENVALE GOLD OCCURRENCE

Sample 7309 Traces of anhedral, 1/200 mm chalcopyrite grains are found in ankerite. Two sphalerite grains (1/50 mm) are found in a quartz and calcite aggregate.

The vein, which makes up the entire slide is made up of quartz (75%), ankerite 20% and chlorite 5%.

Fluid inclusion (probably primary) bubble-fluid ratios are relatively high, precluding a low temperature origin of the veins.



Sample 7310 Subhedral, 1/100 - 1/20 mm magnetite grains are disseminated evenly throughout in quantities of about 3%. The grains are actually partially corroded euhedral grains.

A hand specimen of the quartzwacke is slightly magnetitic. Sphene occurs as small grains in amounts of

<1%. No sulfides are present in the slide.

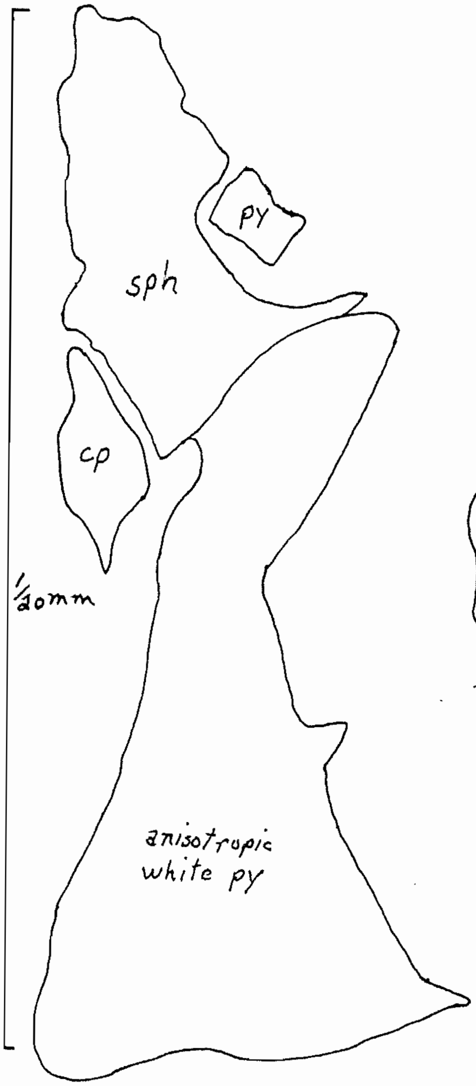
10. MOOSE RIVER COPPER OCCURRENCE

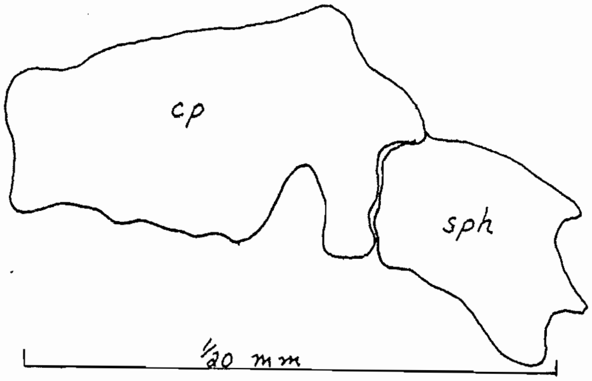
Sample 7217 Pyrite and minor pyrrhotite occur as 1/100 - 1/3 mm anhedral grains in quartz-biotite stringers. Most of the grains are elongated parallel to the veins. Pyrite also occurs in elongated grains outside of the veins and is found as both isotropic (pale yellow) and anisotropic (very pale yellow) varieties. Pyrrhotite has a very characteristic pinkish-yellow hue. These sulfides form indistinct layers in the slide in quantities of about 1%. Most sulfide grains show some iron oxide rim replacement.

Chalcopyrite occurs in trace amounts as discrete 1/40 mm grains. Some pyrite fills cross cutting fractures.

Anatase, rutile and minor sphalerite are found as 1/50 - 1/20 mm discrete grains disseminated evenly throughout in amounts of about 3%.

Sphalerite shows several mutual boundary intergrowths with pyrite and chalcopyrite.

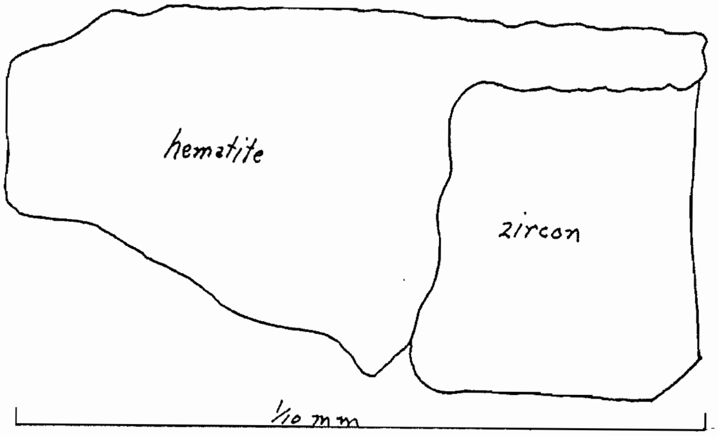




Visual Modal Estimate	py	1%
	po	traces
	cp	traces
	sph	<1%
	anatase and rutile	3%

Sample 7215 The 'unmineralized' host volcanic contains about 2%, <1/100 mm and 1/20 - 1/5 mm anhedral to euhedral hematite grains. The smaller hematite grains form in layers concentrated in silicious bands. The sericitic areas are relatively devoid of hematite. No replacement of feldspar phenocrysts is present.

Zircon is found in trace amounts, in some cases forming ambiguous intergrowths with hematite.



Sample 7214 The rock in contact with the large calcite veins is made up of quartz grains (80%) and calcite (20%).

Rutile and/or anatase is found as anhedral to subhedral, 1/50 - 1/20 mm grains disseminated evenly throughout in quantities of about 1%.

Pyrite occurs as euhedral (to anhedral) 1/50 - 1/40 mm grains disseminated throughout in proportions of <<1%. A few framboids of pyrite occur near calcite grains.

Traces of zircon and/or sphene show a few straight boundaries but are rounded for the most part.

One 1/100 mm grain of chalcopyrite is present.

No fluid inclusions suitable for study are present in the calcite.

12. GEORGEVILLE COPPER OCCURRENCE #2

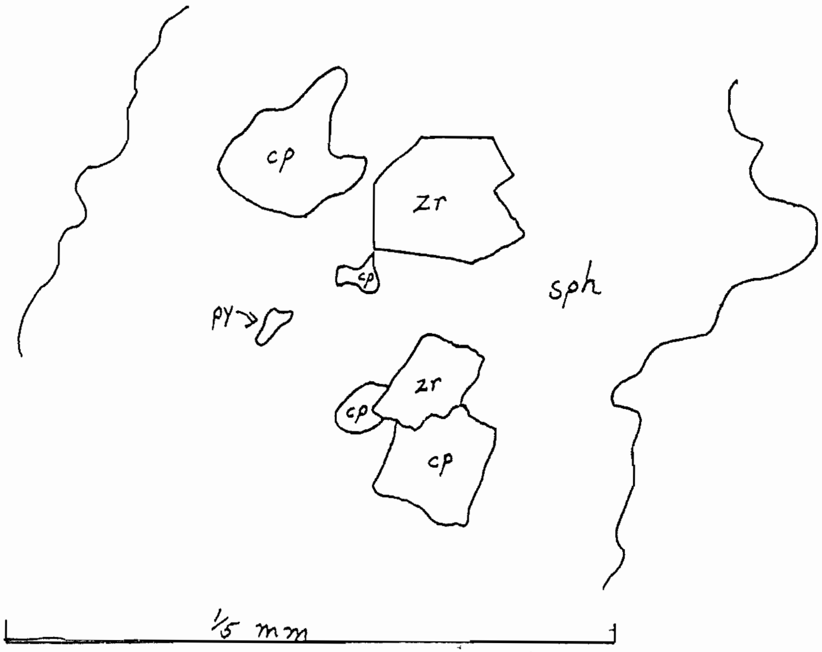
Sample 7125B Anhedral, 1/5 - 1/2 mm (some 1/20 mm) sphalerite grains are found almost exclusively in small (1/10 mm average) calcite stringers showing an irregular vein pattern. The transmitted colour of the sphalerite varies from clear to yellowish to red and reflects, respectively, iron contents of o% to 3%. Sphalerite commonly shows mutual boundary intergrowth with chalcopyrite. The intergrowth probably indicates contemporaneous growth within the veins.

Covellite commonly rims the chalcopyrite-sphalerite intergrowths. Only traces of covellite are found with discrete sphalerite grains.

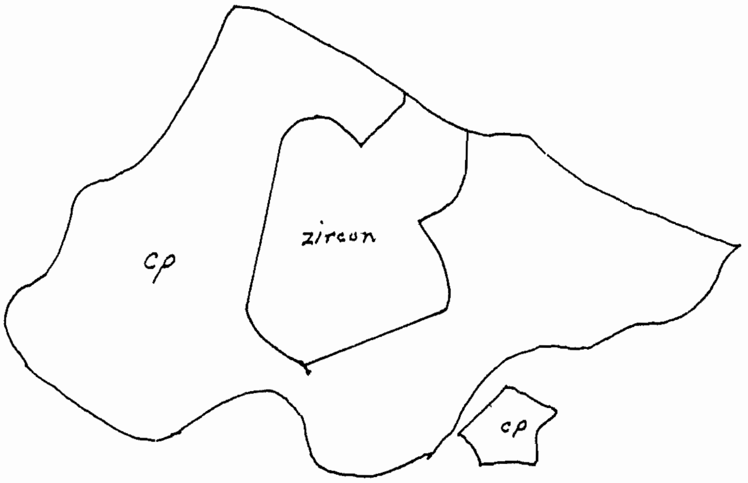
Chalcopyrite also is found as 1/100 - 1/10 mm, anhedral grains associated with calcite stringers and blebs and also with 1/40 mm quartz grains associated with some blebs. The chalcopyrite accounts for <1% of the slide.

Discrete, 1/40 mm pyrite grains are found in trace amounts in the calcite veins. A few pyrite-chalcopyrite intergrowths show irregular boundaries and ambiguous paragenesis.

One sphalerite-chalcopyrite-pyrite-zircon mutual boundary intergrowth also indicates an ambiguous paragenesis. Replacement or contemporaneous growth cannot be determined.

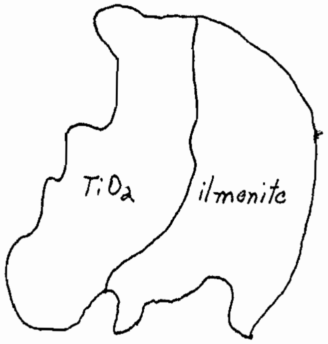


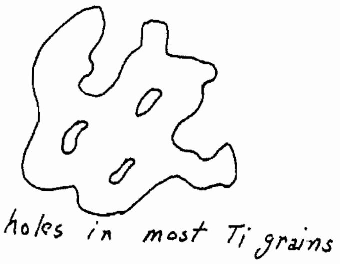
One chalcopyrite-zircon intergrowth near a calcite vein, may show growth of chalcopyrite around very hard zircon.



In this case, if zircon had replaced chalcopyrite then such sharp, straight boundaries may not be expected. However chalcopyrite may form around the zircon without causing corrosion of the very hard zircon grain.

Rutile, anatase and ilmenite occur discretely as 1/50 - 1/30 mm anhedral grains and intergrowths.





These minerals are disseminated throughout the hornfels.

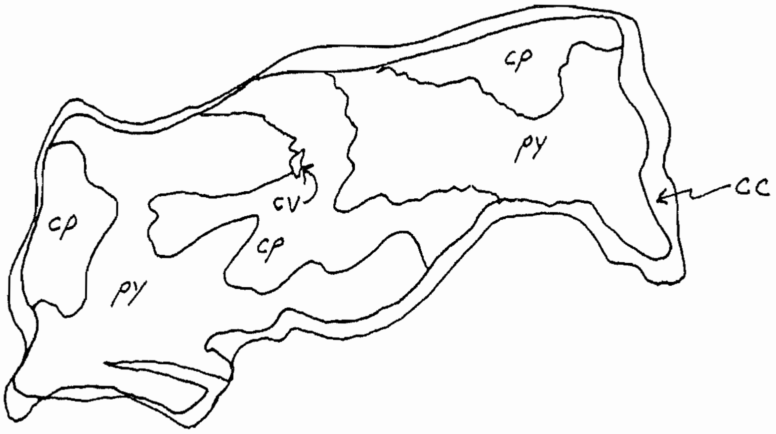
Visual Modal Estimate:	Sphalerite	1/4%
	Chalcopyrite	1/4%
	Pyrite	traces
	Zircon	traces
	TiO_2	3%
	Ilmenite	1%
	Covellite	traces

Sample 7125 Pyrite occurs as anhedral, 1/100 - 1/10 mm corroded grains disseminated unevenly in amounts from 1% to 10%. The pyrite also forms <1/100 mm wide fracture fillings.

Sphalerite occurs as 1/5 mm, anhedral, corroded grains associated with small 1/30 mm quartz and calcite stringers. It is also found filling hair thin fractures (up to 10 mm long).

Titanium oxide minerals and ilmenite occur as described for Sample 7125B. However, the ilmenite is not as corroded as in that sample and shows more rounded shape. Interiors of the grains are typically corroded.

One intergrowth shows a probable (but by no means conclusive) replacement of pyrite by chalcopyrite and subsequent rimming and replacement of pyrite by chalcocite.

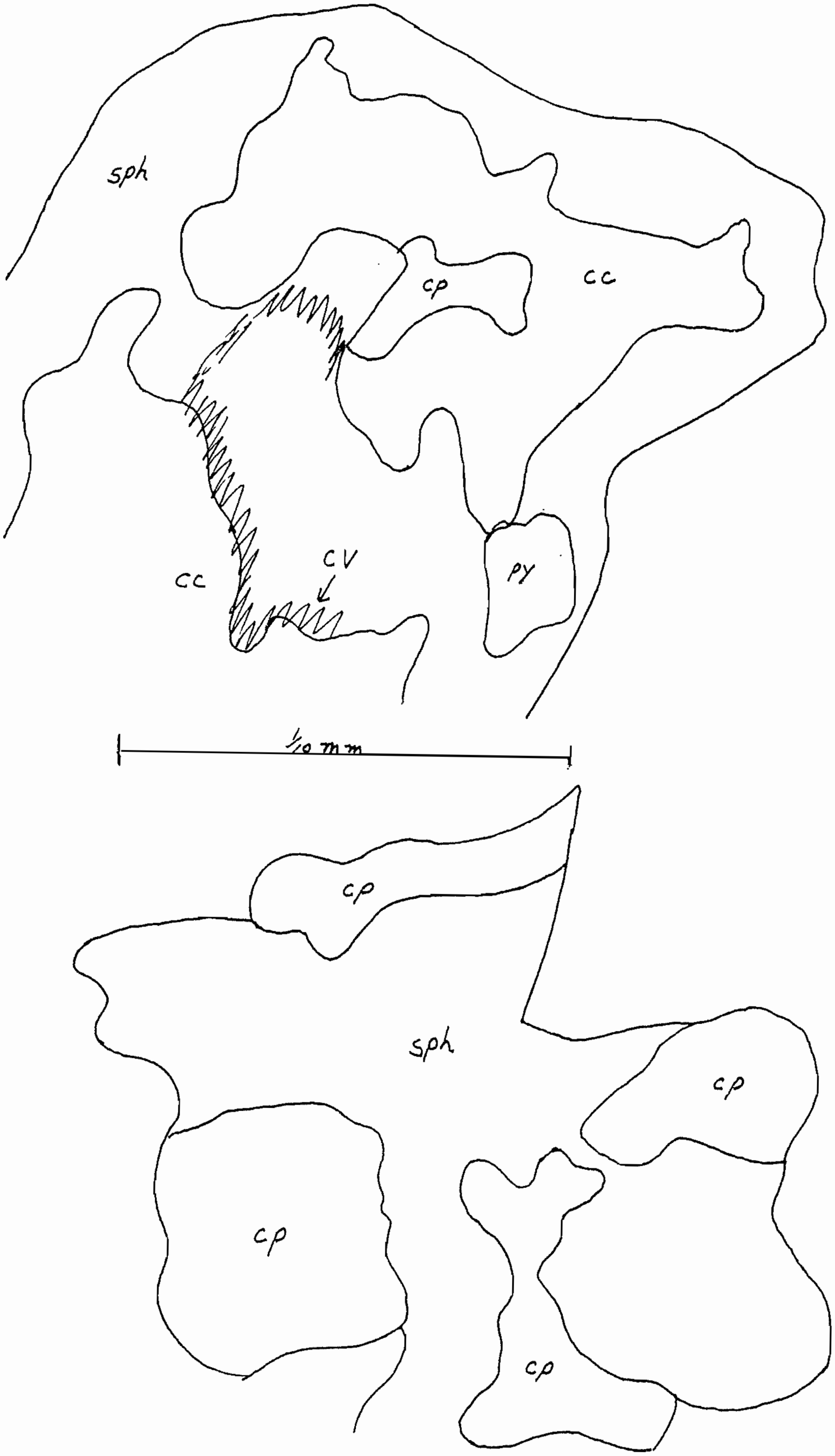


Traces of anisotropic, whitish pyrite are found in places.

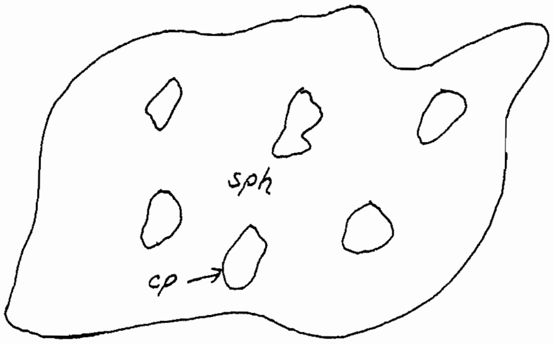
Visual Modal Estimate:	Sphalerite	1/4%
	Pyrite	5%
	Chalcocite	trace
	Chalcopyrite	traces
	Ilmenite & TiO_2	2%
	Covellite	traces

Sample 7125(2) More whitish, anisotropic pyrite is present in this slide. Iron oxide masses form around some pyrite and chalcopyrite grains.

Large mutual boundary intergrowths of chalcopyrite-chalcocite-sphalerite-pyrite are present but show ambiguous paragenesis.


sph
cp
cc
cc
CV
py
1/10 mm
cp
sph
cp
cp
cp

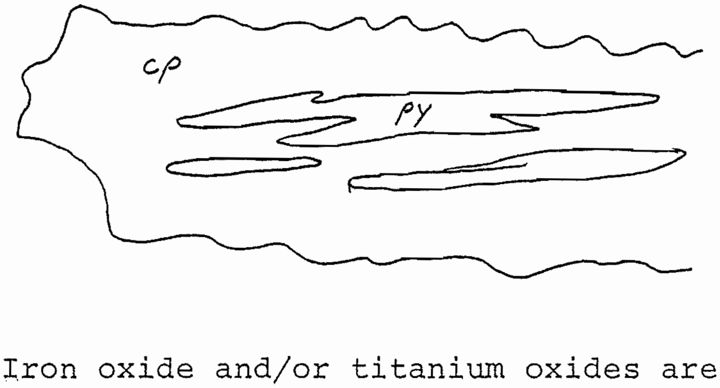
One sphalerite grain shows many chalcopyrite (mutual boundary) blebs within.



Samples 7125(3) & (4) These slides are marked by the same minerals and textures as other 7125 samples, however the abundance of the minerals is much less.

Sample 7125A Pyrrhotite occurs as 1/5 x 1/2 mm, elongated and alligned grains totalling <<1% of the slide. Pyrite is found as 1/10 x 1/2 mm grains.

One chalcopyrite grain contains elongated pyrite blebs.



Iron oxide and/or titanium oxides are disseminated throughout, in amounts of about 1%.

Pyrite and pyrrhotite form a definite lineation in the rock. This texture may reflect the smeared out pyrite (observed in hand specimen) along cleavage and fracture planes.

Sample 7126(1) & (2)   Similar to 7125 samples with much less total mineralization.

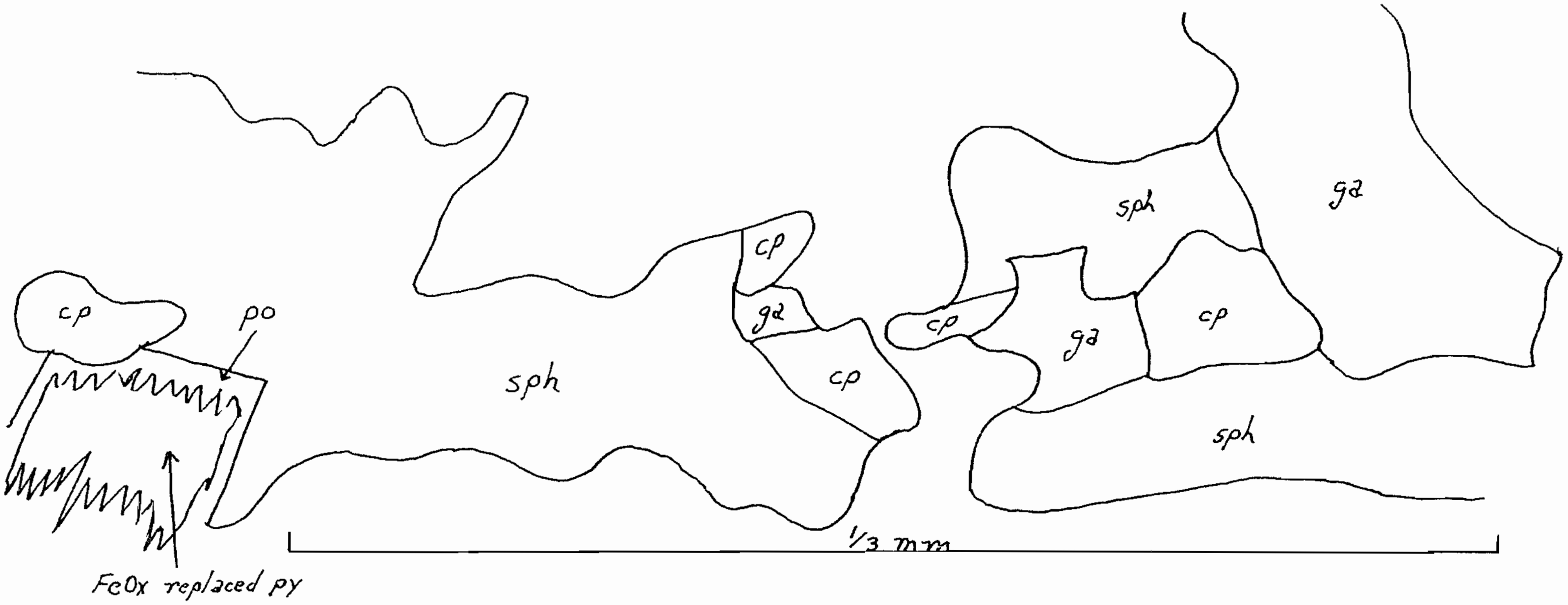
Sample 7126B   Two large (1/3 mm) anhedral chalcopyrite grains fill areas between hornfels breccia fragments. Chalcopyrite also is found as anhedral, 1/30 mm grains mainly in fractures in the breccia. The chalcopyrite amounts to <<1%.

Pyrite is found in trace amounts only.

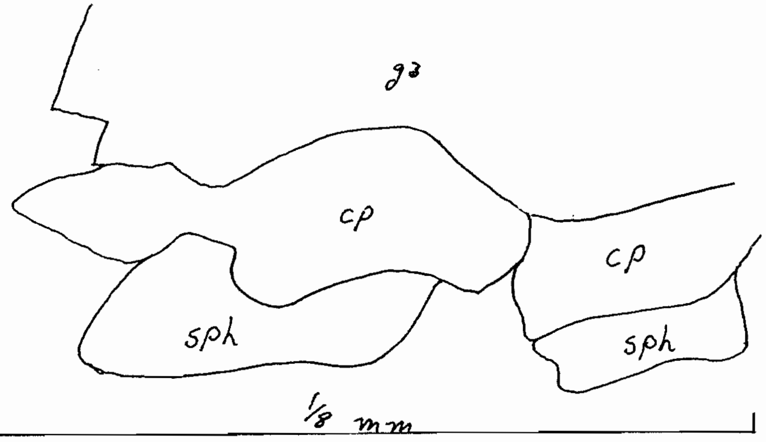
Titanium oxide and ilmenite are disseminated throughout the hornfels, and amounts to <<1% of the total.

12. GEORGEVILLE COPPER OCCURRENCE #1

Sample 7060H   Large mutual boundary intergrowths of sphalerite-chalcopyrite-galena-pyrrhotite are found throughout.

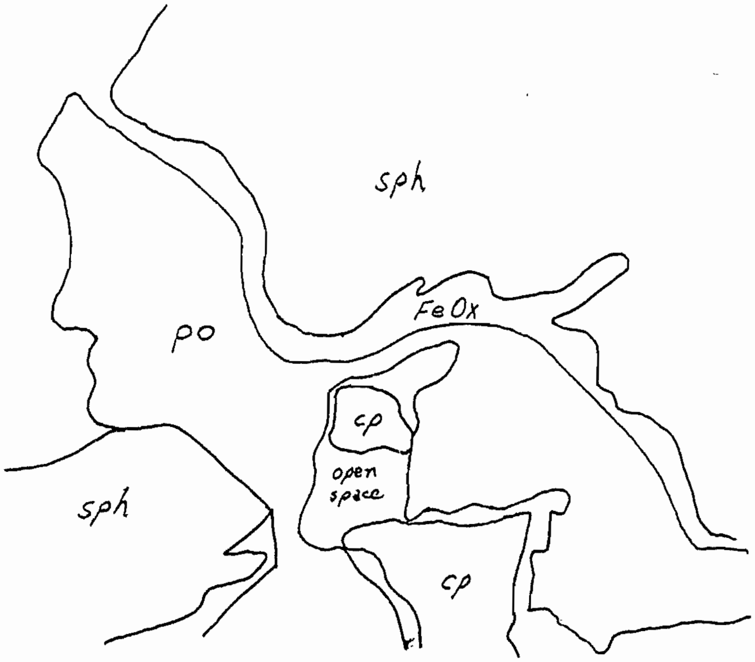


cp
po
sph
cp
ga
cp
sph
ga
cp
ga
cp
sph
FeOx replaced py
1/3 mm

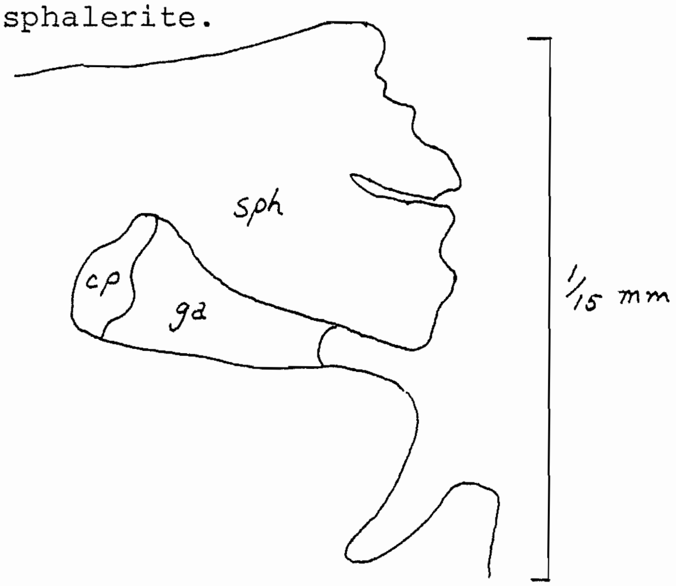


ga
cp
cp
sph
sph
1/8 mm

Some suggestion of replacement is seen as pyrrhotite appears to fill large spaces in sphalerite and chalcopyrite fills spaces in pyrrhotite.



Galena and chalcopyrite also appear to fill gaps in sphalerite.



Sphalerite occurs as anhedral, 1/2 x 1 mm up to 2 mm and 1/20 - 1/5 mm grains associated with fractures and open spaces in the rock. Chalcopyrite is usually associated with the sphalerite.

Pyrrhotite forms mainly as 1/2 mm anhedral discrete grains in fractures with sphalerite. Pyrrhotite and pyrite are also found disseminated throughout the hornfels and in 1/30 mm wide fracture fillings.

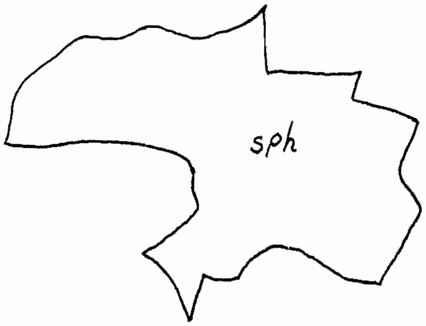
Galena occurs as 1/20 - 1/10 mm anhedral grains found exclusively with other sulfide mineralization in the fractures.

Rutile occurs as 1/50 - 1/30 mm rounded grains disseminated evenly throughout the hornfels in quantities of about 3%.

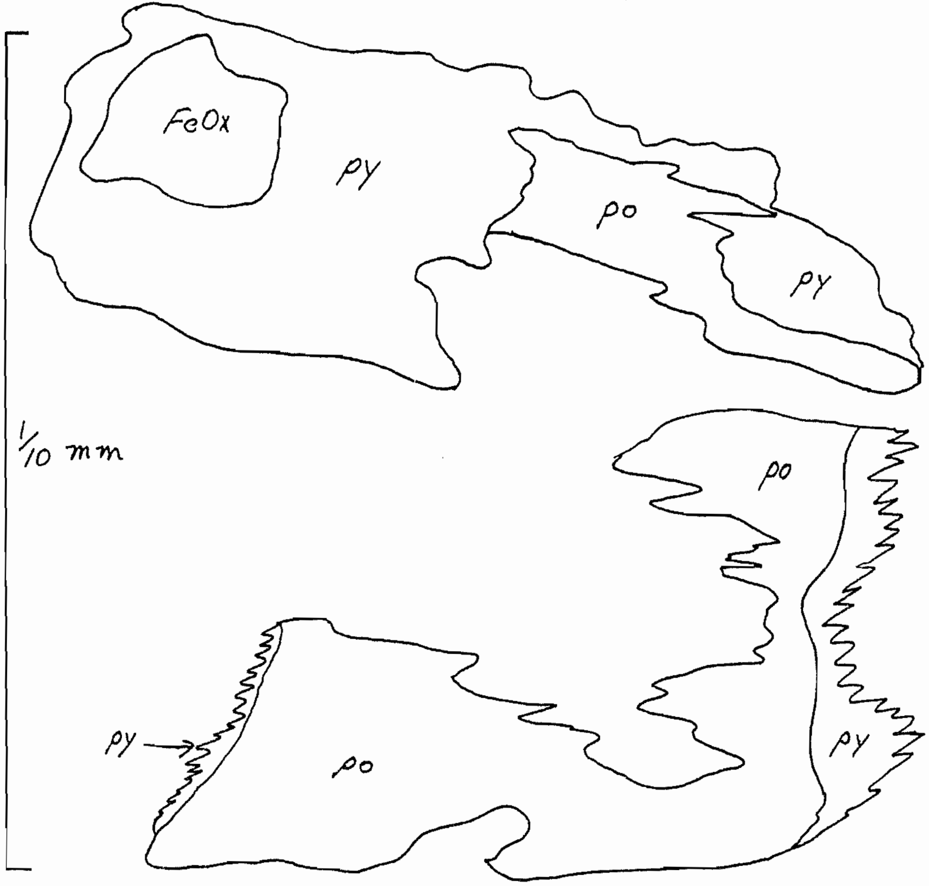
Visual Modal Estimate:

Sphalerite	3%
Pyrite-Pyrrhotite	3%
Chalcopyrite	<<1%
Galena	<<1%
TiO_2	3%

Sample 7060F Sphalerite occurs as 1/10 - 1/20 anhedral grains in fractures in the diorite. The sphalerite may show sharp straight boundaries in some cases.



Pyrite and pyrrhotite are disseminated throughout and also found in stringers. Pyrrhotite occurs discretely as 1/10 mm anhedral grains making up <<1% of the slide. A few pyrite-pyrrhotite irregular intergrowths are present.



Sphene is found disseminated throughout.

Visual Modal Estimate:		
	Pyrite	2%
	Pyrrhotite	<1%
	Sphalerite	2-3%
	Chalcopyrite	traces
	Sphene	5-10%

Sample 7060G Sphene accounts for about 10% of the slide. Corroded, 1/20 - 1/10 mm pyrite shells are disseminated throughout and make up about 5% of the rock.

Traces only of 1/20 mm chalcopyrite grains are found.

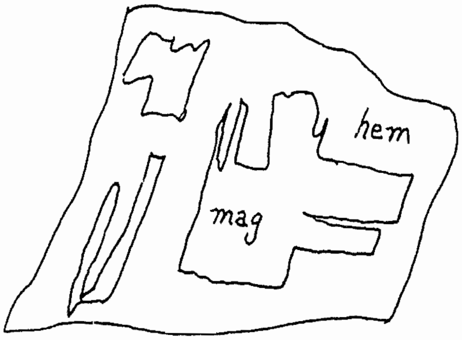
Some pyrite is found in stringers.

Sample 7060E Pyrite occurs as euhedral (cubes) to subhedral 1/50 - 1/10 mm grains in amounts of 1%. This sample of the diorite shows much less alteration and very few fractures.

Traces of 1/50 mm chalcopyrite grains are present. Some rutile is associated with chlorite.

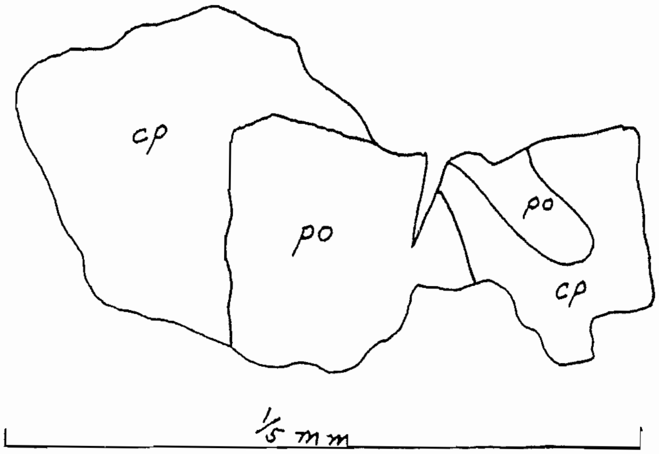
Sample 7064 This sample probably represents a volcanic xenolith in the diorite.

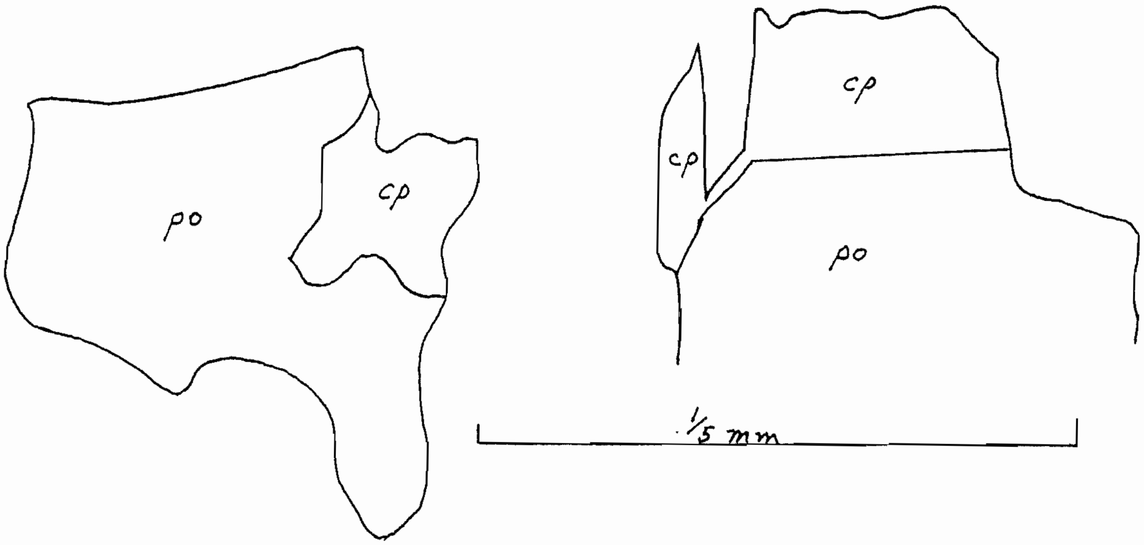
Hematite, with much magnetite, occurs as subhedral to anhedral, <1/100 - 1/10 mm grains disseminated throughout and making up 10-15% of the slide.



The hematite is exclusively associated with chlorite.

Sample 7061 Pyrrhotite and minor pyrite are found as 1/50 - 1/5 mm grains disseminated mainly in the finer grained areas of the diorite and constituting 10-15% of the slide. Pyrite interiors are generally corroded forming pyrite shells while pyrrhotite is mainly solid and may reach 1 mm in size. In some cases pyrrhotite forms intergrowths with chalcopyrite.

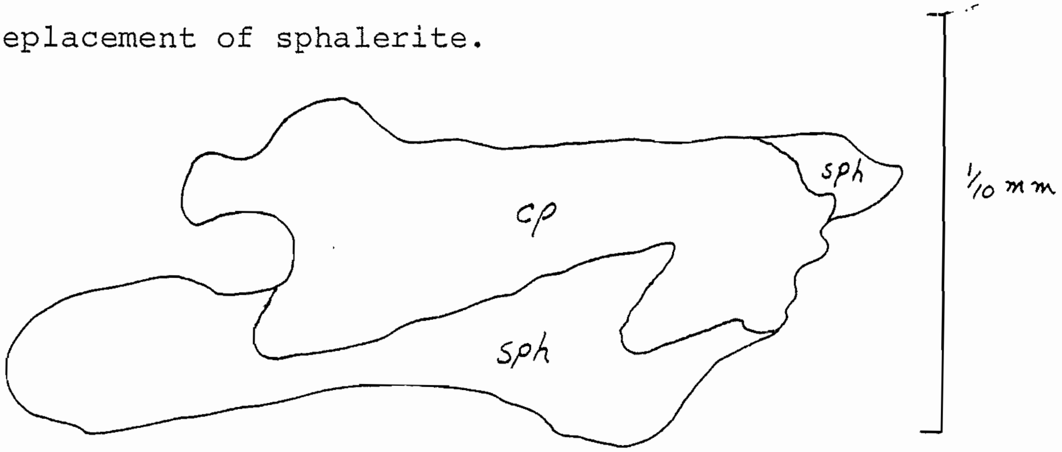




Pyrrhotite typically fills space between diorite grains, and appears as a matrix for the grains.

Sample 7061A   Alternating pyrite and iron oxide bands rim some pyrrhotite grains. All else is the same as Sample 7061.

Sample 7066   Anhedral, 1/20 - 1/30 mm chalcopyrite grains is found in trace amounts. Traces of 1/50 mm grains of pyrite are also evident. One chalcopyrite-sphalerite mutual boundary intergrowth suggests chalcopyrite replacement of sphalerite.



This intergrowth is found in a 1/20 mm quartz vein.

Ilmenite occurs as anhedral, 4/10 mm grains in amounts of <<1%. Pyrrhotite occurs as in other slides of this occurrence in proportions of <1%. Two 1 mm magnetite grains are also present.

13. BALLANTYNES COVE COPPER OCCURRENCE

Sample 7003 Pyrite is found as anhedral to subhedral, 1/100 - 1/20 mm grains disseminated evenly throughout and makes up 5% of the slide.

Covellite occurs as 1/50 - 1/20 mm grains disseminated throughout the matrix of the sediment and makes up <<1% of the slide. It also commonly fills fractures in pyrite.

Rutile is found in minor amounts in the slide.

20. PITCHERS FARM COPPER OCCURRENCE

Sample 7047 Anhedral, 1/50 - 1/20 mm, chalcopyrite grains, rimmed by iron oxide are found in trace amounts in this green quartzite.

Pyrite is found as 1/50 mm, anhedral grains in trace amounts only.

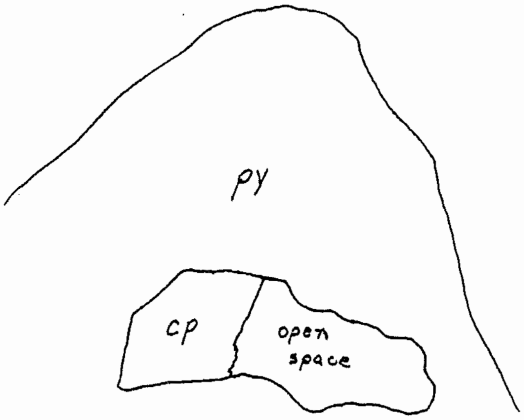
Some titantium oxide is disseminated throughout.

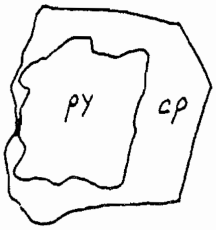
23. BLUE MOUNTAIN COPPER OCCURRENCE

Sample 7180 Hematite occurs as <1/100 - 1/20 mm grains disseminated evenly throughout the sericite-chlorite band in the quartz vein. The hematite constitutes 2% of the band.

The quartz vein, which occupies 80% of the slide, is devoid of mineralization.

Sample 7181 Pyrite occurs as subhedral to anhedral, 1/50 - 1/2 mm grains. One trace of chalcopyrite is found in an open area of a pyrite grain. In another case, chalcopyrite surrounds pyrite. Paragenesis is not conclusive.





Pyrite amounts to <<1% of the slide.

Sample 7188 Quartz, which occupies 50% of the slide, contains no mineralization.

The slatey allignment of platey minerals in the slatey argillite (50% of slide) decreases very conspicuously away from the quartz vein. The argillite is also darker closer to the quartz.

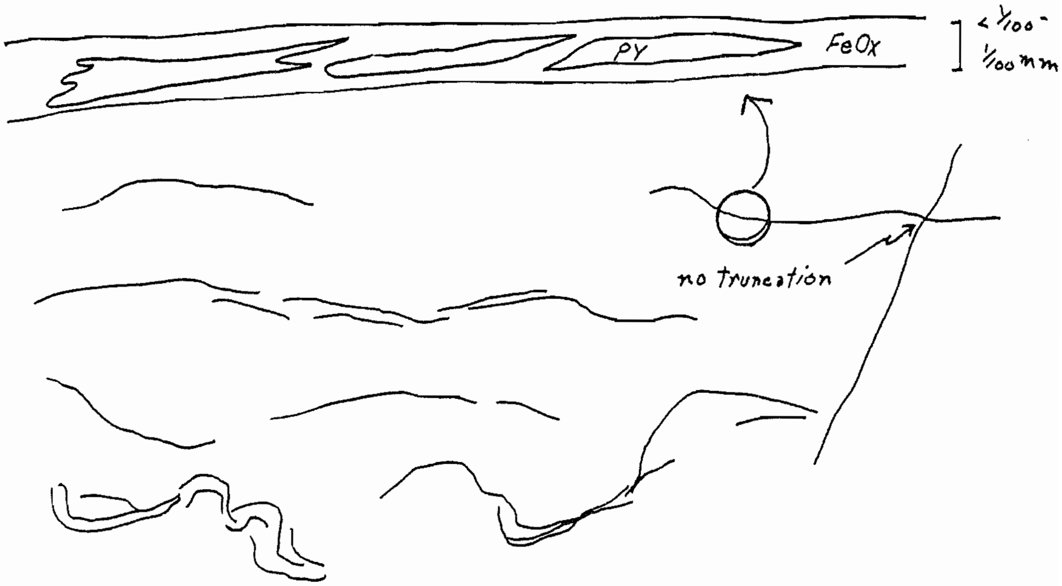
Pyrite concentrates in the argillite within 3 mm of the quartz vein, along the quartz-argillite contact. The pyrite is found as mainly <1/100 mm but in some cases 1/50 mm anhedral to euhedral grains making up 50% of the pyrite content. The remaining pyrite occurs as 1/50 mm framboids.

25. CAPE GEORGE COPPER OCCURRENCE

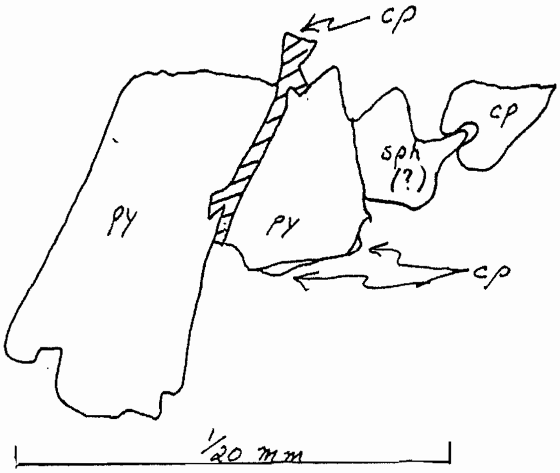
Sample 7057(1) & (2) Pyrite occurs as <1/00 - 1/20 mm anhedral grains disseminated evenly throughout the slide. The pyrite is also found as very finely disseminated grains making up tiny stringers.

Chalcopyrite is found as 1/50 mm anhedral discrete grains making up <<1% of the rock.

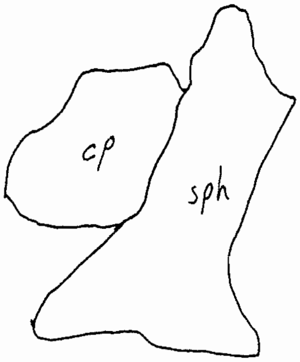
Most of the pyrite stringers are subparallel and consist of elongated pyrite grains.



Chalcopyrite is found filling voids and fractures in pyrite.



One chalcopyrite-sphalerite mutual boundary intergrowth is present.



Visual Modal Estimate:	Pyrite	1%
	Chalcopyrite	traces
	Sphalerite	traces
	TiO_2 & Ilmenite	1%

26. LAKEVALE BARIUM OCCURRENCE

Sample 7261 Pyrite is found as anhedral, 1/50 - 1/20 mm brecciated grains disseminated throughout the carbonate matrix in quantities of about 1%. Some iron oxide is also found in the matrix.

Sample 7255 The limestone breccia contains traces of pyrite, including a few framboids. Traces of titanium are also found throughout.

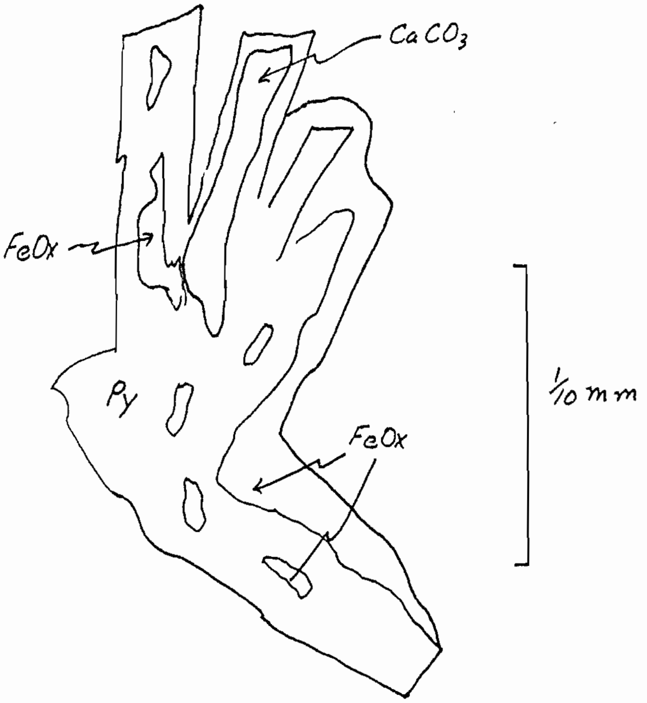
Sample 7263(1) The limestone contains pyrite framboids and anhedral brecciated <1/100 - 1/10 mm corroded grains of pyrite. Pyrite constitutes about 1% of the slide.

One, 1/100 mm chalcopyrite grain is present.

Some titanium oxide is present in minor amounts.

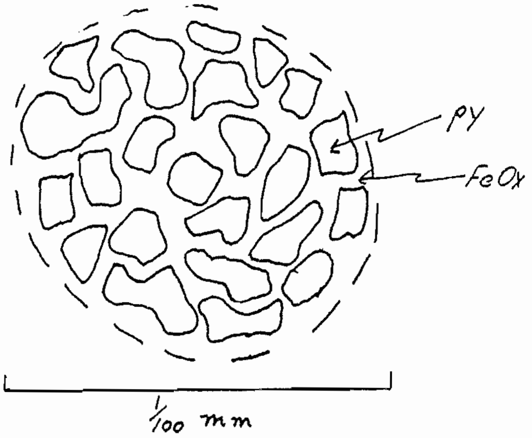
Sample 7262 Pyrite constitutes 1-2% of the limestone-sandstone transition zone and is commonly found as framboids.

It also replaces what appears to be relict feldspar laths.

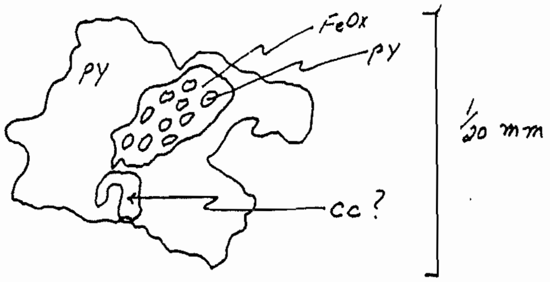


Traces of zircon or sphene are evident.

Typical pyrite framboid texture:



Sample 7263(2) & (3)   Same textural descriptions as Sample 7263(1). Trace amounts of a whitish grey mineral, possibly chalcocite, are found within rare sphalerite and in some pyrite.



The mineral is too small for positive identification.

29. BIG MARSH BARIUM OCCURRENCE

Sample 7280   Some iron oxide is present. No sulfides in slide.

Sample 7279   Iron oxide forms 1/100 - 1/30 mm, pseudo-cubic shaped relict pyrite grains in amounts of about 2%. A few pyrite grains are present in some of the iron oxide masses.

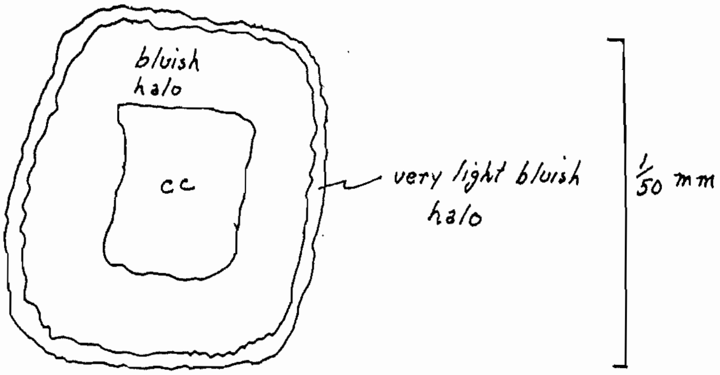
Sample 7276   This limestone sample contains corroded, anhedral, 1/50 mm pyrite grains forming 1% of the slide. The pyrite is distributed mainly along laminations. No pyrite framboids were observed.

Rutile grains are present in trace amounts.

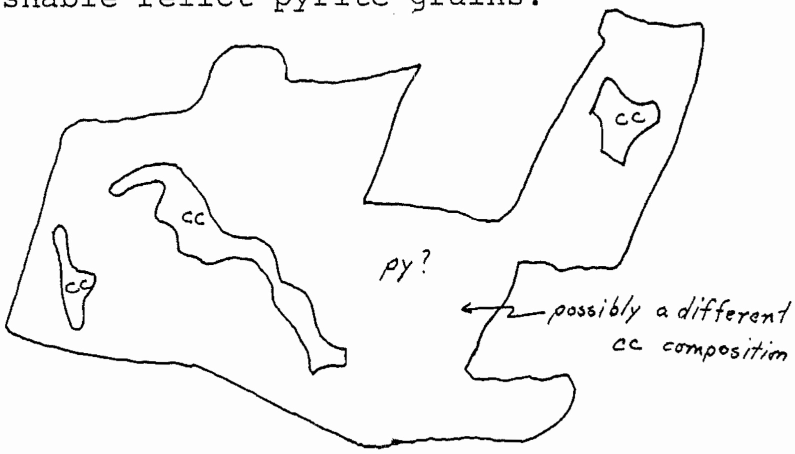
32. McISAAC POINT BARIUM & LEAD OCCURRENCES

Sample 7267 Pyrite is found in the limestone breccia as 1/100 - 1/20 mm anhedral, brecciated grains in amounts of about 1%. Much of the pyrite is distributed in layers parallel to bedding.

Sample 7296 Chalcocite occurs as 1/50 - 1/40 mm anhedral grains disseminated throughout the limestone in amounts of about 2%. All of the chalcocite is rimmed by bluish chalcocite semi-transparent halos.

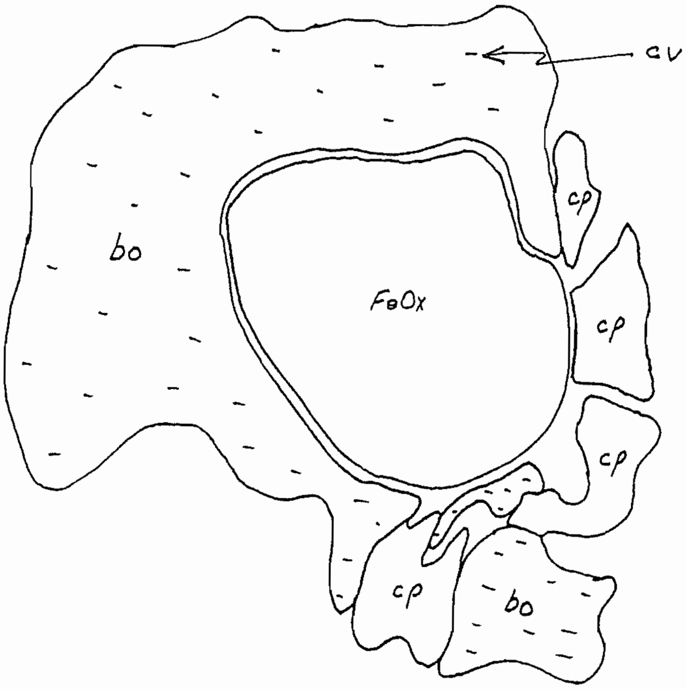


Some chalcocite blebs are found within grey, readily tarnishable relict pyrite? grains.

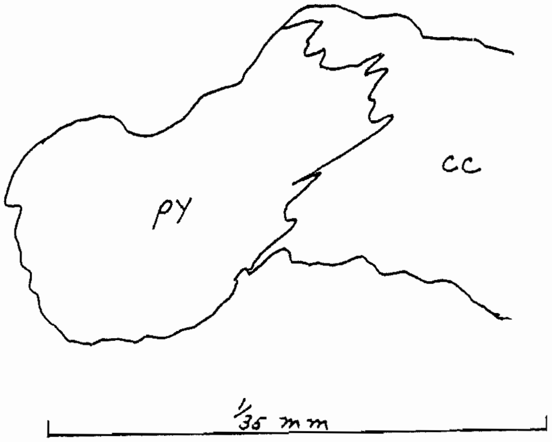


The masses may represent copper and iron oxidation products.

One bornite-chalcopyrite-covellite intergrowth is present. The texture vaguely suggests contemporaneous growth.



Some irregular pyrite-chalcocite intergrowths are evident.



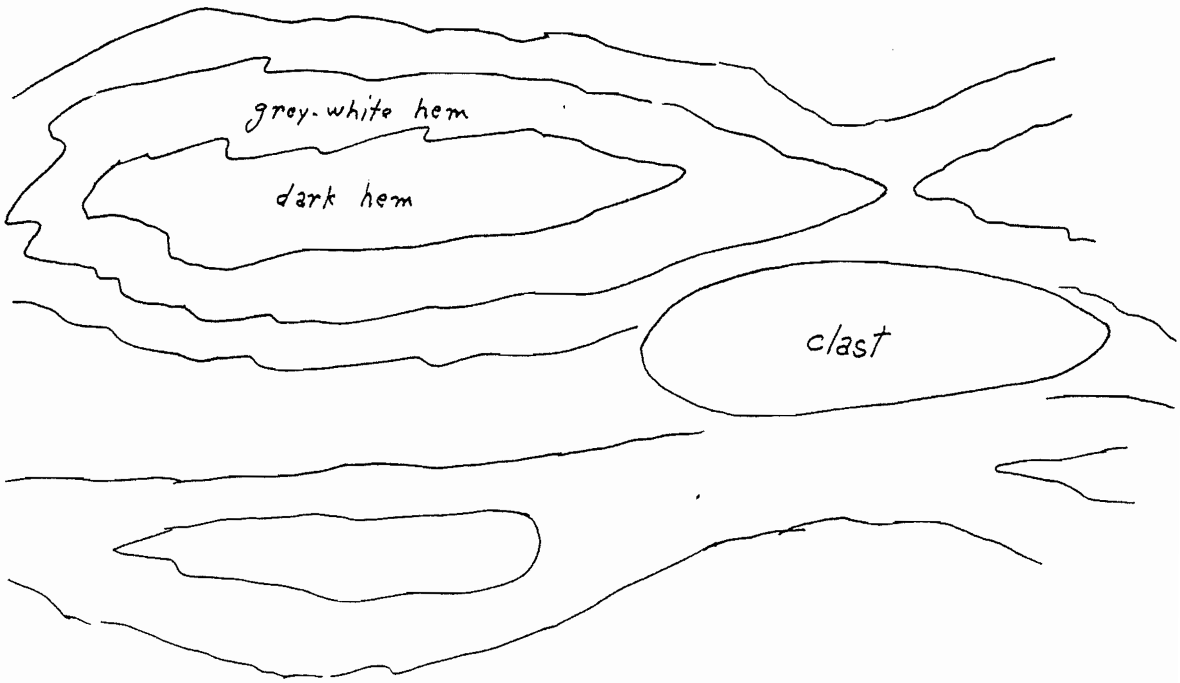
Pyrite commonly occurs as 1/50 mm framboids disseminated evenly throughout, in amounts of about 2%.

One bornite-chalcocite intergrowth is also present.

Visual Modal Estimate:	Chalcocite	2%
	Pyrite	2%
	Copper	traces
	Bornite	traces
	Chalcopyrite	traces

36. ARISAIG BROOK IRON OCCURRENCE

Sample 7410 Hematite makes up the matrix of the ironstone. Grey-white hematite forms lens shells filled by dark hematite.



Also see Plate IV-1.

Visual Modal Estimate:	Hematite	75&
	Quartz Clasts	25%

37. ARISAIG IRON DISTRICT, IRON OCCURRENCES

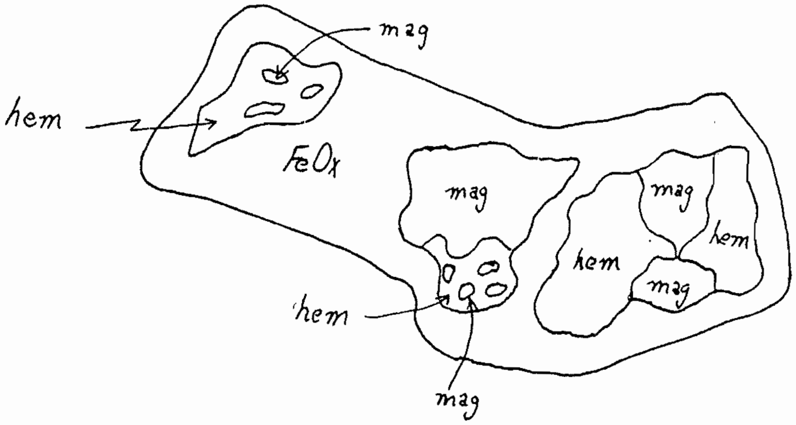
Sample 7422 Hematite forms a solid matrix of the ironstones. About 10% of the hematite is whitish-grey 1/100 - 1/10 mm grains.

Cherty bands (see Sample 7422, Appendix II-B) contain thin layers of reddish iron oxide parallel to bedding of the chert. (See Plate IV-1).

44. MOOSE RIVER IRON OCCURRENCE

Sampel 7347 Hematite forms large (1/3 - 1 mm) laths following discontinuous calcite veins and empty fractures in the volcanics (Plate A-I-2). The lathes represent cross sections of basal hematite plates (Ramdohr 1969). The laths commonly show curved lamelli.

Hematite is also disseminated throughout the matrix of the tuffaceous volcanics. Magnetite makes up about 25% of the disseminated hematite.

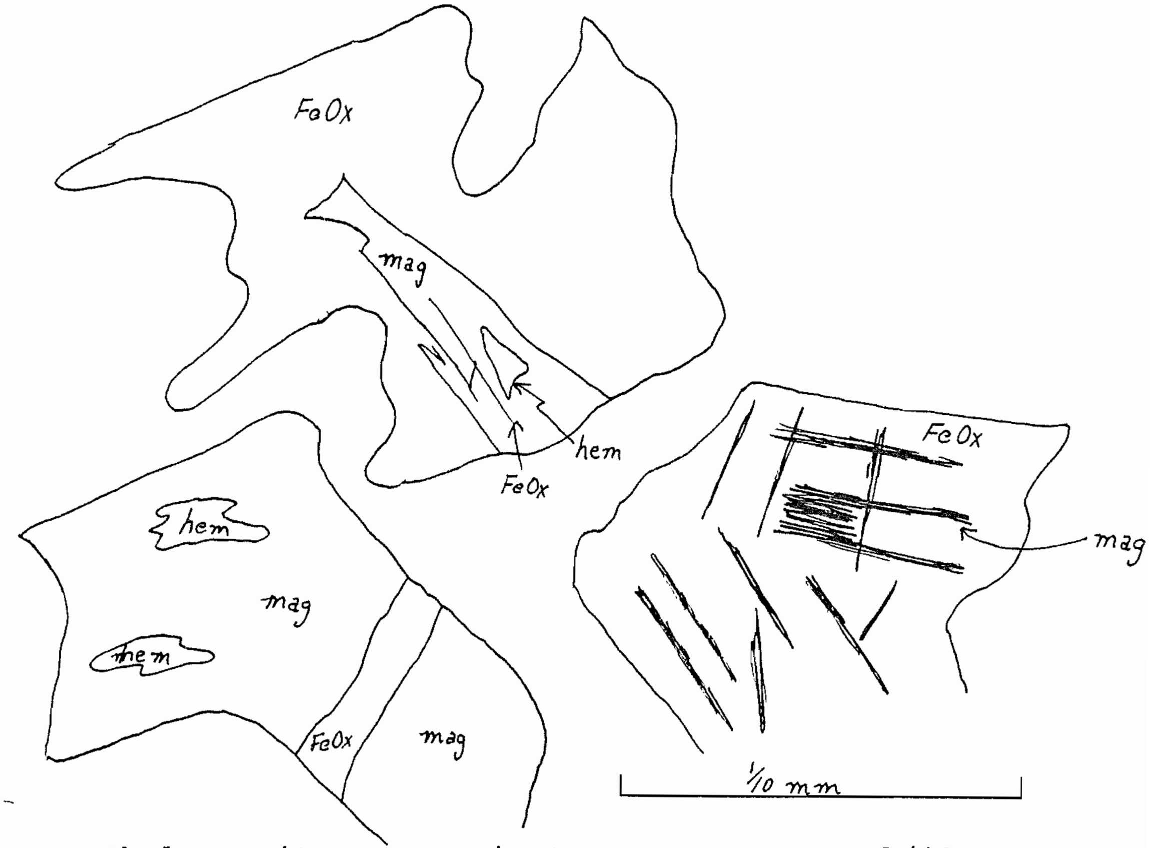


Traces of chalcopyrite are found as 1/100 mm grains in the matrix. One grain is found partially in a quartz grain and partially in the matrix. Another contains a trace of pyrite.

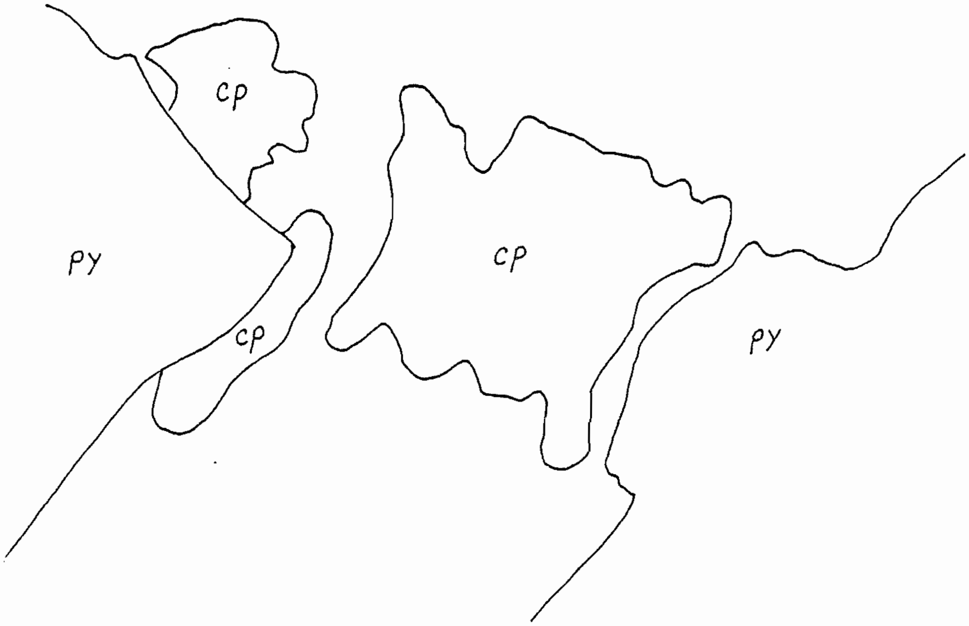
Hematite totals 5% of the slide.

Sample 7350 Hematite occurs as grains disseminated throughout in quantities of about 1%.

Sample 7348 Magnetite occurs as subhedral to euhedral 1/20 mm (up to 1/20 x 1/2 mm) grains containing minor magnetite. The magnetite is usually associated with a mass of iron oxide products in chlorite masses. Total iron oxides account for 15% of the slide, 5% of which is magnetite and <<1% hematite.

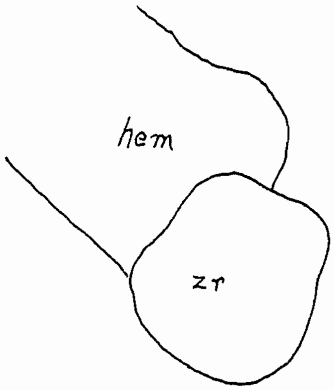


Chalcopyrite occurs in trace amounts as 1/40 mm masses which appear to replace feldspar laths in many cases. Pyrite is also found replacing feldspar laths (<<1%). In one case, chalcopyrite appears to form around pyrite.

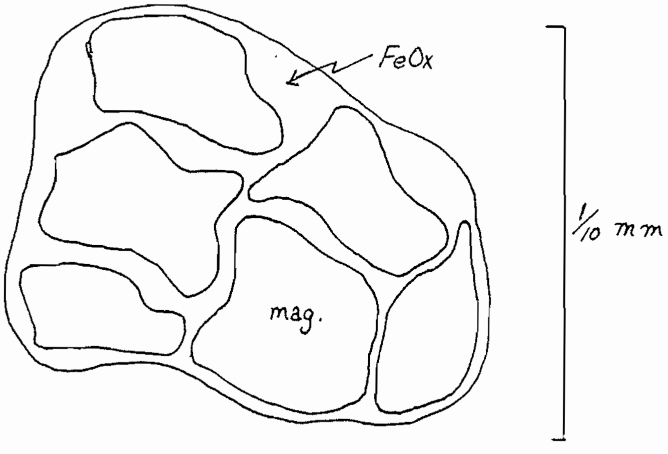


Sample 7360 Bimodal size range (<1/100 mm and 1/10 - 1/15 mm) of hematite is found. The hematite occurs as anhedral grains (constituted by about 5% magnetite) in iron oxide masses.

One zircon-hematite ambiguous intergrowth occurs.



Sample 7356 Magnetite forms 5-7% of the schistose rock. It occurs as anhedral to subhedral, 1/10 - 1/5 mm in a few cases, up to 1/2 mm grains disseminated throughout. Minor hematite grains are present.



One 1/40 mm chalcopyrite grain in an iron oxide mass in chlorite is present. One pyrite grain (1/40 mm) occurs in a similar texture.

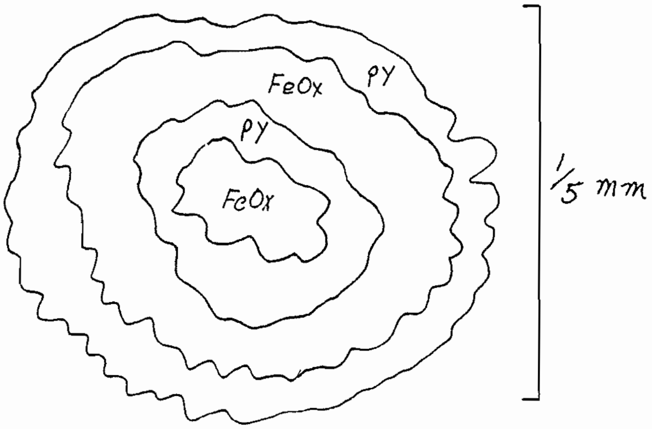
A few 1/20 mm zircon grains are present in the matrix.

45. BEAVER LAKE IRON OCCURRENCE

Sample 7363(1) The diorite contains 1/20 - 1/2 mm anhedral grains of pyrrhotite which constitute about 1/4% of the slide.

Chalcopyrite occurs as 1/20 mm grains in trace amounts only.

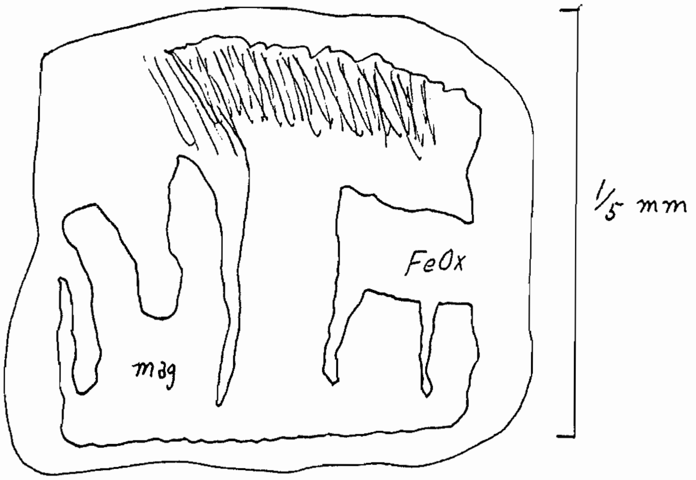
Pyrite is found as 1/15 mm cubes and 1/5 mm rings alternating with iron oxide.



Some pyrrhotite has replaced hornblende grains. One pyrrhotite-galena intergrowth was observed, however its paragenetic relationship remains ambiguous.

Sample 7363(2) This diorite slide shows much more alteration of feldspars and mafic minerals.

Magnetite constitutes about 7% of the slide. It occurs as 1/10 - 1/5 mm very corroded anhedral to subhedral grains disseminated throughout.



48. SILVER MINE LEAD OCCURRENCE

Sample 7452B Pyrite occurs as 1/5 - 1/10 mm euhedral grains distributed only in finer grained (1/50 - 1/100 mm) quartzite. Boundaries into coarser grained (1/20 - 1/50 mm) quartzite is gradational. Many of the pyrite grains form perfect cubes.

A few (three) tiny chalcopyrite inclusions in pyrite are present. The rare intergrowth is characterized by mutual boundary texture.

MISCELLANEOUS RELATED OCCURRENCES

CAPE JACK COPPER-LEAD OCCURRENCE

Sample 7438 The sandstone contains some minor hematite in some cases intergrown with ilmenite. Other iron and titanium oxides are disseminated throughout the matrix.

Sample 7437 Pyrite is commonly found as 1/50 mm framboids and framboid-like mozaic textures disseminated throughout. Pyrite constitutes <1% of the limestone.

One complex intergrowth of covellite-tennantite-bornite-chalcopyrite-sphalerite-galena-pyrite is found (Plate V-27). Paragenesis cannot be determined. A few other intergrowths with some of the above minerals are also found.

Pyrite commonly (1%) occurs as 1/50 mm framboids. Rutile forms as 1/50 mm grains disseminated throughout.

A calcite vein contains a trace (<1/100 mm) of chalcopyrite.

CAPE BLUE COPPER-LEAD OCCURRENCE

Sample 7440(1) Sphalerite occurs as 1/50 mm grains disseminated in trace amounts in the limestone.

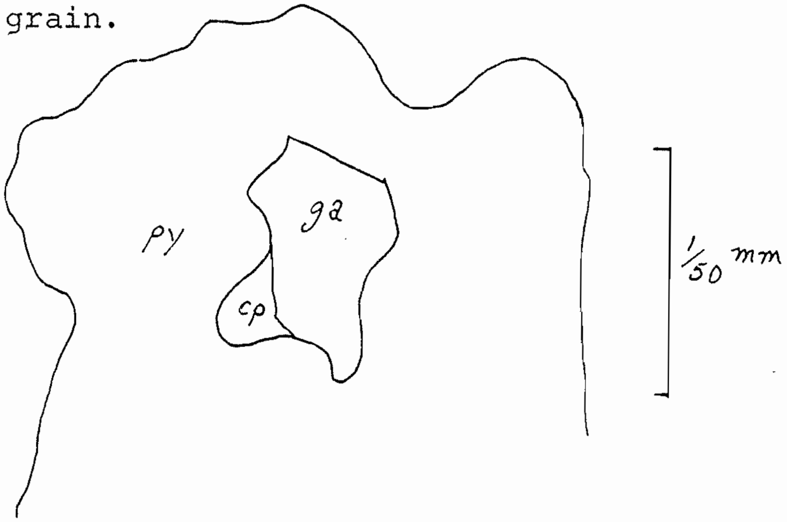
Pyrite occurs as tiny framboids making up about 1% of the slide. Some of the pyrite is concentrated in indistinct 2 mm bands. One band is cut by a calcite vein.

On 1/50 mm chalcopyrite grain is present.

Sample 7440(2) No metallic mineralization is found in the calcite vein.

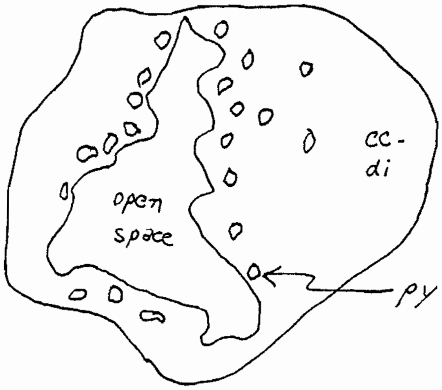
Pyrite framboids (1/100 mm) are found disseminated throughout the limestone is amounts of about 1%. Titanium oxide grains (1/100 mm) are found in trace amounts. Pyrite is also found as corroded grains up to 1/5 mm.

One chalcopyrite-galena intergrowth appears to replace a pyrite grain.

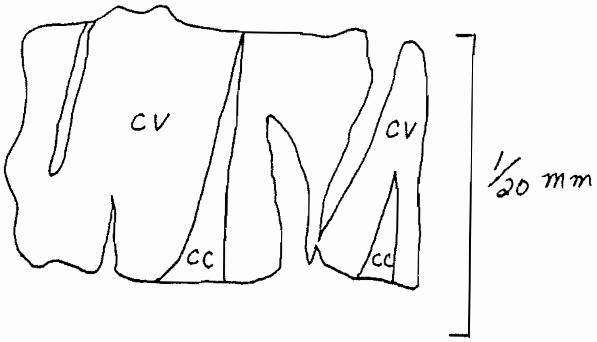


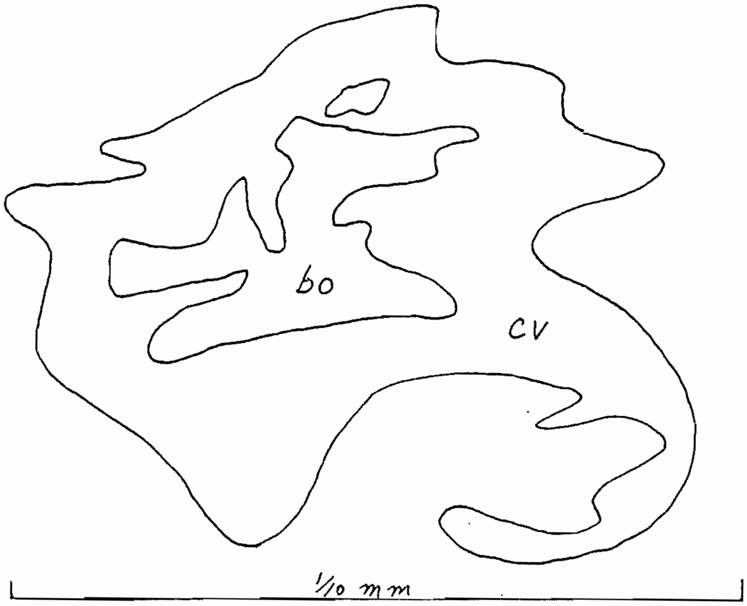
Textural differences in pyrite are seggregated parallel to the limestone laminations. Pyrite grains accounting for 1-2% of the upper 1/4 of the slide give way to predominantly pyrite framboids making up <1% of the other 3/4 of the slide.

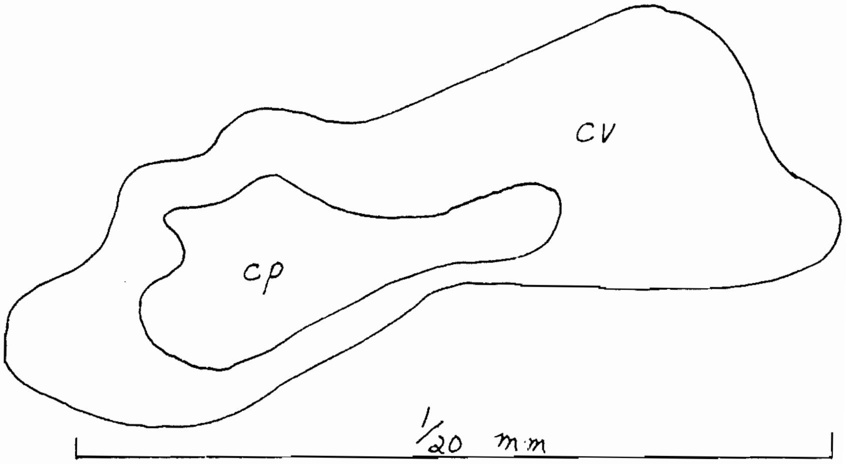
Sample 7442 Chalcocite with minor digenite occurs as 1/10 - 1/20 mm discrete grains found in the limy matrix of the sediments. Pyrite is found associated with some digenite-chalcocite.



Discrete grains of lamellar covellite as well as covellite on digenite boundaries are found throughout. Some covellite is also associated with chalcocite, bornite or chalcopyrite.


cv
cv
cc
cc
1/20 mm

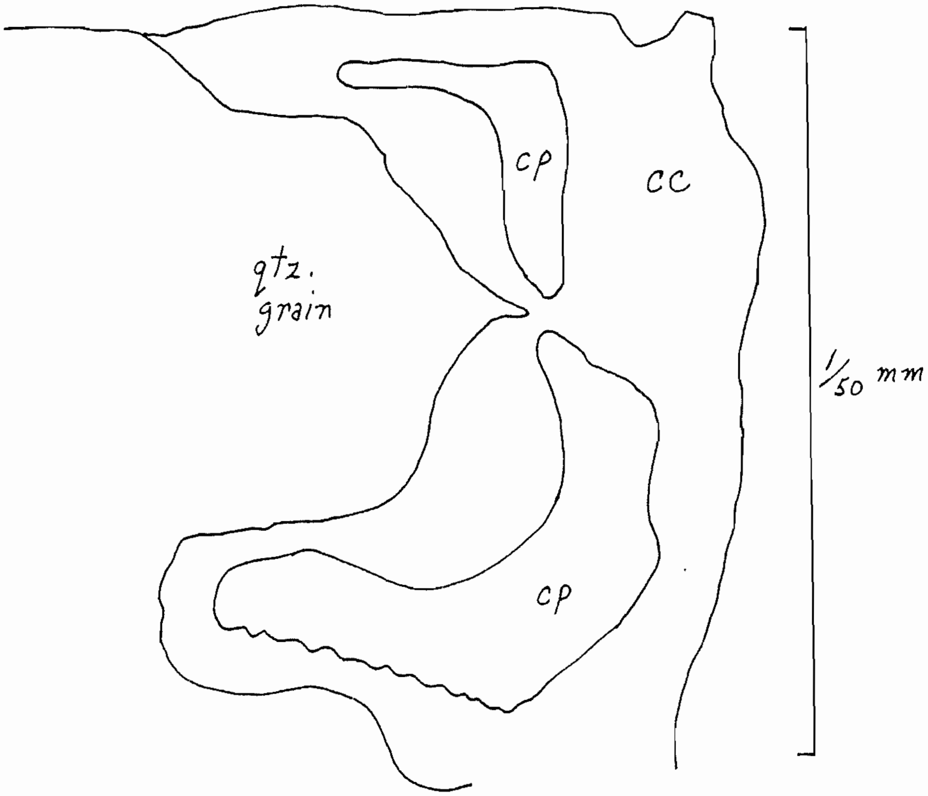

bo
cv
1/10 mm

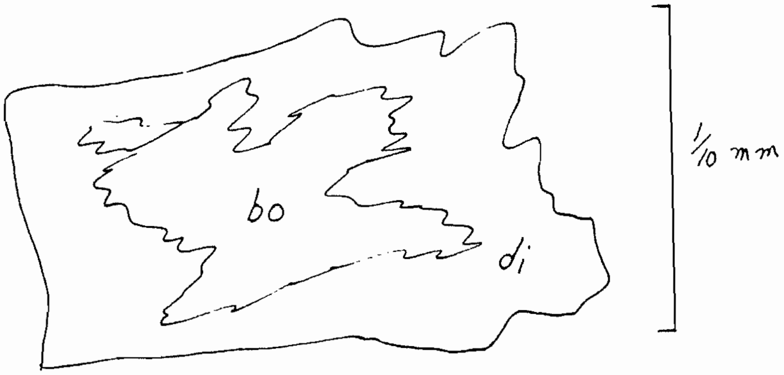

cv
cp
1/20 mm

Pyrite is found exclusively in digenite, not chalcocite.

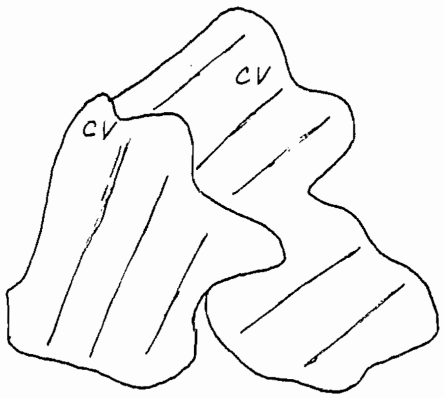
Titanium oxide grains (1/50 - 1/20 mm) are disseminated evenly throughout and account for about 1% of the slide.

Other intergrowths include chalcopyrite-chalcocite and bornite-digenite.





Discrete covellite grains commonly show shrinkage cracks and in some cases distinguish differently oriented grains in one mass.

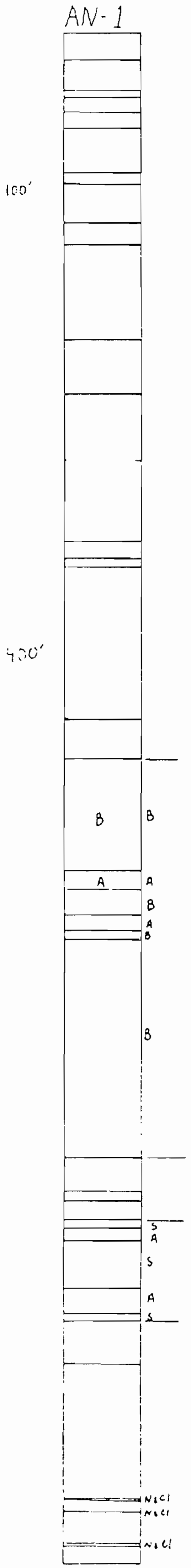


Sulfide minerals commonly form around detrital quartz clasts. The sulfides are disseminated evenly over the slide.

Visual Modal Estimate:	Copper Sulfides	1-2%
	Chalcopyrite	traces
	Bornite-Chalcocite- Copper-Digenite	about even proportions

APPENDIX III

DIAMOND DRILL HOLE LOG SUMMARY



Overburden

Siltstone, red

Sandstone, red + grey

Siltstone, red + grey

Sandstone, red + grey

Siltstone, red

Sandstone, red

Siltstone + sandy siltstone, red + grey

Shale, red

Siltstone + sandstone, red + grey

Siltstone, brecciated, red + grey, gyp stringers py, cp, qz fractures

Shale, some calcareous; dark grey

Limestone, black laminated

Siltstone, green, brecciated

Siltstone breccia, red + green, gyp cement

Anhydrite, grey, laminated

Siltstone breccia + anhydrite, interbedded; some gyp veinlets + cement
red + green grey

Sandstone, red

Anhydrite

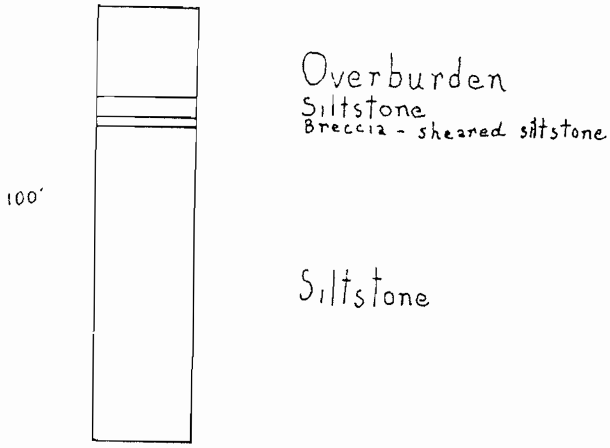
Breccia (siltstone), some anh. cement

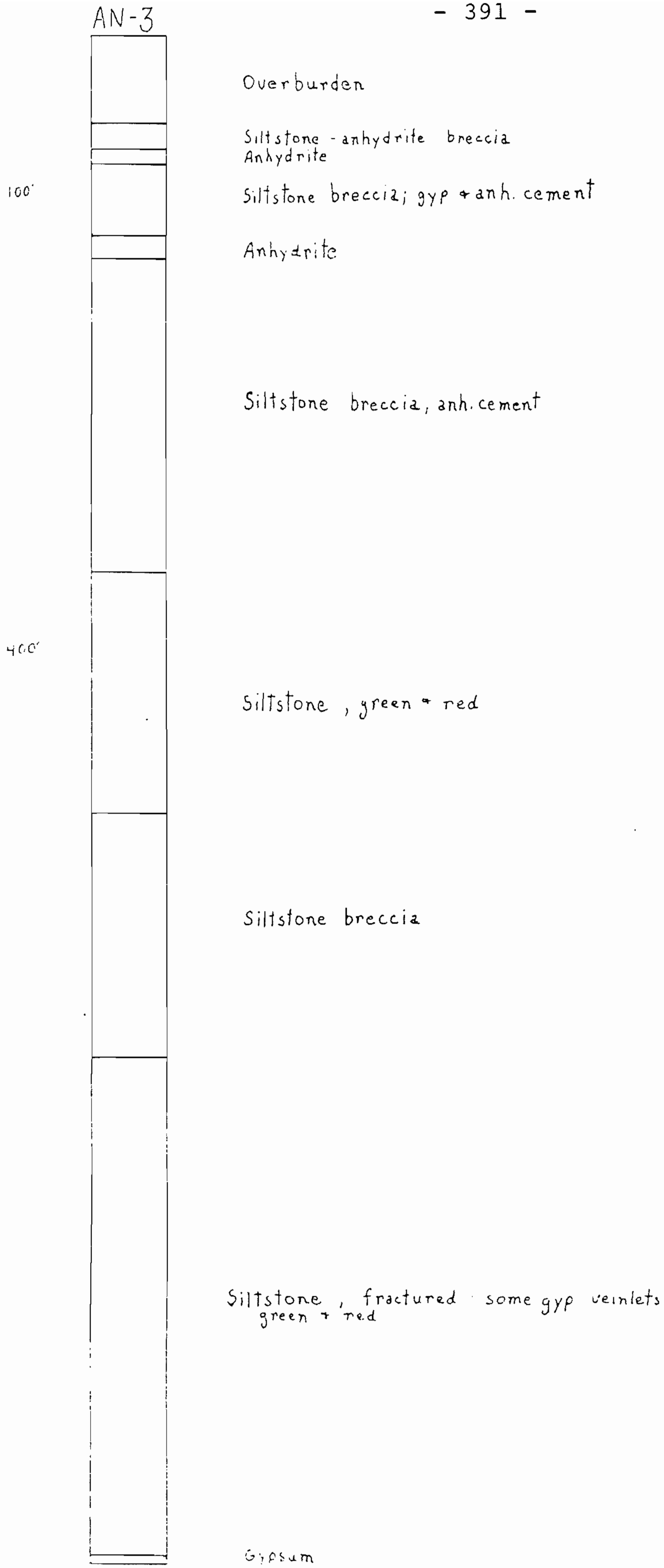
Siltstone, red + grey, some gyp veinlets & Anhydrite, grey massive

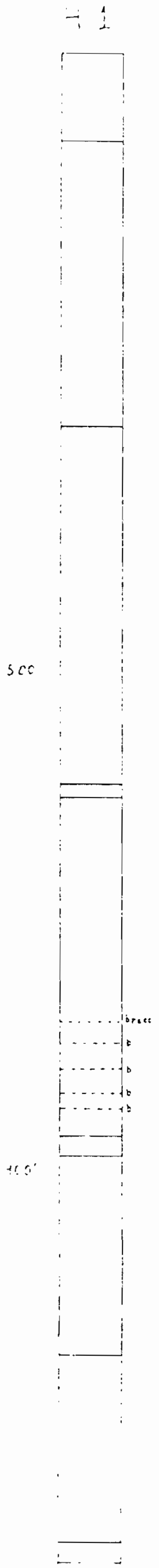
Siltstone breccia, green + red, anh. cement

Anhydrite, grey, laminated

AN-2


100'
Overburden
Siltstone
Breccia - sheared siltstone
Siltstone


AN-3
100'
400'
Overburden
Siltstone - anhydrite breccia
Anhydrite
Siltstone breccia; gyp + anh. cement
Anhydrite
Siltstone breccia, anh. cement
Siltstone, green + red
Siltstone breccia
Siltstone, fractured some gyp veinlets
green + red
Gypsum



Overburden

Mudstone

Shale, Siltstone, calcareous, laminated, red + grey, very minor lmst ; minor brecciation

Lmst, silty : rare cf

Shale red + grey, minor siltstone calcareous ; minor gyp stringers

← gyp 8'

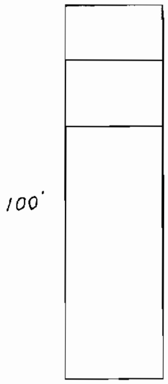
Gyp. Anhy

Shale much brecciated much gyp stringers
red + grey

Salt [illegible], parts

Shale, minor gyp

H 4

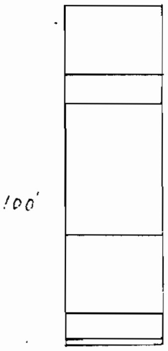


Overburden

Shale, grey + red, slightly calcareous, cp in fractures + calcite veins (in grey sh)

Shale, grey + red, some siltstone

H 3



Overburden

Dolomitic lmst.

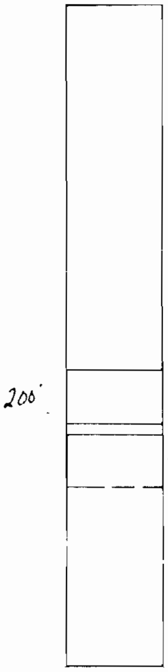
Shale, red, broken, lmst frags.

Clay

Breccia, green, Horton

Basement; Br Mtn.

H 2



Overburden

Lmst. shaly bands

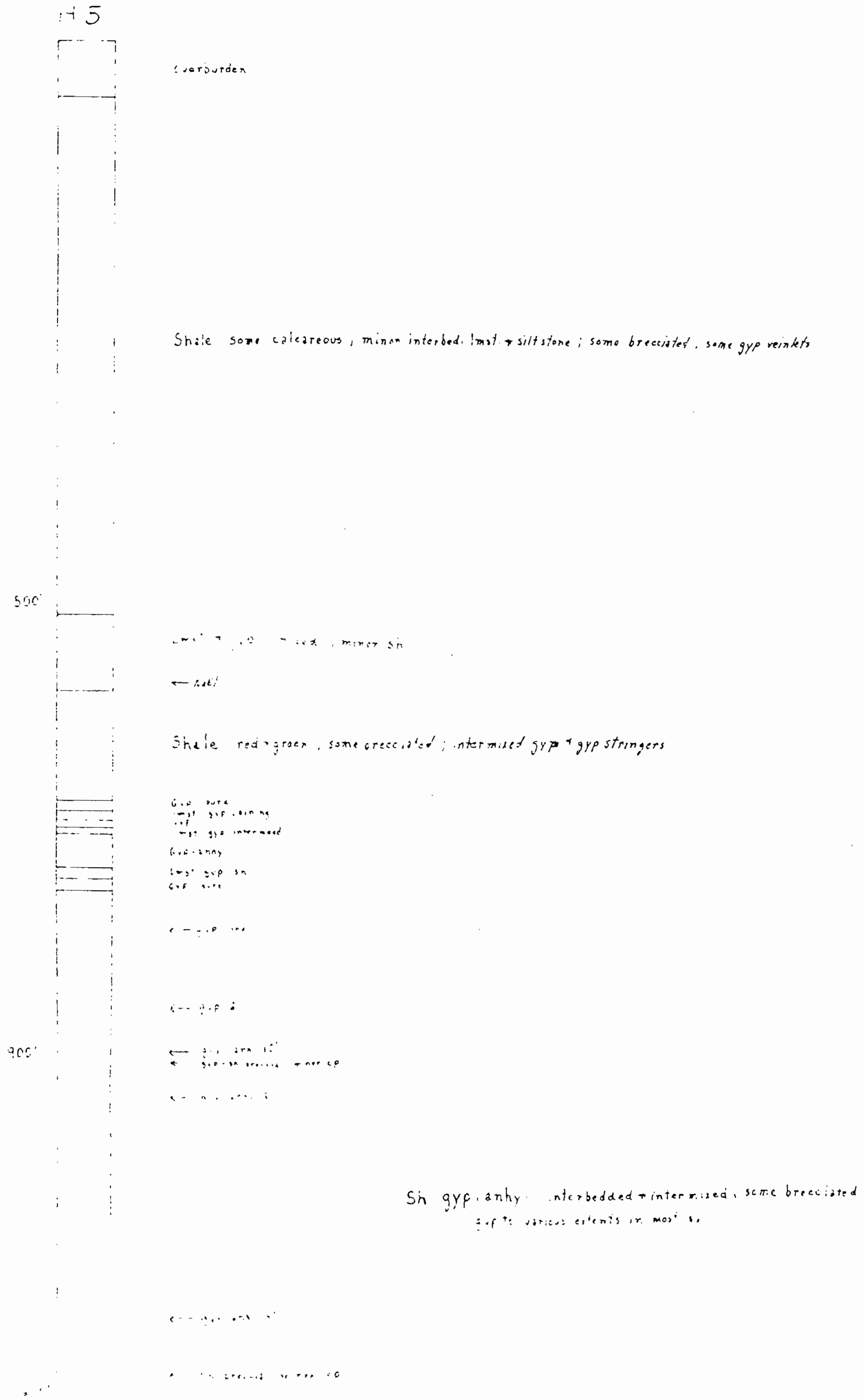
Breccia, $CaCO_3$ cement ~ .2% Cu; cp throughout

volc. calcite veins; som cp in upper sections

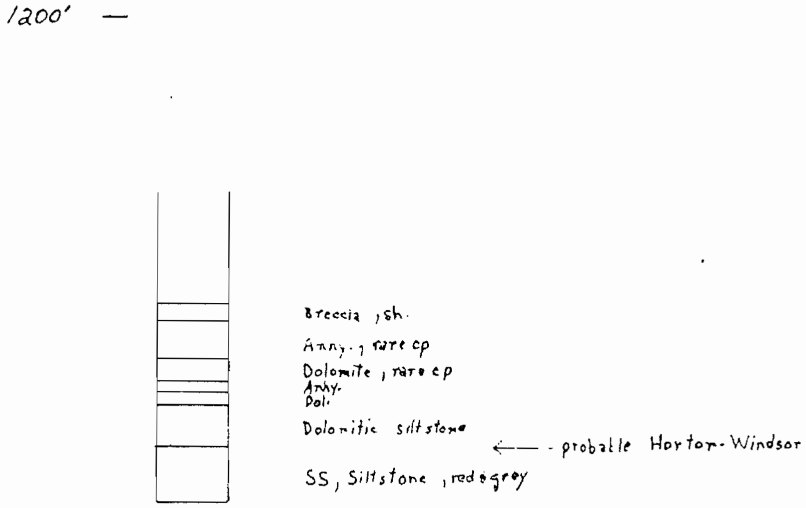
Basement. Br Mtn.

volcs

some brecciated; assays no Cu


H5
Overburden
Shale some calcareous; minor interbed. lmst. + siltstone; some brecciated, some gyp veinlets
500'
Lmst + gyp intermixed, minor sh
← fault
Shale red + green, some brecciated; intermixed gyp + gyp stringers
Gyp pure
lmst gyp veining
lmst gyp intermixed
Gyp + anhy
lmst gyp sh
Gyp pure
← gyp
← gyp
900'
← gyp anh 10'
← gyp-sh breccia + core lp
Sh gyp, anhy, interbedded + intermixed, some brecciated
gyp to various extents in most sh
← gyp anh
← breccia

H-5 con't.


1200'
Breccia, sh.
Anhy., rare cp
Dolomite, rare cp
Anhy.
Dol.
Dolomitic siltstone
← - probable Horton-Windsor
SS, Siltstone, red & grey

H 6

Overburden

Shale red

← oolitic , cp throughout replaces oolites ; .03 % Cu

Lmst sandy , porous

← porous , Cu .02%

Sandstone Shale interbedded ; grey

Lmst , oolitic + brecciated , some cp in calcite veins some dissem. cp.

Lmst. silty ; siltstone beds in upper zone ;
some lmst dolomitic . porous

Congl. calcareous , lmst + sh frags

lmst , dolomitic , porous

SS. Sh + Siltstone ; red + grey

Qtzite , red , broken

lmst silty

Qtzite broken , lmst frags in lower part

lmst

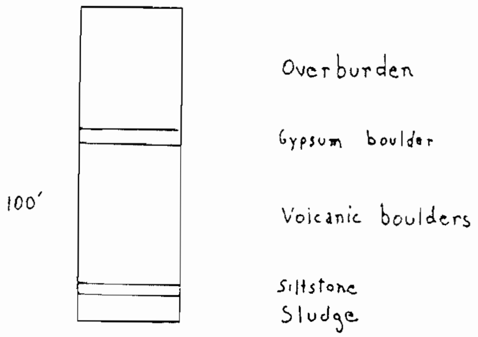
Sh & Siltstone

red oolite minor sh + siltstone

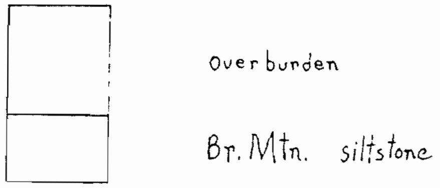
Congl. ; ss. sh, sltst., anhy. frags ; gyp cement

Shale minor siltstone , lmst , calcareous ; some gyp veins
red + grey

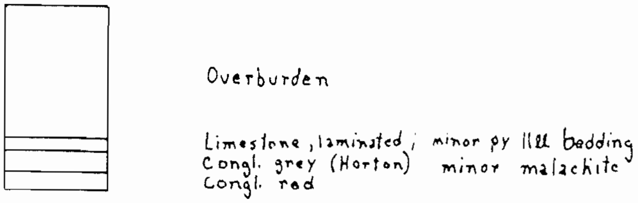
JR-1



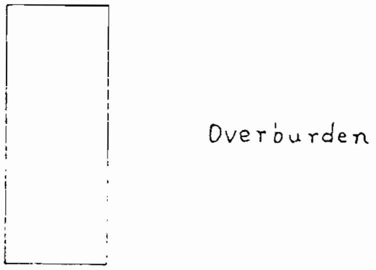
JR-4



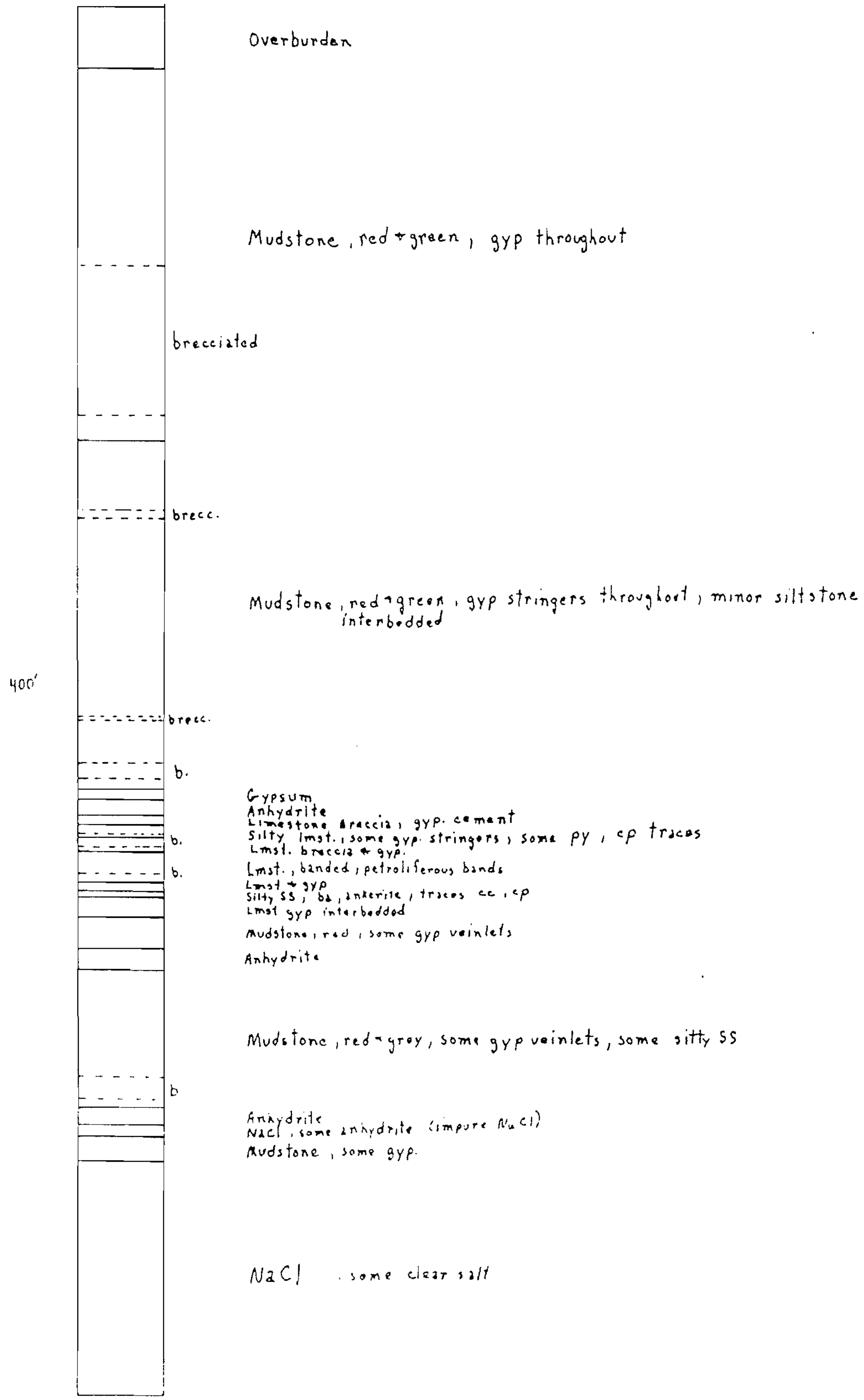
JR-6



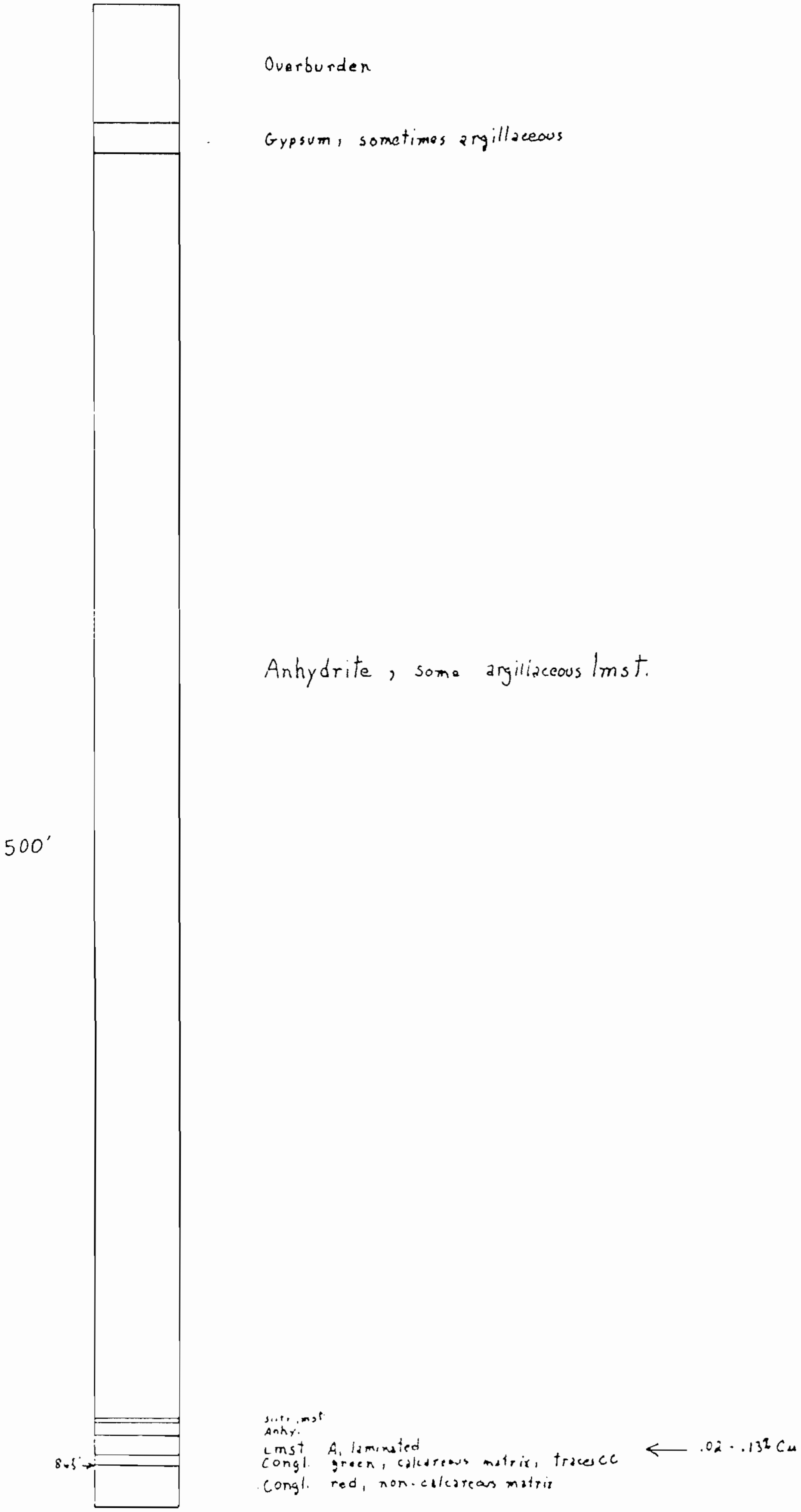
JR-2



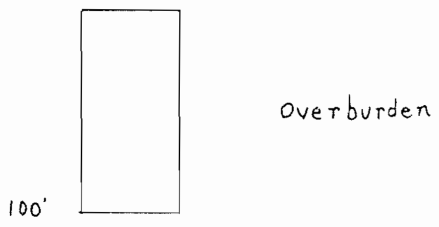
JR-3


Overburden
Mudstone, red + green, gyp throughout
brecciated
brecc.
Mudstone, red + green, gyp stringers throughout, minor siltstone interbedded
400'
brecc.
b.
Gypsum
Anhydrite
Limestone breccia, gyp. cement
b.
Silty lmst., some gyp. stringers, some py, cp traces
Lmst. breccia + gyp.
b.
Lmst., banded, petroliferous bands
Lmst + gyp
Silty SS, ba, ankerite, traces cc, cp
Lmst gyp interbedded
Mudstone, red, some gyp veinlets
Anhydrite
Mudstone, red + grey, some gyp veinlets, some silty SS
b
Anhydrite
NaCl, some anhydrite (impure NaCl)
Mudstone, some gyp.
NaCl, some clear salt

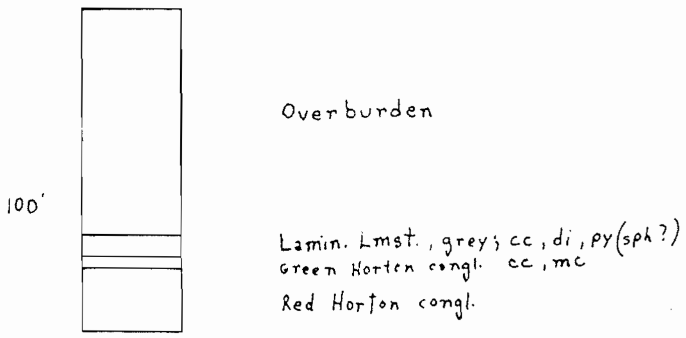
SV-74-1


Overburden
Gypsum, sometimes argillaceous
Anhydrite, some argillaceous lmst.
500'
silty lmst
Anhy.
Lmst A, laminated
Congl. green, calcareous matrix, traces CC
Congl. red, non-calcareous matrix
805'
.02 - .13% Cu

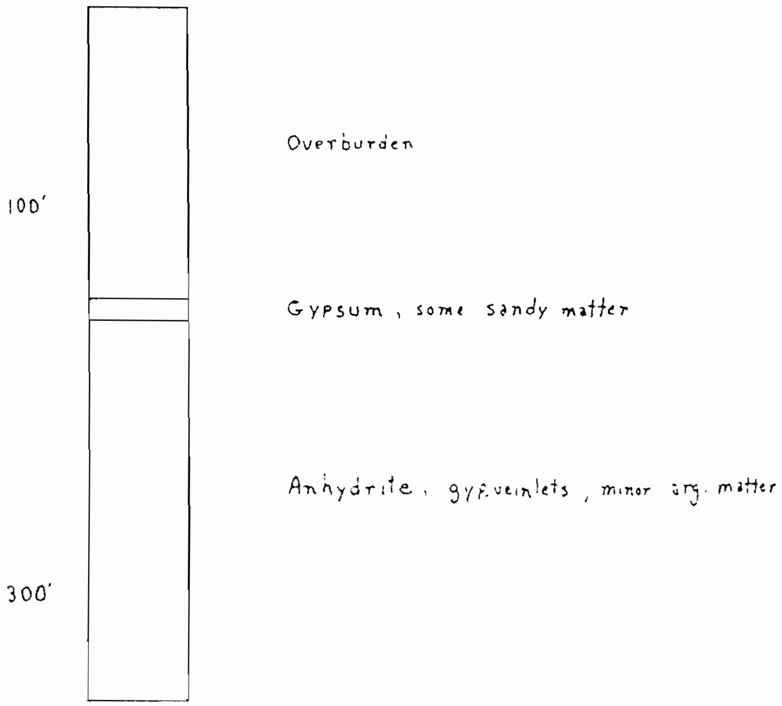
SV-73-1

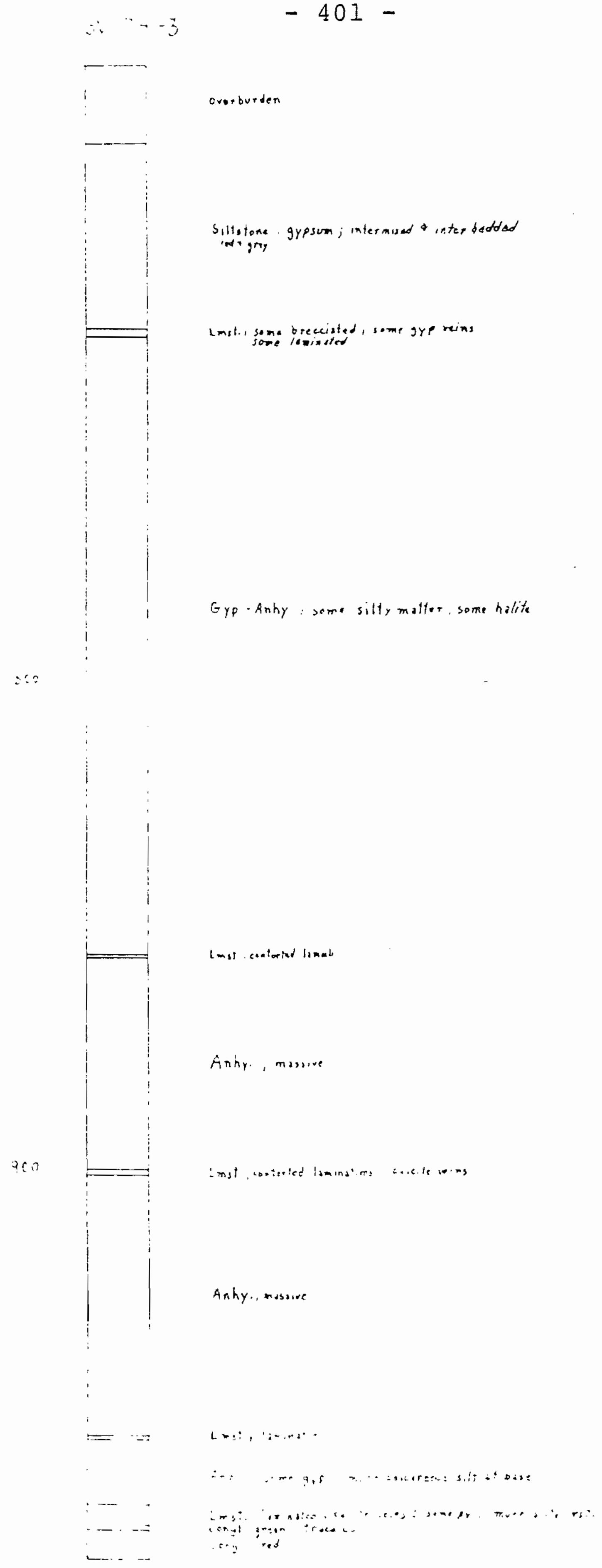


SV-73-2

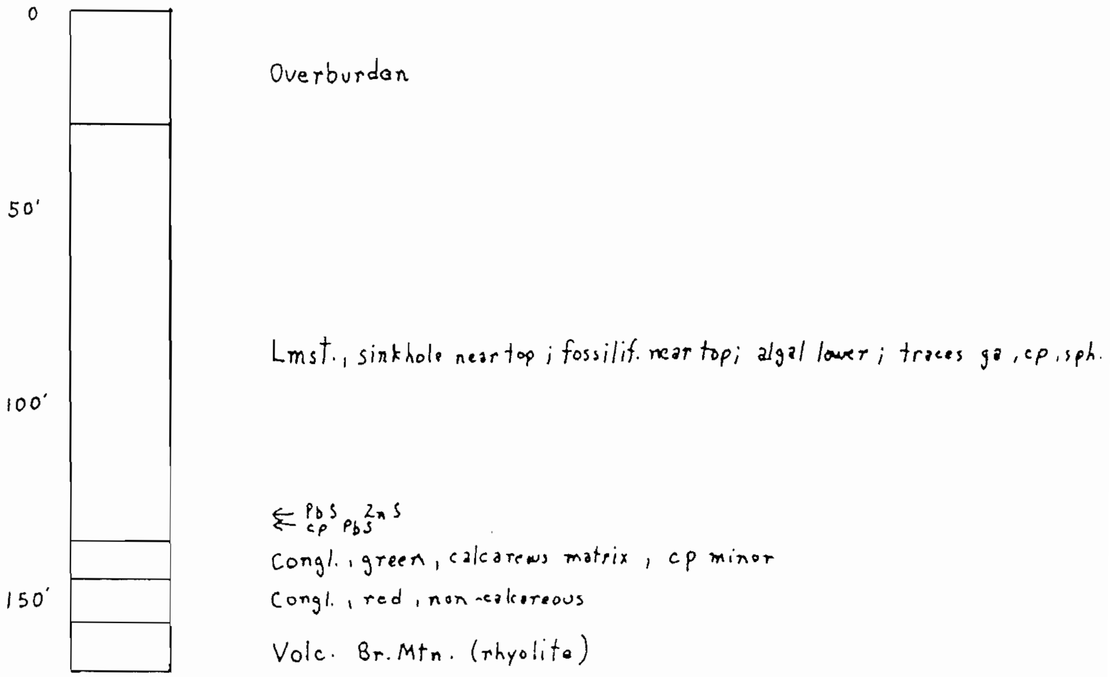


SV-73-3

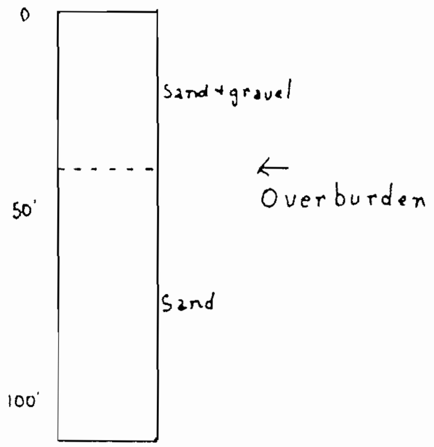



overburden
Siltstone, gypsum; intermixed + interbedded
red + grey
Lmst.: some brecciated, some gyp veins
some laminated
Gyp - Anhy.: some silty matter, some halite
500
Lmst. contorted lamin.
Anhy., massive
900
Lmst, contorted laminations, calcite veins
Anhy., massive
Lmst, laminated
Anhy., some gyp, more calcareous silt at base
Lmst.
Congl. green, trace cu
Congl. red

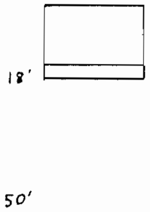
OH - 1


0
50'
100'
150'
Overburden
Lmst., sinkhole near top ; fossilif. near top; algal lower ; traces ga, cp, sph.
← PbS ZnS
← cp PbS
Congl., green, calcareous matrix, cp minor
Congl., red, non-calcareous
Volc. Br. Mtn. (rhyolite)

OH - 6


0
50'
100'
Sand + gravel
← Overburden
Sand

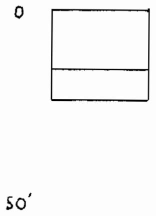
OH - 2



Overburden

Volc. Br. Mtn. (feld. porphry) tracepy

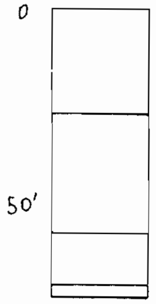
OH - 3



Overburden

Volc. Br. Mtn. (porphry and.) trace py

OH - 4

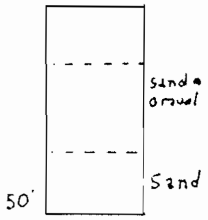


Overburden

Lmst., micrite; fossiliferous near top ; algal near bottom
Trace g8 in calcite cavity ; trace cp & mc

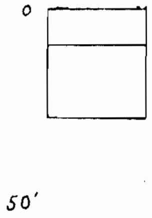
Congl., limy matrix
Volc. Br. Mtn. (rhyolite)

OH - 5



Overburden

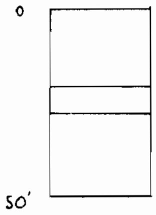
OH-7



Overburden

Volc. Br. Mtn. (andesite)

OH-8

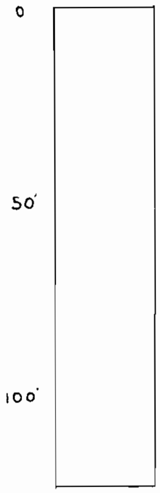


Overburden

Lmst. breccia; sitlstone, and./lmst. frags in carbonate matrix .09% Cu 1.93% Zn cp in

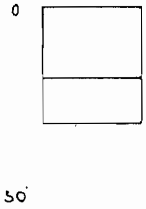
Volc. Br. Mtn. (and.)

OH-9



Overburden; sand + gravel

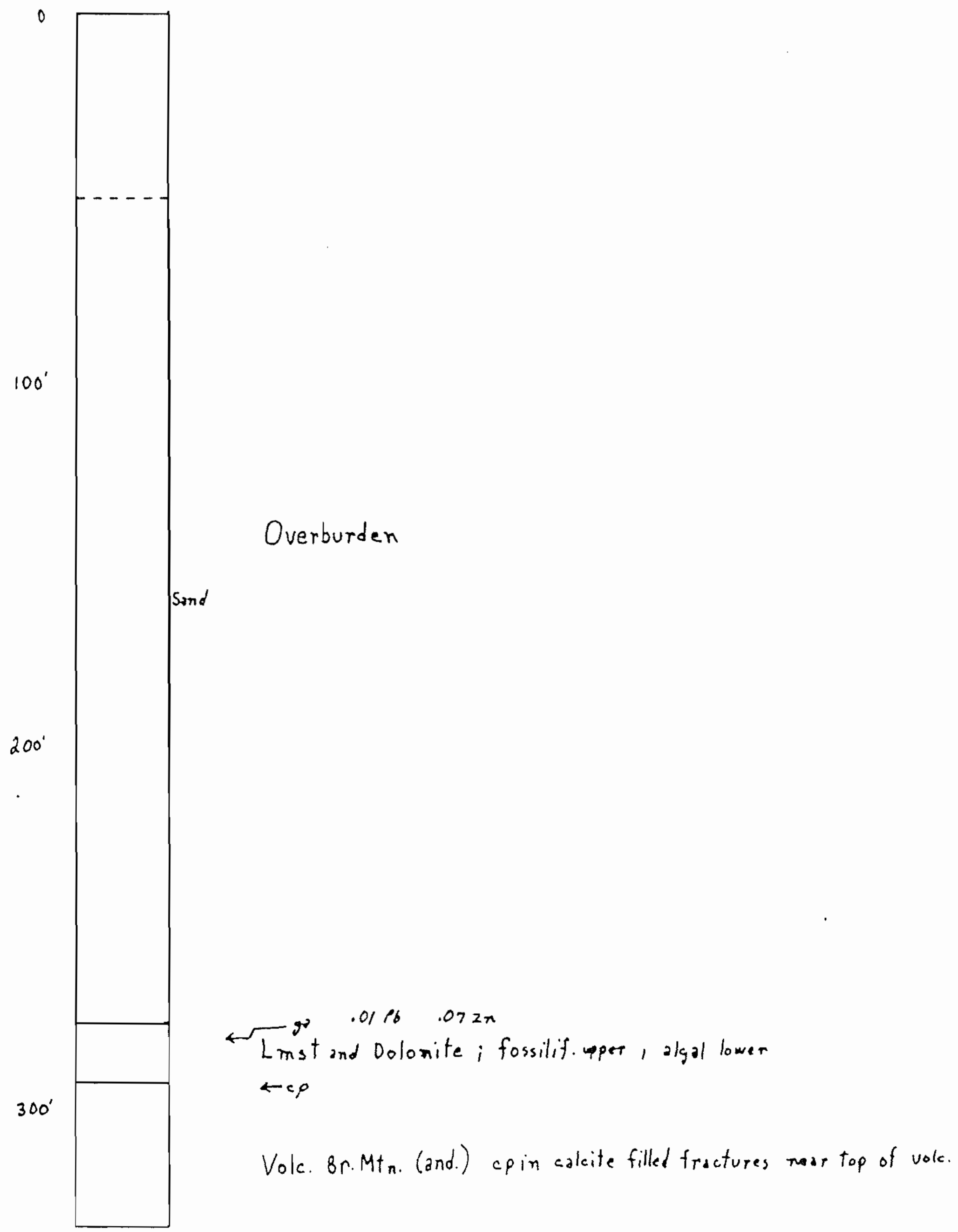
OH-11

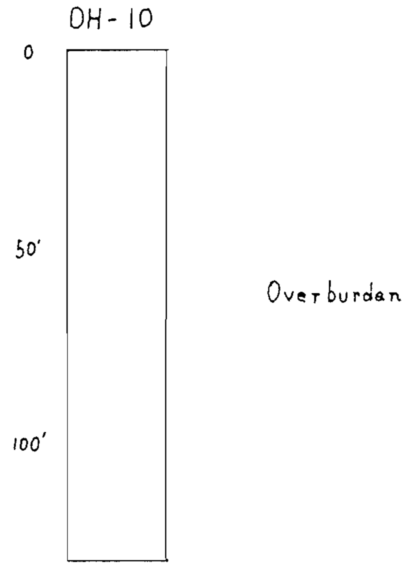


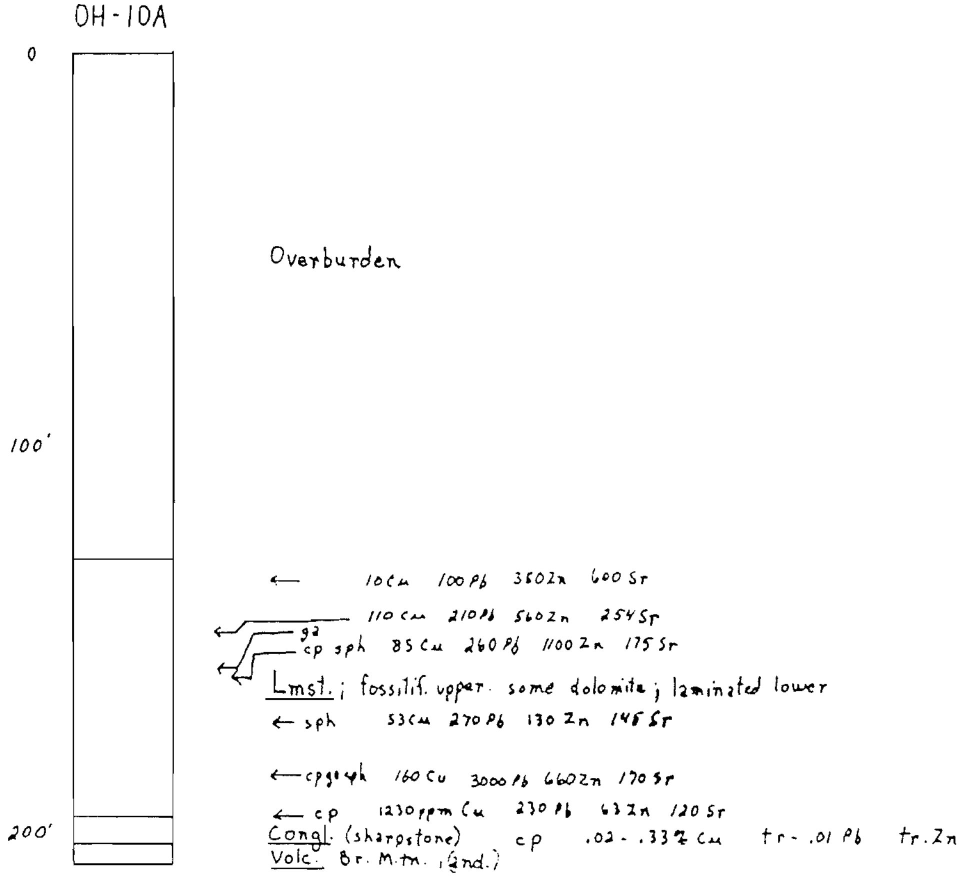
Overburden

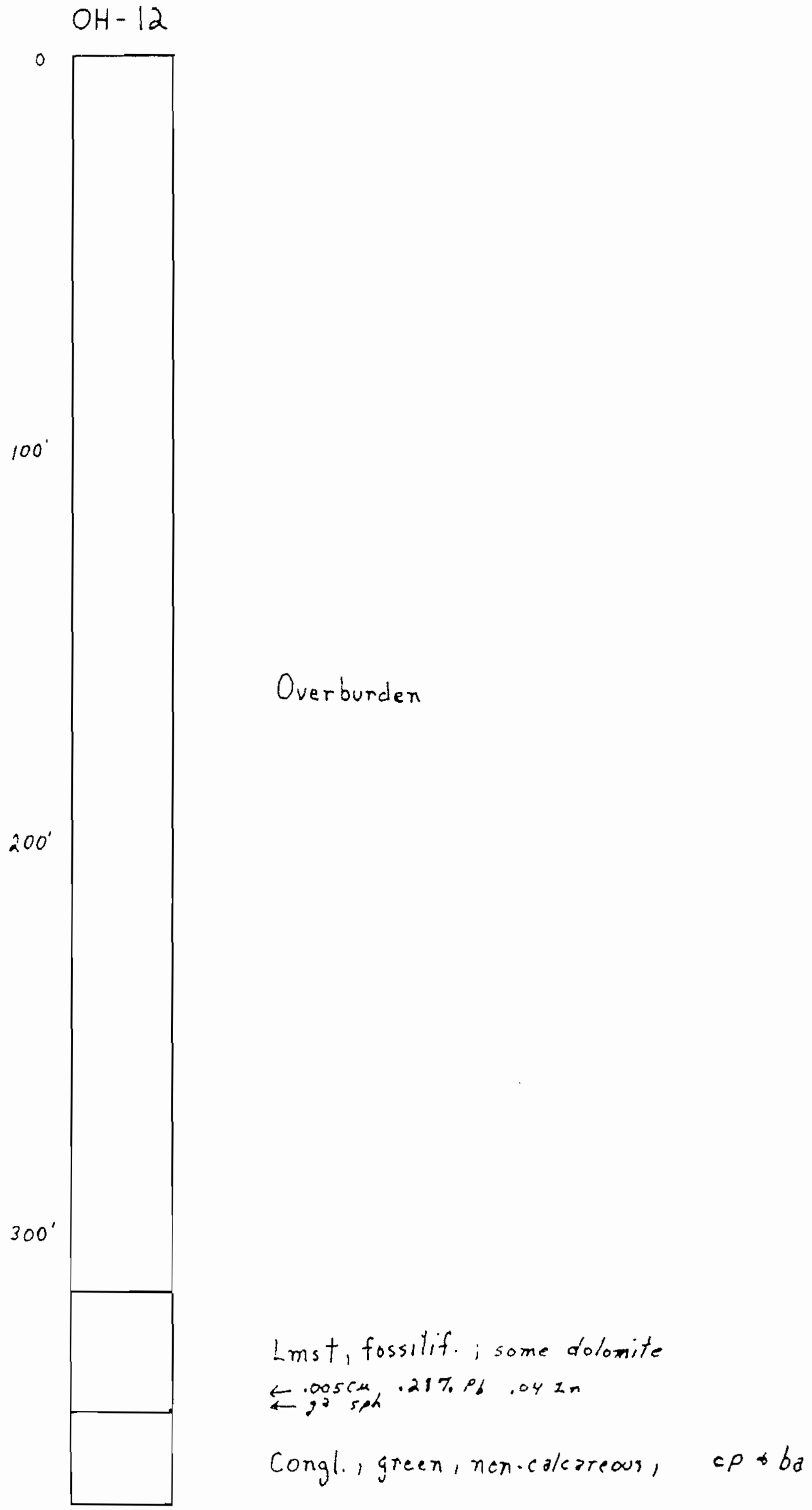
Volc. Br Mtn (rhyolite)

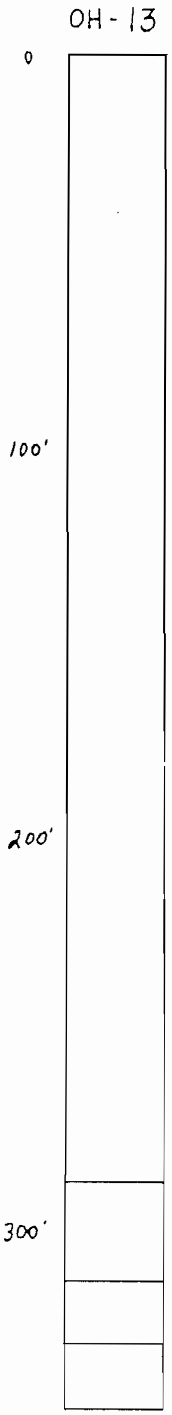
OH-9A


0
100'
200'
300'
Overburden
Sand
gn
.01 Pb
.07 Zn
Lmst and Dolomite ; fossilif. upper , algal lower
cp
Volc. Br. Mtn. (and.) cp in calcite filled fractures near top of volc.


OH-10
0
50'
100'
Overburden


OH-10A
0
100'
200'
Overburden
← 10 Cu 100 Pb 350 Zn 600 Sr
110 Cu 210 Pb 560 Zn 254 Sr
ga
cp sph 85 Cu 260 Pb 1100 Zn 175 Sr
Lmst.; fossilif. upper. some dolomite; laminated lower
← sph 53 Cu 270 Pb 130 Zn 145 Sr
← cp ga sph 160 Cu 3000 Pb 660 Zn 170 Sr
← cp 1230 ppm Cu 230 Pb 63 Zn 120 Sr
Congl. (sharpstone) cp .02 - .33% Cu tr - .01 Pb tr. Zn
Volc. Br. Mtn. (And.)


OH-12
0
100'
200'
300'
Overburden
Lmst, fossilif. ; some dolomite
← .005 Cu, .21% Pb .04 Zn
← ga sph
Congl., green, non-calcareous, cp + ba



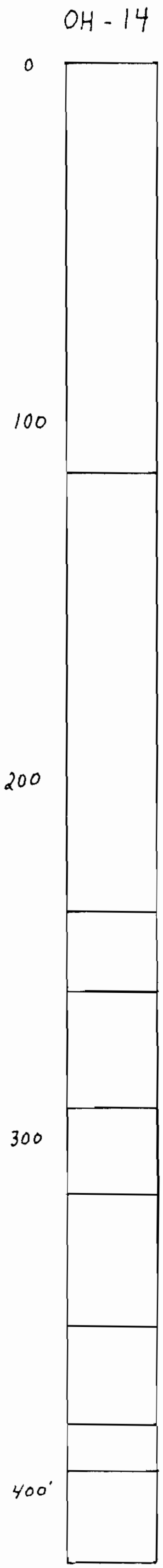
Overburden

← ga
Lmst., fossilif., laminated

⇇ ga sph .005 Cu .11 Pb .16 Zn
cp .01 .42 .03

Congl., calcareous matrix, cp ga .01-.17 Cu .005-1.81 Pb .005-.08 Zn

Volc. Br. Mtn. (rhy.)



Overburden

Siltstone, red & grey, c̄ gyp veinlets

Lmst., argillaceous, skeletal py

Siltstone breccia

Lmst, arg., skel. py

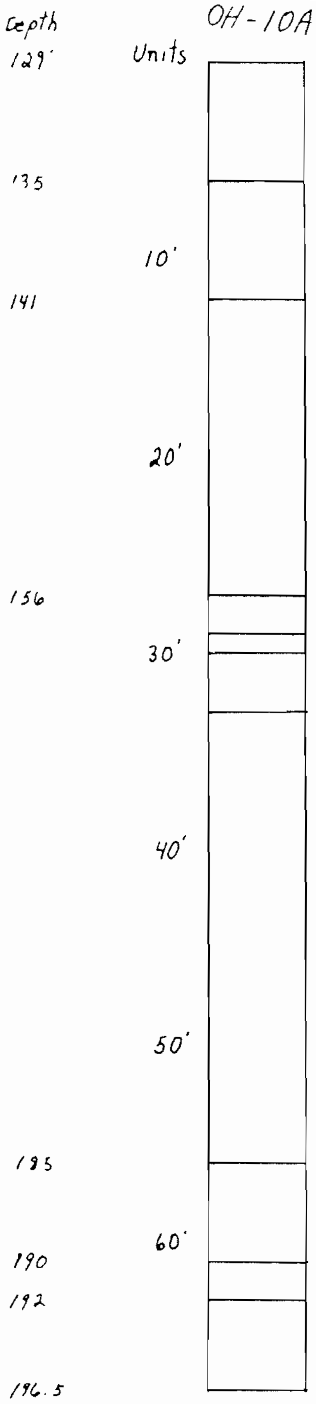
Unconsolidated sand & silt; some pebbles

Gypsum, siltstone pebbles common

Siltstone breccia, red & green

Rubble of volc. frags.

OH-10A EXPANDED CARBONATES



Skeletal lmst. (brachs), patchily dolomitic

Rubble, pelloidal lmst, brachs algal encrusted

Dolomite, leached, sandy

Skeletal Sand lmst. (gastropods & ostracods) ga in fractures
Peloidal lmst, sparce skeletal frags. ga throughout, cp cc trace
Algal, pelloidal lmst. (sparce brachs) cp sph

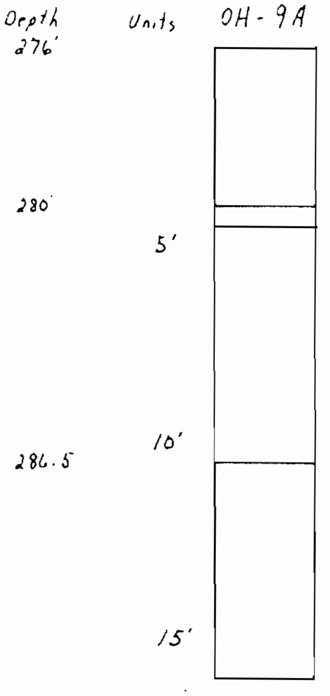
Skeletal lmst., recrystallized cp ga sph esp in lower section

Thickly to thinly laminated lmst, re-Xtallized, calcite blebs

Thick. to thin. lam. lmst. reXtall. $CaCO_3$ blebs, angular clasts of basement

Thinly laminated carbonaceous lmst. 0.5% cp in fractures + along lamelli

EXPANDED CARBONATES

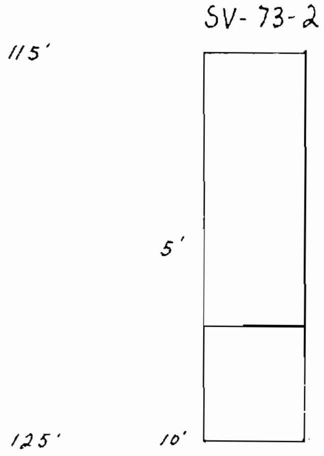


Dolomite, leached, sandy, loose (altered skeletal sand ?)

Algal lmst. ; minor corals or bryozoA near top PbS

Algal (stromatolites) lmst. ; 10% calcite filled vugs , Calcareous silt + mud between algal layers
minor brachs. minor dolomite

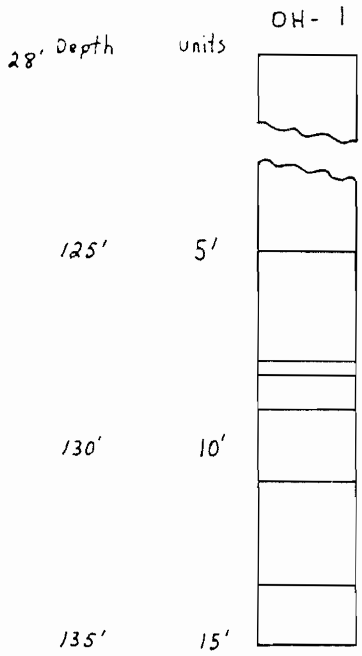
Thinly laminated calc. rich muds and intermittent algal material



Finely laminated, fairly silty, (micritic ?) lmst. ; rare brachs.
cc py (ga ?)

Finely laminated lmst. cc di sph

EXPANDED CARBONATES



Sinkhole ; leached micritic lmst. (buff)

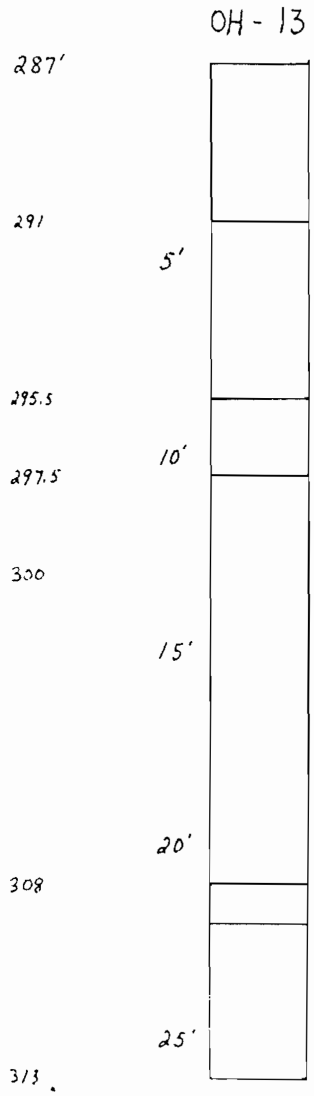
Finely laminated foram. lmst. (minor brachs)

calcareous black silt
Algal Lmst., vug fillings PbS ZnS

Algal Lmst (micritic) some re-Xtaliz^{n} cp PbS (top 0.3' finely laminated foram. lms

Finely laminated foram. lmst. (some carbonaceous) cp PbS

Algal lmst. some re-Xtaliz^{n}



Leached, buff lmst. (micritic)

Skeletal Micritic Lmst (mainly brachs 5%)
← PbS

Thickly laminated, argillaceous lmst. ← PbS

← PbS

← PbS

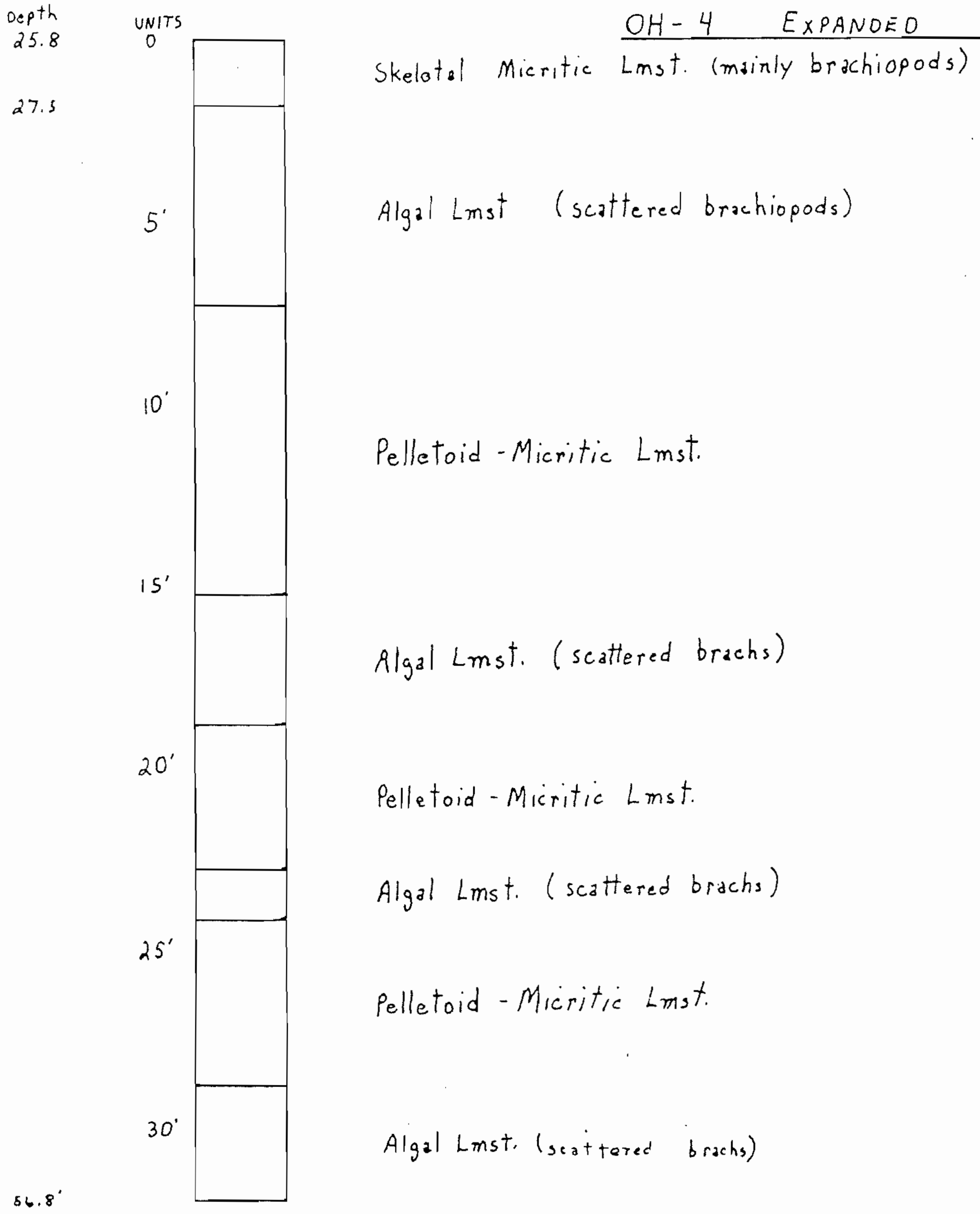
← PbS
Algal Skeletal micritic lmst. ; calcite vugs (scattered brachs)
← PbS

⇇ PbS

Thickly laminated micritic lmst.

Thinly to thickly laminated skeletal (gastropods) lmst (carbonaceous)
PbS in fractures

OH- 4 EXPANDED CARBONATES



APPENDIX IV

CHEMICAL ANALYSIS DATA

MINERAL TABLE

Q - Quartz
C - Corundum
OR - Orthoclase
AB - Albite
AN - Anorthite
LC - Leucite
NE - Nepheline
KP - Kaliophylite
AC - Acmite
DI - Diopside
HE - Hedenbergite
EN - Enstatite
FS - Ferrosilite
FO - Forsterite
FA - Fayalite

WO - Wollastonite
LA - Larnite
MT - Magnetite
IL - Ilmenite
CR - Chromite
CC - Calcite
HM - Hematite
AP - Apatite
PY - Pyrite
NS - Sodium Metasilicate
KS - Potassium Metasilicate
RU - Rutile
AG - Augite
HY - Hypersthene
OL - Olivine
PL - Plagioclase

SAMPLE #7328

CROSS ROADS OHIO TUFF UNIT

Analysis (Weight Percent)				Adjusted to 100 Percent			
SI02	50.17	TI02	1.82	SI02	52.15	TI02	1.89
AL203	22.47	P205	0.00	AL203	23.36	P205	0.00
FE203	8.03	MN0	.04	FE203	8.35	MN0	.04
FE0	1.82	S	0.00	FE0	1.89	S	0.00
MG0	2.00	NI0	0.00	MG0	2.08	NI0	0.00
CA0	1.21	CR203	0.00	CA0	1.26	CR203	0.00
NA20	1.77	CO2	.67	NA20	1.84	CO2	.70
K20	6.21	H20	3.37	K20	6.45	H20	0.00

Cation Percent: SI = 49.10, AL = 25.92, FE3 = 5.91, FE2 = 1.52, CA = 1.27, MG = 2.92, NA = 3.36, K = 7.76, TI = 1.34, P = 0.00, S = 0.00, CR = 0.00, CO2 = .90

Norm (Weight Percent and Cation Equivalents)

Q	12.824	12.075	DI	0.000	0.000	MT	.750	.550
C	12.662	14.053	HE	0.000	0.000	IL	3.593	2.679
OR	38.179	38.810	EN	5.177	5.834	CR	0.000	0.000
AB	15.565	16.792	FS	.000	.000	HM	7.829	5.548
AN	1.837	1.868	FO	0.000	0.000	AP	0.000	0.000
LC	0.000	0.000	FA	0.000	0.000	PY	0.000	0.000
NE	0.000	0.000	WO	0.000	0.000	NS	0.000	0.000
KP	0.000	0.000	LA	0.000	0.000	KS	0.000	0.000
AC	0.000	0.000	RU	0.000	0.000	CC	1.584	1.791

Norm Ratios	(Cation Equivalents)			(Weight Percent)		
MG/MG+FE2		1.00			1.00	
AN/AN+AB		10.01			10.56	
OR/AB/AN	67.53	29.22	3.25	68.69	28.00	3.31
Q /AB/OR	17.84	24.81	57.35	19.26	23.38	57.35
OL/HY/AG	0.00	100.00	0.00	0.00	100.00	0.00
Q /HY/AG	67.42	32.58	0.00	71.24	28.76	0.00
PL/AG/HY	76.18	0.00	23.82	77.07	0.00	22.93
AG/PL/HY+4Q	0.00	25.63	74.37	0.00	23.56	76.44
OL+/PL/Q+	18.95	68.33	12.73	18.23	66.85	14.92Adjust
OL+/AG/Q+	24.43	0.00	75.57	21.57	0.00	78.43 for
						Corund

Rock Name - Tholeiitic Dacite

K-Rich Series

SAMPLE #7331A

CROSS ROADS OHIO VOLCANICS

Analysis (Weight Percent)				Adjusted to 100 Percent			
SI02	55.20	TI02	1.50	SI02	56.28	TI02	1.53
A1203	19.25	P205	0.00	A1203	19.63	P205	0.00
FE203	2.11	MN0	.14	FE203	2.15	MN0	.14
FE0	1.28	S	0.00	FE0	1.31	S	0.00
MG0	2.12	NI0	0.00	MG0	2.16	NI0	0.00
CA0	4.71	CR203	0.00	CA0	4.80	CR203	0.00
NA20	2.62	CO2	4.75	NA20	2.67	CO2	4.84
K20	4.40	H20	2.26	K20	4.49	H20	0.00

Cation Percent: SI = 51.50, AL = 21.17, FE3 = 1.48, FE2 = 1.11,
CA = 4.71, MG = 2.95, NA = 4.74, K = 5.24, TI = 1.05, P = 0.00,
S = 0.00, CR = 0.00, CO2 = 6.05

Norm (Weight Percent and Cation Equivalents)

Q	21.717	19.949	DI	0.000	0.000	MT	.239	.171
C	10.332	11.187	HE	0.000	0.000	IL	2.893	2.105
OR	26.433	26.214	EN	2.920	3.211	CR	0.000	0.000
AB	22.514	23.694	FS	.000	.000	HM	1.978	1.368
AN	0.000	0.000	FO	0.000	0.000	AP	0.000	0.000
LC	0.000	0.000	FA	0.000	0.000	PY	0.000	0.000
NE	0.000	0.000	WO	0.000	0.000	NS	0.000	0.000
KP	0.000	0.000	LA	0.000	0.000	KS	0.000	0.000
AC	0.000	0.000	RU	0.000	0.000	CC	10.972	12.101

Norm Ratios (Cation Equivalents)				(Weight Percent)		
MG/MG+FE2		1.00			1.00	
AN/AN+AB		0.00			0.00	
OR/AB/AN	52.52	47.48	0.00	54.00	46.00	0.00
Q /AB/OR	28.56	33.92	37.52	30.73	31.86	37.41
OL/HY/AG	0.00	100.00	0.00	0.00	100.00	0.00
Q /HY/AG	86.14	13.86	0.00	88.15	11.85	0.00
PL/AG/HY	88.07	0.00	11.93	88.52	0.00	11.48
AG/PL/HY+AG	0.00	22.21	77.79	0.00	20.05	79.95
OL/PL/Q+	13.43	64.24	22.33	12.72	61.86	25.42
OL+/AG/Q+	10.40	0.00	89.60	8.89	0.00	91.11

Rock Name - Calc-Alkaline Rhyolite
"Average" Series

SAMPLE #7336

CROSS ROADS OHIO VOLCANICS

Analysis (Weight Percent)				Adjusted to 100 Percent			
SI02	70.11	TI02	.33	SI02	71.11	TI02	.33
AL203	14.43	P205	0.00	AL203	14.64	P205	0.00
FE203	1.59	MN0	.01	FE203	1.61	MN0	.01
FE0	.71	S	0.00	FE0	.72	S	0.00
MG0	.51	NI0	0.00	MG0	.52	NI0	0.00
CA0	1.71	CR203	0.00	CA0	1.73	CR203	0.00
NA20	5.00	CO2	.32	NA20	5.07	CO2	.32
K20	3.87	H20	.96	K20	3.93	H20	0.00

Cation Percent: SI = 65.63, AL = 15.92, FE3 = 1.12, FE2 = .56, CA = 1.72, MG = .71, NA = 9.07, K = 4.63, TI = .23, P = 0.00, S = 0.00, CR = 0.00, CO2 = .41

Norm (Weight Percent and Cation Equivalents)

Q	23.187	21.398	DI	.764	.783	MT	1.384	.994
C	0.000	0.000	HE	.000	.000	IL	.636	.465
OR	23.219	23.133	EN	.934	1.031	CR	0.000	0.000
AB	42.909	45.368	FS	.000	.000	HM	.658	.457
AN	5.571	5.552	FO	0.000	0.000	AP	0.000	0.000
LC	0.000	0.000	FA	0.000	0.000	PY	0.000	0.000
NE	0.000	0.000	WO	0.000	0.000	NS	0.000	0.000
KP	0.000	0.000	LA	0.000	0.000	KS	0.000	0.000
AC	0.000	0.000	RU	0.000	0.000	CC	.738	.818

Norm Ratios	(Cation Equivalents)			(Weight Percent)		
MG/MG+FE2		1.00			1.00	
AN/AN+AB		10.90			11.49	
OR/AB/AN	31.24	61.26	7.50	32.38	59.85	7.77
Q /AB/OR	23.80	50.47	25.73	25.96	48.04	26.00
OL/HY/AG	0.00	56.85	43.15	0.00	54.99	45.01
Q /HY/AG	92.18	4.44	3.37	93.18	3.75	3.07
PL/AG/HY	96.56	1.48	1.96	96.62	1.52	1.86
AG/PL/HY+4Q	.57	36.81	62.62	.01	33.92	65.55
OL+/PL/Q+	1.05	69.42	29.52	.96	66.78	32.26
OL+/AG/Q+	3.33	3.37	93.29	2.81	3.07	94.11

Rock Name - Calc-Alkaline Rhyolite
"Average" Series

	ATOM %			PPM			%
Sample	Pb	Cu	Zn	Pb	Cu	Zn	Fe
7030	.34	96.72	2.94	8.00	2300.00	70.00	1.39
7033	0.00	12.16	87.84	0.00	9.00	65.00	2.76
7038A	20.00	32.73	47.27	44.00	72.00	104.00	0.38
7125	22.36	3.67	73.98	1360.00	223.00	4500.00	2.67
7126	1.21	64.31	34.48	68.00	3600.00	1930.00	2.28
7193	15.88	63.86	20.26	776.00	3120.00	990.00	2.38
7195	0.00	27.10	72.90	0.00	29.00	78.00	4.00
7197	14.26	69.64	16.10	1444.00	7050.00	1630.00	0.71
7197A	22.78	57.30	19.93	640.00	1610.00	560.00	1.49
7198	5.66	86.94	7.40	1620.00	24900.00	2120.00	2.00
7199	21.10	62.00	16.91	262.00	770.00	210.00	1.82
7200A	8.07	71.75	20.18	900.00	8000.00	2250.00	2.43
7201	5.38	88.30	6.31	524.00	8600.00	615.00	1.49
7203	3.60	44.60	51.80	5.00	62.00	72.00	2.95
7204	0.00	8.99	91.01	0.00	8.00	81.00	2.57
7223	.65	98.85	.50	17.00	2570.00	13.00	1.07
7227	11.51	74.20	14.29	54.00	348.00	67.00	6.00
7282	1.24	94.29	4.47	1760.00	134000.00	6350.00	14.00
7282B	.09	96.59	3.32	28.00	31100.00	1070.00	2.49
7286	3.27	40.90	55.83	16.00	200.00	273.00	0.60
7289	.87	3.46	95.67	20.00	80.00	2210.00	1.15
7309	1.64	24.59	73.77	2.00	30.00	90.00	2.57
7319	81.59	1.42	16.98	4180.00	73.00	870.00	0.05
7320	6.35	79.70	13.95	988.00	12400.00	2170.00	1.53
7320B	7.34	75.17	17.48	840.00	8600.00	2000.00	1.15
7321A	30.00	1.67	68.33	18.00	1.00	41.00	1.2
7323	4.86	73.24	21.89	18.00	271.00	81.00	0.4
7324	9.76	64.02	26.22	16.00	105.00	43.00	0.02
7326	1.59	94.36	4.05	38.00	2260.00	97.00	0.3
7329	26.47	38.24	35.29	18.00	26.00	24.00	2.64
7330	1.62	96.57	1.81	26.00	1550.00	29.00	1.78
7332	14.12	0.00	85.88	12.00	0.00	73.00	4.65
7334	11.24	6.74	82.02	10.00	6.00	73.00	2.1
7338	1.39	11.81	86.81	2.00	17.00	125.00	3.26
7341	16.67	51.39	31.94	48.00	148.00	92.00	0.3
7344	16.85	55.98	27.17	62.00	206.00	100.00	0.07
7345A	18.54	47.14	34.32	94.00	239.00	174.00	0.3
7345B	15.64	35.20	49.16	140.00	315.00	440.00	.38
7345C	12.02	60.08	27.90	90.00	450.00	209.00	.33
7347	5.71	69.14	25.14	10.00	121.00	44.00	1.26
7383	.23	98.75	1.02	14.00	6000.00	62.00	.15
7383A	.40	98.07	1.53	15.00	3660.00	57.00	.19
7384	1.72	97.17	1.12	191.00	10800.00	124.00	1.65
7386	.60	98.05	1.35	40.00	6550.00	90.00	.1
7391	.38	95.18	4.44	31.00	7800.00	364.00	1.44
7392	.22	95.53	4.25	7.00	3100.00	138.00	.85
7399	16.94	68.76	14.30	308.00	1250.00	260.00	.77
7403	1.48	73.39	25.12	21.00	1040.00	356.00	.19
7404				11.00	1260.00	101.00	.76
7406	2.74	69.86	27.40	20.00	510.00	200.00	.38
7455A	1.60	83.70	14.70	11.00	575.00	101.00	3.31