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A VOLCANIC-HOSTED GOLD OCCURRENCE IN MARATHON COUNTY, WISCONSIN

by

William P. Scott

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WILLIAM P. SCOTT

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PREFACE

This open-file report is a Master of Science thesis by William P. Scott, University of Wisconsin-Madison Department of Geology and Geophysics. The work was initiated while Mr. Scott was employed with the Wisconsin Geological and Natural History Survey and reflects the Survey's continuing interest in the mineral resources of Wisconsin. The Survey aided this study by funding field work, chemical analyses, and manuscript typing.

The Town of Easton gold prospect, referred to in the industry as the Reef Prospect, has been known for a long period of time. This report focuses on the recent period of exploration activity, which is still underway, and provides an overview of the rock present in the area and discusses the nature of the metalliferous mineralization.

ACKNOWLEDGMENTS

Many people and organizations made this study possible. W.A. Broughton and Thomas J. Evans inspired my keen interest in mineral resources. Dr. Meredith E. Ostrom provided encouragement and made possible my pursuit of this study. Professor Philip E. Brown taught me a great deal about economic geology and guided me through the academic maze. The Wisconsin Geological and Natural History Survey funded field work, chemical analyses and typing of the manuscript. Daniel O'Brien of Kennecott provided access to drillcore. The late, Edward H. Eisenbrey, Jr., of Ernest K. Lehmann and Associates, donated drill core from North Central Mineral Ventures. Randy Maass patiently discussed my work and carefully challenged my assertions. Michael G. Mudrey, Jr., provided me with the Geochemical Program Package, computer software by Geist, Baker and McBirney (1985), and discussed the chemistry of the rocks and the presentation of my data. Gene L. LaBerge performed a commendable job of regional mapping in Marathon County, and inadvertently provided me with an excellent base map. To all these people and organizations, I extend my sincere appreciation.

To my loving wife, Heidi, who has patiently acquired an intimate knowledge of the term "geologic time" during the five years I spent on this project, I express my deepest thanks.

ABSTRACT

This study was undertaken to investigate the impetus for an anomalously great amount of recent mineral exploration occurring close to the abandoned shaft of a reputed gold mine. Within a six mi^2 area, four companies drilled 60 holes over a 20 year period. The area is composed of steeply dipping, basaltic to dacitic, early Proterozoic volcanic rocks that have been regionally metamorphosed to the greenschist facies. These rock units have been intruded by gabbro, dacite and granodiorite. The study area is bounded on the west by a shear zone and on the east by the anorogenic, granitic, Wolf River Batholith.

Variable degrees of shear deformation exist in the study area. Petrographic evidence suggests that intercalated zones of sheared and unsheared rock are present east of the Eau Claire River and that the intensity of shearing gradually decreases eastward from the river. Evidence of shearing is visible despite the resemblance of some primary volcaniclastic textures to mylonitic textures, and despite considerable recrystallization of the finer grained portions of the rocks.

The observed mineralization consists of disseminated sulfides, mainly pyrite and pyrrhotite, and stringers and veins of pyrite, pyrrhotite, magnetite and chalcopyrite. Subordinate sphalerite and

galena are present. No visible gold was encountered. Assays found gold as abundant as 590 ppb associated with chalcopyrite near quartz veins in mafic volcanics. All rock units, except the Wolf river Batholith, are mineralized. The volcanic rocks contain twelve times as much gold as average volcanics, but the gabbro and granodiorite contain only average values of gold. The mineralization has a Cu-Zn signature, with very little lead and almost no arsenic. The only arsenic-rich sample analyzed also contained the most lead. Mineral zonation could not be established because of structural complexity.

The gold occurrence is attributed to a three stage process. Early mineralization was syngenetic with the subaqueous deposition of intermediate to mafic volcanic rocks. The second stage involved a volcanogenic hydrothermal system which was interrupted by a deformational event, resulting in an epigenetic stringer zone and stockwork. The final stage, chronologically much later than and genetically unrelated to the earlier stages, involved the intrusion of large, barren quartz veins. The gold was probably deposited in the first two stages, with remobilization occurring in the second stage. Quartz veins are commonly 1 cm wide but were observed in widths up to 3 m close to the Wolf River Batholith. Some quartz veins, including wide ones, are barren of sulfide mineralization except where they contact the host lithology. Deformed stringers and veins, cross cutting relationships, mineralized breccia zones, and mineralized fault planes suggest that sudden failure occurred during mineralization. Replacement textures indicate that slow metasomatism, in addition to rapid, open-space-filling, was involved in the mineralization process.

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INTRODUCTION

This study of a reported occurrence of gold in the Town of Easton, Marathon County, Wisconsin, was undertaken to investigate the geologic environment and any mineralization present. The six square-mile study area encompasses 60 known exploration drillholes and the reputed shaft of a "gold mine" reported in the files of the Wisconsin Geological and Natural History Survey (WGNHS) (figure 1, and table 1). Three additional drillholes are known from the vicinity. All of the known drillholes are believed to have been drilled between 1967 and 1987. Relatively continuous exploration of the study area and vicinity by at least four companies piqued the author's curiosity and led to this undertaking. Drilling was still taking place in 1987.

The bedrock geology of Marathon County is portrayed on a map by LaBerge and Meyers (1983) that became available after this study was underway. The bedrock in the study area consists of intermediate to mafic volcanics (1850 Ma) that have been intruded by gabbro and granodiorite plutons (age uncertain), the granitic Wolf River Batholith (1485 Ma), and some mafic dikes (figure 2). Shearing and metamorphism have affected most of these rocks. Veins and stringers of sulfide minerals, magnetite, quartz, epidote and calcite are common.

Figure 1. Location of study area, sections 25, 26, 27, 34, 35 & 36, T. 29 N., R. 9 E., Marathon County

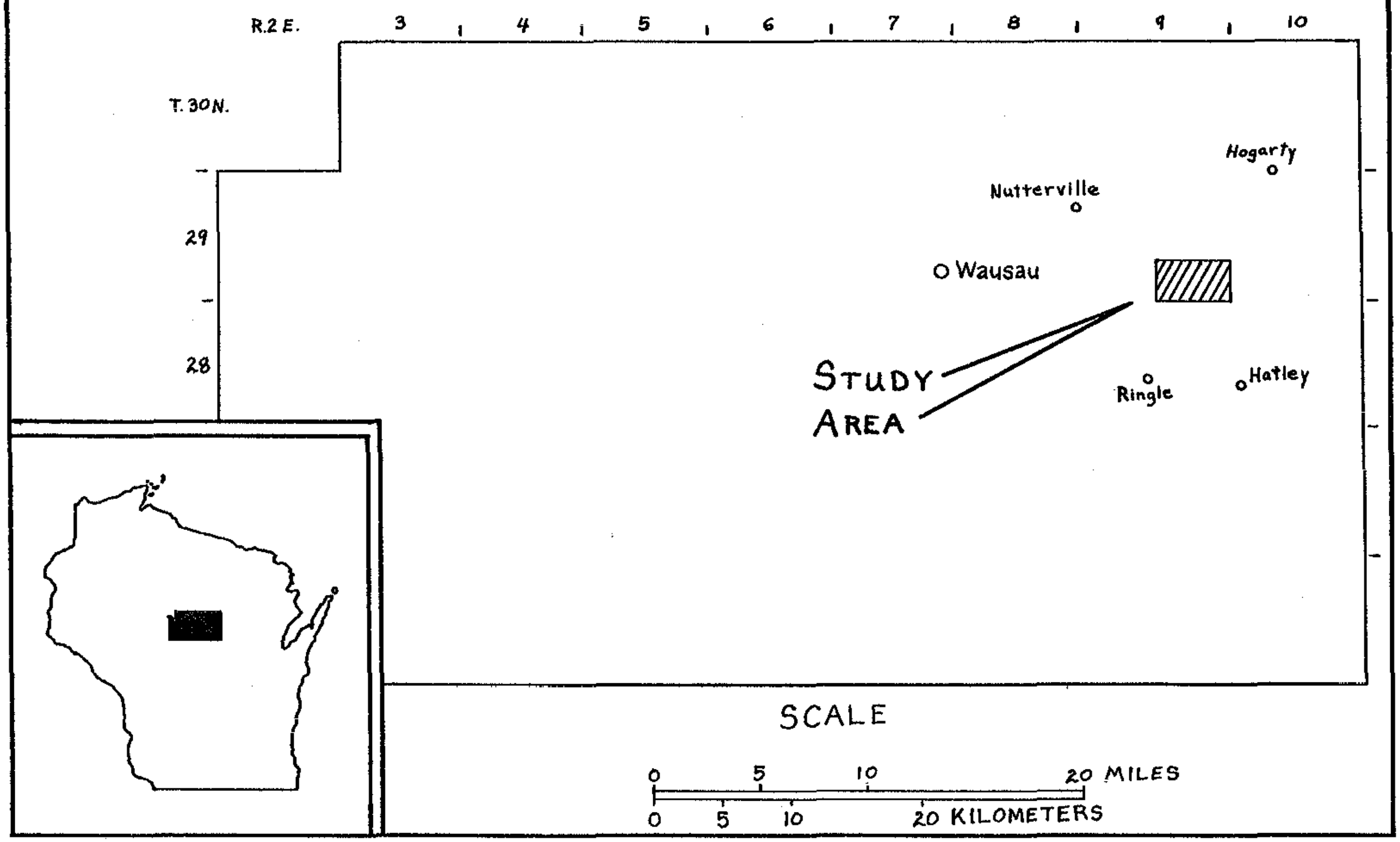
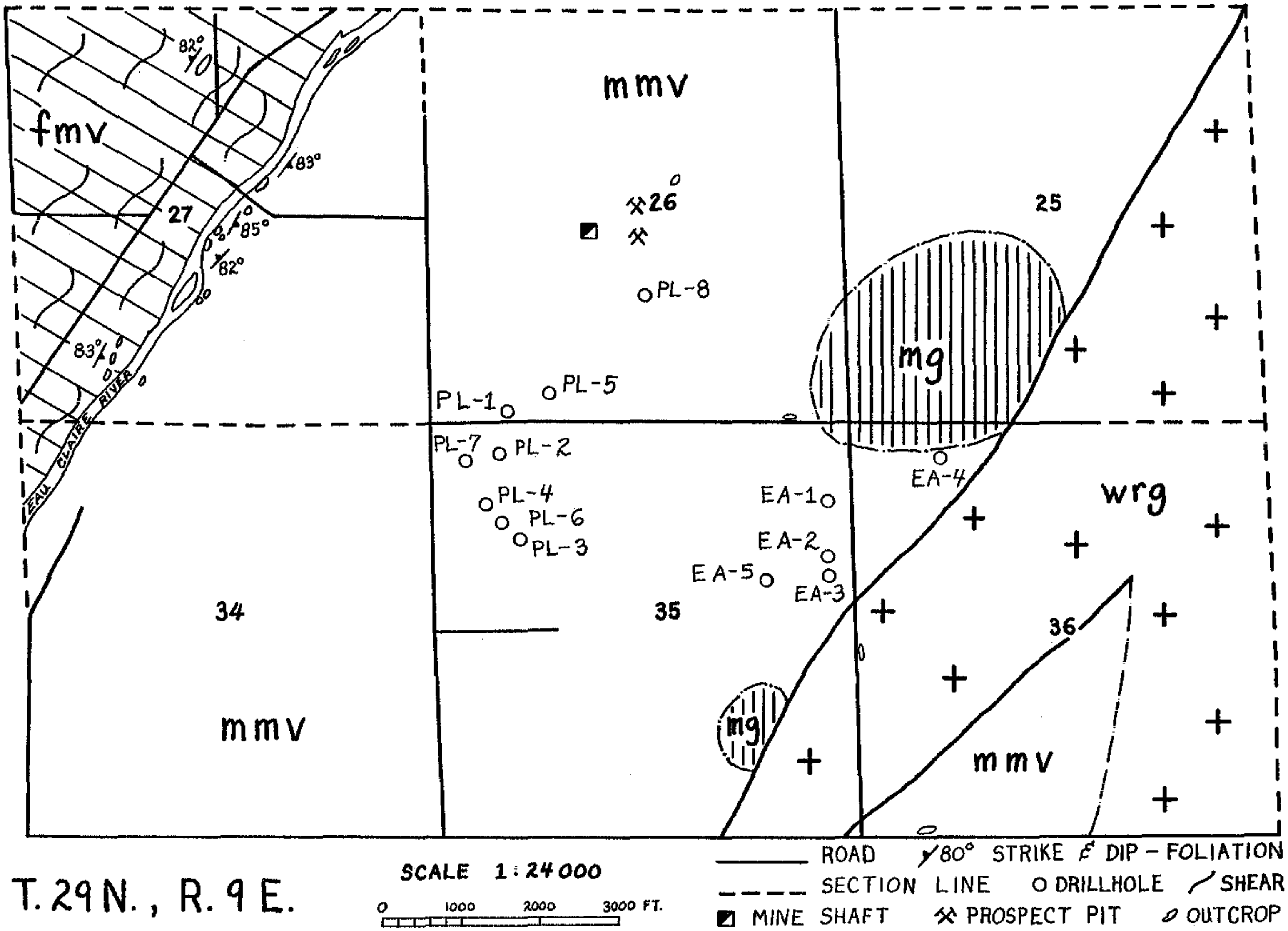


Table 1. Known exploration drilling in and near study area[1]

Company, Drilling Date(s)	Location	Drillhole Identification Number(s)
Cominco American, Inc., 1978	sec. 6, T. 28 N., R. 9 E.	D-78-1, D-78-2
Bear Creek (Kennecott), late 1960's	sec. 35, T. 29 N., R. 9 E.	EA-1, EA-2, EA-3, EA-5
	sec. 36, T. 29 N., R. 9 E.	EA-4
North Central Mineral Ventures (Ernest K. Lehmann & Associates), 1976-1977	sec. 26, T. 29 N., R. 9 E.	PL-76-1, PL-76-5, PL-77-8, PL-77-9
	sec. 35, T. 29 N., R. 9 E.	PL-76-2, PL-76-3, PL-76-4, PL-77-6, PL-77-7
Noranda Exploration, Inc., 1977, 1986-1987	sec. 31, T. 29 N., R. 9 E.	21
	sec. 35, T. 29 N., R. 9 E.	81, 83, 89, 95, 96
	sec. 36, T. 29 N., R. 9 E.	82, 84, 85, 86, 87, 88, 90, 91, 92, 93, 94
American Copper & Nickel Co., Inc., 1980-1984	sec. 25, T. 29 N., R. 9 E.	63671, 63672, 63673, 63674, 63675, 63676, 63677
	sec. 26, T. 29 N., R. 9 E.	4100, 54773, 54935, 54936, 63297, 63298
	sec. 35, T. 29 N., R. 9 E.	54774, 54929, 54932, 54933, 63296, 63299, 63300, 63326, 63327, 63328, 63329
	sec. 36, T. 29 N., R. 9 E.	54917, 54930, 54931, 54934, 63330, 63331

[1] Data from Wisconsin Department of Natural Resources drillhole abandonment reports.

Figure 2. Bedrock geology of study area, modified slightly from LaBerge and Meyers (1983). (fmv = felsic metavolcanics, mmv = mafic metavolcanics, mg = metagabbro, wrg = Wolf River Granite)


fmv
mmv
mg
wrg
mmv
mmv
mg
27
26
25
34
35
36
82°
83°
85°
82°
83°
EAU CLAIRE RIVER
PL-1
PL-2
PL-3
PL-4
PL-5
PL-6
PL-7
PL-8
EA-1
EA-2
EA-3
EA-4
EA-5
T. 29 N., R. 9 E.
SCALE 1:24000
0 1000 2000 3000 FT.
ROAD
80° STRIKE & DIP – FOLIATION
SECTION LINE
DRILLHOLE
SHEAR
MINE SHAFT
PROSPECT PIT
OUTCROP

Field mapping in 1984 resulted in few changes to the map of LaBerge and Meyers (1983) and provided insufficient material to conduct a geologic study of the bedrock. Extensive glacial deposits have left few outcrops in the study area. The scarcity of outcrop relegates much importance to drillcores that become available for study. Eight cores (3,963 feet) drilled by North Central Mineral Ventures (in possession of the WGNHS) and five cores (2,872 feet) drilled by Bear Creek Mining Co. (Kennecott Corp.) were logged and sampled in 1984. Additional drillcores from the area belong to E.K. Lehman and Associates, of Minneapolis, Reef Exploration, of Denver, and Noranda Exploration Co. Ltd, of Toronto. Examination of 95 polished thin sections was necessary due to the aphanitic character of most of the rocks in the area. Major and minor analyses were performed by Bondar-Clegg & Co. Ltd. Ottawa, Ontario, Canada. Analyses include 42 gold assays using fire assay preconcentration of a 30 g sample and atomic absorption of an aqua regia extraction. Also performed were 26 whole rock analyses by direct coupled plasma on a borate fusion extraction, and 143 trace element analyses by direct coupled plasma on an HF - $HClO_4$- HNO_3- HCl extraction. This thesis describes the lithologies and mineralization observed in the study area, and offers a reasoned interpretation of the area's geologic history.

Most specimens referenced in this thesis are on repository with the Department of Geology and Geophysics, University of

Wisconsin-Madison under file number U.W. 1817. Specimens without a U.W. number are the property of Kennecott Corporation or the Wisconsin Geological and Natural History Survey. The convention used for naming drillcore samples is to hyphenate a core designation before a footage designation. The prefix "E" or "EA" signifies a core drilled by Bear Creek Mining Corporation whereas the prefix "P" or "PL" indicates the core was drilled by North Central Mineral Ventures. For example, E4-377 is Bear Creek drillcore number 4 sampled at 377 feet down from the collar. Outcrop samples collected from the Hatley USGS topographic quadrangle are prefixed "Oa" whereas outcrop samples from the Ringle quadrangle are prefixed "Ob".

GEOLOGIC SETTING

The study area lies near the southern margin of the exposed Precambrian shield at the confluence of the Penokean volcanic belt, the granitic Wolf River Batholith, and the Eau Claire River shear zone (LaBerge and Meyers, 1983). Several small plutons in the vicinity represent compositions from granite to gabbro. Mafic dikes are common. The eastern margin of the study area is occupied by the terminal moraine of the Green Bay lobe of the Cary advance.

The Penokean Volcanic Belt is an east-west trending, early Proterozoic (1850 Ma) tectonic terrane composed of dominantly subaqueous, basaltic to rhyolitic, calc-alkaline volcanics, with some clastic sediments (Greenberg and Brown, 1983). Based on geochemical and structural data, Greenberg and Brown propose a complex island arc setting for the belt, with a rifted continental margin and arc lying to the north. The volcanic rocks in the study area are now dominantly phyllites or phyllonites, schists and microschists. The phyllites are interlayered with granoblastic appearing, micro-porphyries. The phyllites display a characteristic banding of color and texture. They are believed to be epiclastic volcanic sandstones, barely reworked crystal tuffs, and lahars. The more massive volcanic rocks present are believed to be lava and ash flows, but could be sills. Pillow lavas were indicated by surface mapping (LaBerge and Meyers, 1983), but pillows were not identified in drillcore. The volcanics are

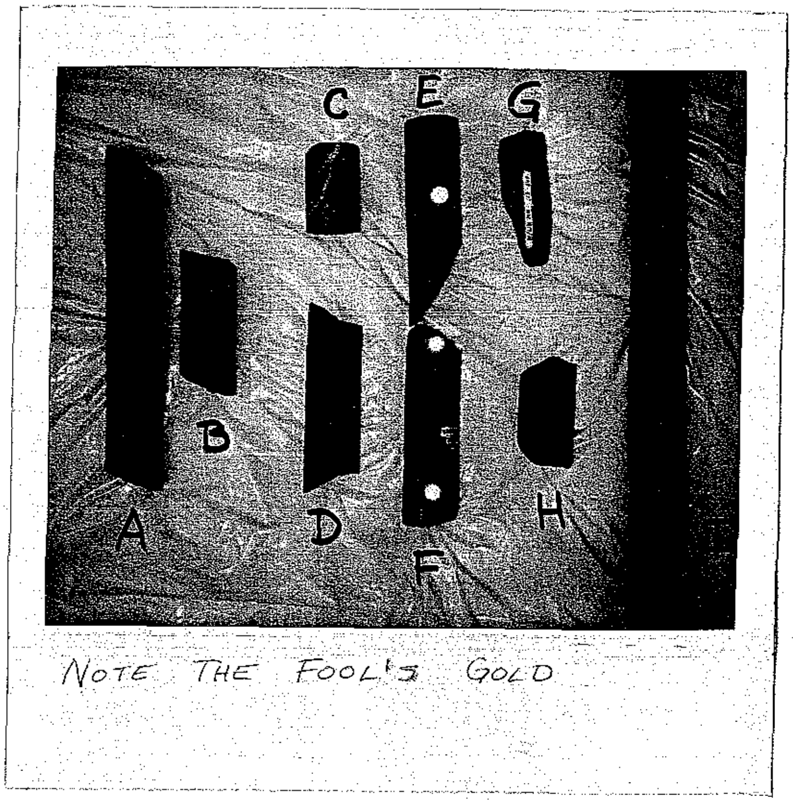


Plate 1. Representative samples of the main rock units in the study area show the contrasts in fabric: A--layered phyllitic metavolcaniclastic (PL4-545, U.W. 1817/19); B--sheared phyllitic metavolcaniclastic (PL1-598, U.W. 1817/20); C--course grained metagabbro (EA5-1072, U.W. 1817/11); D--medium grained metagabbro (EA2-87, U.W. 1817/12); E-- incipient shearing in metagabbro (EA2-66, U.W. 1817/10); F--metagabbro semischist (EA2-158, U.W. 1817/13); G--metagabbro schist (EA2-61, U.W. 1817/16); H--"salt and pepper" sheared metagabbro (PL7--269, U.W. 1817/15); I--deformed metagranodiorite (PL4-125, U.W. 1817/26).

metamorphosed to the greenschist facies, probably the result of regional metamorphism during the Penokean Orogeny (1900-1800 Ma) (Maass, 1986). Contact metamorphism to higher grades has taken place adjacent to some plutons.

The Wolf River Batholith (1485 Ma) is an anorogenic rapakivi massif composed of 11 distinct lithologies in an area of approximately 4500 km^2 (Greenberg, et al., 1986). In the study area the batholith appears as an orange, medium grained, biotite adamellite. A pink, aplitic phase is also present. These rocks look very different than the reddish, coarse grained Wolf River Granite cropping out three miles away at the intersection of County Highways Y and Z. It is not known if the adamellite in the study area is a border phase of the Wolf River Granite or a different pluton. The adamellite described by Anderson (1975) displays the pyterlite variety of rapakivi texture, in which 3-10% of the potassium feldspar grains are mantled with plagioclase. This author did not note any rapakivi texture. Perhaps the adamellite thin sections examined for this study were not representative.

Other rocks encountered in the study area include variously metamorphosed gabbro, granodiorite, and mafic dikes, listed in decreasing order of observed volume. These rocks intrude the 1850 Ma volcanics but their exact ages are unknown. Metamorphism has drastically altered the appearance of the metagabbro and metagranodiorite protoliths. The degree to which the changes were caused by kinetic metamorphism is unclear. This author believes these rocks exhibit numerous localized zones of shear stress, but evidence of the extent of shearing in the area is uncertain. LaBerge and Meyers (1983) mapped the western extremity of the study area as part of a 3 km wide shear zone, called the "Eau Claire River shear zone." Maass, (1986) disputes the existence of shearing at a locality close to the study area which LaBerge and Meyers mapped as part of the same shear zone.

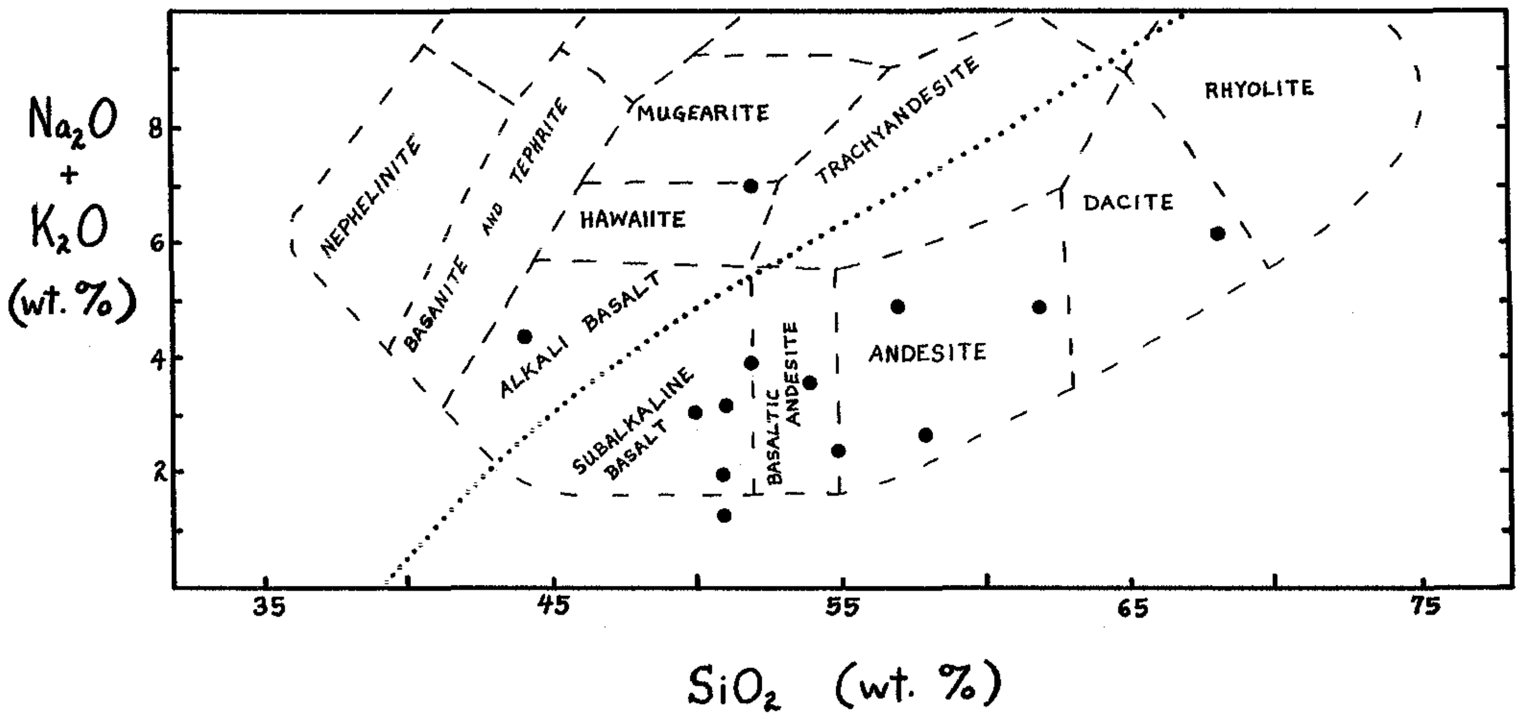
DESCRIPTION OF UNITS

Interlayered metavolcanics

The obvious commonality of the rocks of this unit is some element of a volcanic heritage. A section of metavolcanics several hundred feet thick commonly is composed of dominantly phyllitic volcaniclastics with abundant interbedded lava and ash flows several feet to tens of feet thick. The most voluminous rock in the study area consists of grayish-green banded, amphibole-biotite phyllite with a layered structure, rare sedimentary structures, broken and rounded grains, and a range of grain-size sorting. The phyllites are believed to be reworked tuffs with a coarse ash and lapilli airfall component. The lava flows are greenish-black, massive-looking microporphyritic andesites with sharp contacts. The ash flows are mottled andesites and indistinctly layered, grayish-brown diorites that may have gradational contacts. Petrographic evidence suggests that this unit is a partially recrystallized sequence of volcanic sediments and interbeded flows deposited in a subaqueous setting.

Figure 3 is an alkali-silica diagram modified from Cox, Bell and Pankhurst (1979). The figure demonstrates the mafic to felsic variability of the metavolcanics and their subalkaline affinity. The rocks plotting above the dotted alkaline - subalkaline discriminant

Figure 3. Alkali-silica plot of metavolcanics. The dashed classification fields are from Cox, Bell and Pankhurst (1979). The dotted line separates alkaline rocks (above) from sub-alkaline rocks (below) (Irvine and Baragar, 1971).



(Irvine and Baragar, 1971) contain sericite and are believed to be highly altered. It is prudent to note that all analyses presented in this study contain excess iron due to iron sulfides. The metavolcanics would plot differently if the ubiquitous iron sulfides had been separated from the rock prior to analysis. Because sulfur was not analyzed it is not possible to accurately attribute a portion of the total iron to iron sulfides. If the excess iron were corrected for, the weight percent of SiO_2 and $Na_2O + K_2O$ would increase causing the rocks to plot as a more intermediate composition on Figure 3.

Figure 4 is an A-F-M diagram, in mole percent, that clearly demonstrates the calc-alkaline trend of the metavolcanics. Correction for iron sulfide content would shift the volcanic points away from the FeO apex for the granodiorites, but the trend would be the same.

The whole-rock analyses in mole percent, and the CIPW norms for the metavolcanic rocks, are listed in Table 2. These rocks are highly altered and recrystallized. No attempt was made to make adjustments for the alteration, or for iron sulfide mineralization. The weight percent whole-rock analyses and trace element analyses are listed in Appendix A, Table A-1. These analyses suggest the metavolcanics are dominantly andesites according to andesitic compositions listed in Cox, et al. (1979), Nockolds, et al. (1979), and McBirney (1984), if the excess iron is taken into account.

Figure 4. AFM diagram in mole percent

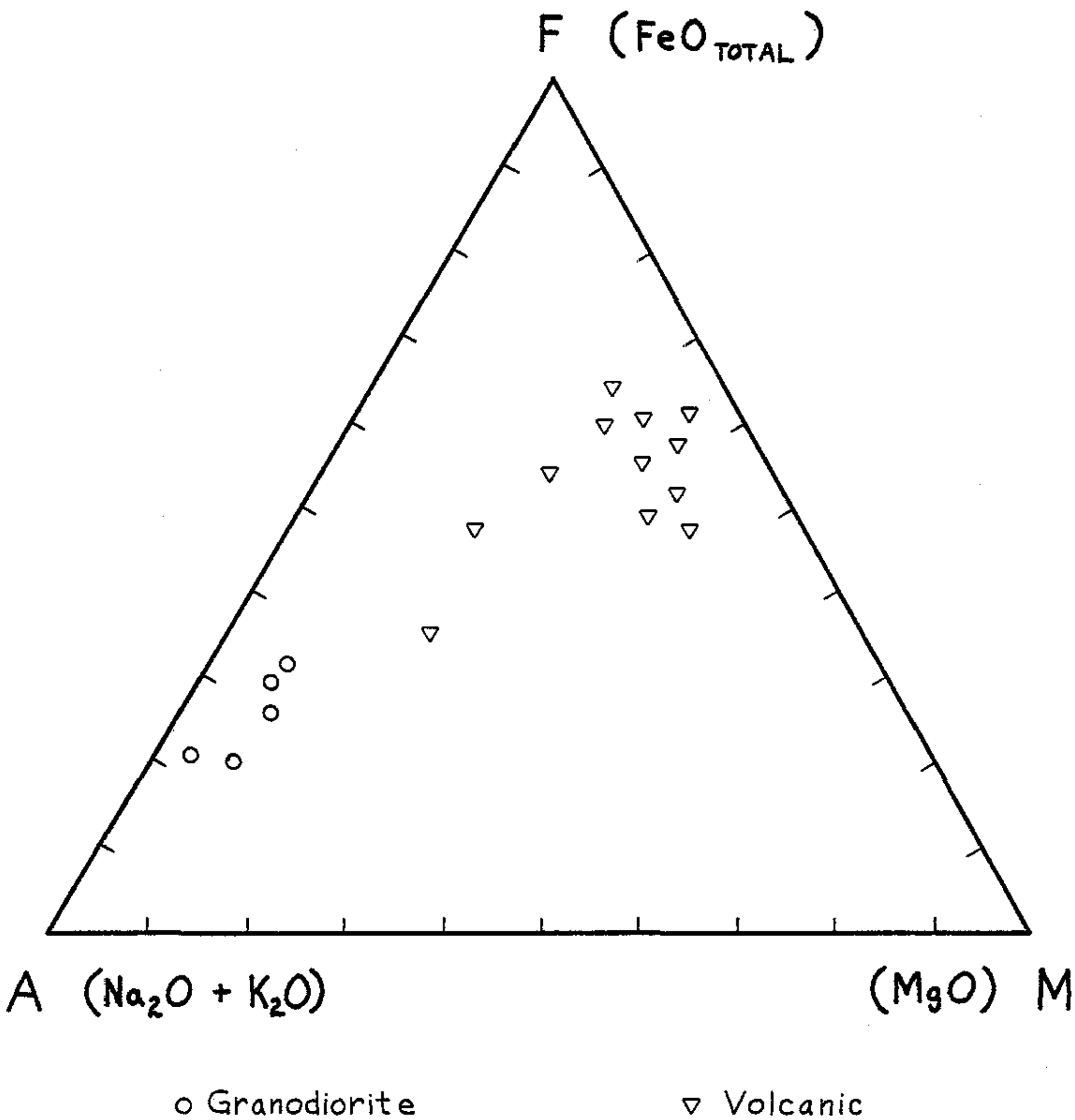


Table 2. Whole-rock analyses of volcanic rocks. The major elements are expressed in mole percent. The CIPW norm is listed. The last four samples are believed to be flows (P2-309, P3-83, P5-289, P8-500).

	P1-215	P2-271	P5-250	P5-271	P5-295	P5-297	P5-539	P5-584	P7-426	P2-309
SIO2	57.31	49.22	52.18	55.60	47.40	42.61	53.94	49.38	64.41	50.56
TIO2	0.52	0.47	0.39	0.28		0.47	0.41	0.42	0.43	0.46
AL2O3	18.27	16.50	13.47	11.94	13.94	15.86	11.98	14.91	15.65	14.71
FE2O3	0.86	2.15	1.37	1.82	1.88	2.08	1.81	1.56	0.63	1.81
FEO	4.26	10.62	6.79	8.97	9.29	10.30	8.94	7.71	3.10	8.93
MNO	0.05	0.09	0.16	0.14	0.15	0.12	0.17	0.17	0.03	0.13
MGO	3.78	10.04	11.09	7.68	14.81	19.92	9.75	12.77	4.04	8.65
CAO	6.51	0.62	8.92	9.36	7.71	2.47	8.85	6.77	1.46	8.71
NA2O	7.44	4.97	4.22	3.18	3.25	3.29	2.94	4.46	7.85	5.74
K2O	0.85	5.32	1.32	0.96	1.45	2.71	0.98	1.71	2.19	0.29
H2O+										
H2O-										
P2O5	0.14	0.01	0.09	0.07	0.13	0.17	0.25	0.14	0.20	0.02
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Ap	0.42	0.02	0.27	0.22	0.40	0.46	0.75	0.44	0.56	0.07
Il	1.51	1.39	1.18	0.80		1.24	1.20	1.29	1.17	1.39
Mt	1.91	4.81	3.17	4.01	4.40	4.16	4.04	3.70	1.31	4.21
Or	4.50	28.57	7.30	5.09	8.13	12.96	5.27	9.74	10.97	1.59
Ab	37.20	25.13	22.03	15.88	17.18	14.83	14.81	23.94	37.07	30.19
An	26.46	3.27	21.99	20.66	25.94	10.45	21.55	24.86	5.65	24.22
Di	5.70		22.74	23.61	13.76		19.86	10.55		20.29
Hy	6.54	17.03	14.65	11.33	19.68	12.33	14.88	21.40	6.96	14.11
Ol		6.87			7.73	27.21				
C		9.84				9.68			6.16	
Q	16.08		7.02	16.52			14.09	0.61	27.71	3.76
Total	100.32	96.93	100.36	98.11	97.23	93.33	96.44	96.53	97.56	99.83

Table 2 continued.

	P3-83	P5-289	P8-500
SIO2	47.88	47.55	49.14
TIO2	0.47	0.46	0.53
AL2O3	16.52	15.00	15.04
FE2O3	1.73	1.75	1.75
FEO	8.53	8.63	8.63
MNO	0.18	0.16	0.14
MGO	10.60	11.02	11.56
CAO	12.09	9.93	10.07
NA2O	1.62	5.12	1.54
K2O	0.31	0.30	1.31
H2O+			
H2O-			
P2O5	0.06	0.08	0.28
TOTAL	100.00	100.00	100.00
Ap	0.20	0.24	0.88
Il	1.43	1.36	1.62
Mt	3.99	3.90	4.04
Or	1.73	1.60	7.26
Ab	8.47	25.79	8.07
An	40.37	25.63	33.78
Di	22.01	22.66	16.45
Hy	15.71	11.39	18.38
Ol		6.05	
C			
Q	5.77		7.14
Total	99.68	98.63	97.63

Volcaniclastics: Banded or layered, phyllitic to schistose volcaniclastics form the volumetrically dominant lithology in the study area. Schists are rare in this fine-grained unit. Greenish, intermediate compositions predominate, but tan, sericite-rich, felsic compositions are present. Compositional and textural layering is the most distinctive characteristic of this extremely heterogeneous lithology.

In the intermediate phyllites, thin biotite-rich layers (0.5 mm - 2 cm) are separated by equally thin layers of lineated green amphibole plus feldspar and quartz. The thickness of an individual layer generally changes across the 3.7 cm width of a BQ core sample. The overall appearance is one of pronounced layering with common necking-down or flaring-out of layers and less common, oddly-shaped masses sandwiched between layers. Compositionally distinct lenses and oddly-shaped masses with sharp upper, lower and latteral boundaries are common. Some compositional layers display ragged, intertonging, and somewhat gradational, latteral boundaries. Most layers are planar or slightly wavy, but convolute layering is also present.

Textural layering is present but less obvious than the compositional layering. Narrow zones of extremely thin (< 2 mm) lensoidal layers are present but uncommon (PL1-598, U.W. 1817/20). Some layers of phyllite are dotted with whitish, feldspar magacrysts. Different layers of phyllite vary from poorly sorted and unlayered to size-sorted or even graded. Sedimentary structures observed in drillcore include lensing, intertonging, grading, rough cross-bedding, soft-sediment deformation and slump deposition.

In thinsection, the intermediate phyllites are microporphyritic. Their grain size is variable. Compared to the smaller grained samples, the larger-grained samples are more variable in grain size and contain a higher proportion of phenocrysts. The groundmass is dominated by untwinned feldspar but also contains quartz and may contain variable proportions of amphibole and biotite. The phenocrysts are coarse ash to lapilli of quartz and feldspar. Some euhedral faces are preserved but most phenocrysts are broken and sub-angular to sub-rounded. The smaller grained samples display a more highly developed compositional and textural layering and contain fewer phenocrysts. Quartzo-feldspathic layers are separated by minutely thin, sharply bounded, dark-colored seams composed of amphibole, biotite and sericite. Grain size within a quartzo-feldspathic layer is uniform, but varies from layer to layer.

A rare but distinctive texture, probably tuffaceous, is interlayered with the phyllite. These appear as spotted zones (3-20 cm thick) which contain sparsely distributed, rounded to subangular, white, feldspar megacrysts (0.5-1 mm) set in an aphanitic matrix (PL4-245, U.W. 1817/2). Some of these zones exhibit gradational packing density of the feldspar spots from one end of the zone to the other. Rarely, the megacrysts are up to 6 mm long. These large megacrysts are elongate, may have conformable trailing edges and may occur with yellowish, elongate, possibly multimineralic (lithic) megaclasts (1 cm) (PL5-352, U.W. 1817/3).

Incipient to weak, biotitic foliation is present in some massive-looking to indistinctly-laminated phyllite. Each folia is composed of fine biotite flakes which are densely clustered to form a thin, planar lense conformable with the layering. The lenses are roughly circular in plan view (5-15 mm diameter) and appear as short, dark streaks in cross section. The biotite folia occur within distinct cross-sectional zones 5 cm to 1 m thick. In the narrower zones, the folia are more densely distributed toward the center of the zone. In the wider zones, the density of cross-sectional distribution of the folia alternates from sparse to dense, like a group of narrow zones. These biotite-spotted phyllites may represent an immature stage in the development of a compositionally banded phyllite. Biotite-spotting also occurs in some massive looking phyllites, suggesting the possibility that some banded phyllites are metamorphosed or metasomatized flows. Metasomatism could have produced banded phyllites from any of several protoliths.

Mineralization is also characteristic of this unit. Quartz, pyrrhotite, pyrite, chalcopyrite, magnetite, epidote, green amphibole, and rarely chlorite, are localized in lenses, pods, undulating layers, stringers and veins. Where present, although these mineral bodies are commonly concordant with lithologic layering, many of them crosscut the layering suggesting a secondary origin for at least some of the mineralization. The concordant quartz bodies and some of the vein-like sulfide accumulations appear to be bedded. Perhaps some of the quartz bodies are metachert nodules. Evidence of secondary mineralization includes symmetrical banding of vein sulfides, sulfide veins crosscutting lithologic layers, and mineral segregation bands parallel to some concordant quartz bodies. The segregation bands are green, brown or white in color. Adjacent to the vein are green bands consisting of amphibole and plagioclase. The brown bands are biotite and plagioclase. A white band of plagioclase may separate the green and brown bands. In thin section, these bands appear as coplanar layers of lineated, euhedral crystals of amphibole or biotite forming a strong fabric in a vague, granular, feldspar mosaic.

Flows: A minor proportion of the metavolcanic unit is composed of massive to indistinctly-layered, andesite and diorite flows which are randomly interbedded with the volcaniclastics. Upon cursory examination, the flows appear to be unusually-wide mineral segregation bands in phyllitic volcaniclastics. However, the absence of planar fabric distinguishes the flows from the volcaniclastics. Whereas the volcaniclastics fracture predictably along a strong foliation which displays the characteristic phyllitic sheen, the flows fracture along randomly oriented, hackly surfaces. What appears in the field as a greenish-black massive basalt, is a microporphyritic andesite in thinsection. The grayish-brown diorite is an indistinctly-laminated to mottled, granular to inequigranular, quartzofeldspathic rock that may grade into laminated phyllite. The irregularly shaped quartz and sulfide bodies, so common in the volcaniclastics, are absent in the basalt and uncommon in the diorite. Coarse schists are believed to be metabreccia zones, not flow-top breccias. Pillows were not identified in drillcore but are reported from the vicinity (LaBerge and Meyers, 1983).

The flows are the most uniform rocks in the metavolcanic unit. These rocks may be equigranular but are generally microporphyritic, rarely micro-glomeroporphyritic, with an intergranular to trachytic groundmass. The phenocrysts are relict euhedral laths of feldspar. Rarely present are equant, relict, plagioclase megaphenocrysts. The recrystallized groundmass is made of approximately equal proportions of feldspar laths, green amphibole prisms and brown biotite flakes. Accessory minerals include scattered opaques. Quartz is absent. As compared to the light colored diorites, the basalts are dark colored, contain more green amphibole and less feldspar, and are slightly finer grained.

Metagranodiorite

This unit includes several lithologies, all believed to have formed from a similar protolith. These rocks are foliated and unfoliated, light gray to brownish-gray, quartz-feldspar rocks of medium to coarse grain size. Their textures range from hypidiomorphic-granular to pseudo-porphyritic to schistose. The pseudo-porphyritic rocks look porphyritic but may be porphyroclastic or porphyroblastic. They are sheared and metasomatized granular rocks without visible K-spar.

The hypidiomorphic-granular rocks are medium grained, modal granodiorites (E5-1005, U.W. 1817-7). Their texture is serriate, the finest grains being interstitial potassium feldspar. The potassium feldspar and some plagioclase grains exhibit recrystallization into very fine, rounded subgrains. Small amounts of opaque minerals are present on fractures. Sample Oa-26 (U.W. 1817/8) is a fine grained, pink, aplitic granodiorite found as float together with float from the Wolf River Batholith. Except for color and grain size, sample OA-26 looks like sample E5-1005.

The pseudo-porphyritic samples are coarser grained and modally tonalitic. They are strongly lineated by aligned, elongate plagioclase grains, or relict plagioclase grains now composed of sericite. The proportion of quartz varies but potassium feldspar is absent. Accessory biotite and opaque minerals account for a small proportion of the rock. The porphyritic constituents are set in a dark, aphanitic, equigranular matrix which accounts for 25 to 50% of the rock. Rocks with a higher proportion of matrix are darker in color and display a strong fabric in which the quartz megacrysts are more rounded and the plagioclase megacrysts are elongated and more sericitized. These differences are believed to derive from the deformational history of this unit.

Relatively undeformed or unaltered protolith is illustrated by thinsections PL2-131 (U.W. 1817/4) and PL2-124 (U.W. 1817/5). Many of the megacrysts, both feldspar and quartz, are fractured and display pronounced fracture trace comminution. Quartz grains are highly strained and partially broken into subgrains. Most of the quartz and some of the plagioclase megacrysts display sub-rounding caused by grain edge comminution. Sericite has replaced plagioclase along fractures and also in the cores of grains. Approximately 40% of each sample is composed of a fine quartz-plagioclase matrix with scattered biotite and chlorite accounting for another 5 to 20%.

A relatively deformed portion of the unit is illustrated by thinsection PL4-96 (U.W. 1817/6). It is a fine grained, sericite-rich rock composed of 20% quartz megacrysts. Most megacrysts are well rounded and consist of two parts; a mass of strained quartz showing grain-edge and fracture-trace comminution and an adjacent mass of less-strained quartz subgrains. Some megacrysts have been completely broken down into subgrains. The groundmass is of very fine grained, equant, unstrained quartz and feldspar with a strong fabric resulting from oriented, elongate masses and sub-rectangular blocks of sericitized plagioclase feldspar.

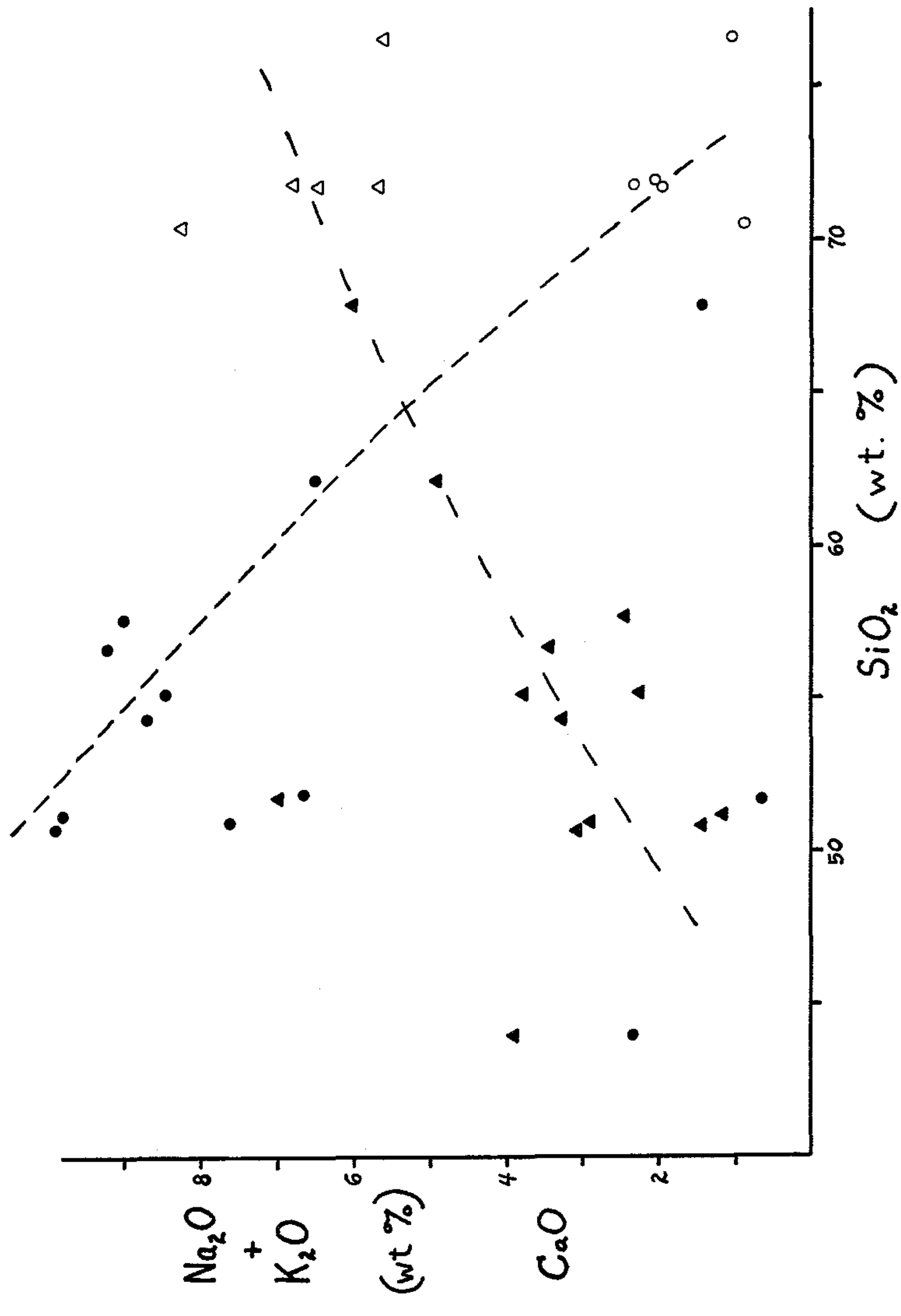
Several possible protoliths were considered for this unit before selecting a granodiorite intrusive. The silica contents suggest these rocks could be rhyolites, but they are alkali-deficient (table 3, figure 5), and the modal composition is too low in potassium feldspar. The whole rock analyses of table 3 and table A-2 are not corrected for alteration or iron sulfides, both of which are present. Sample E5-1005 contains the least amount of sulfides and looks the least altered (U.W. 1817/7A).

The textural differences could indicate that these rocks are from several rock units and should not be lumped. The modal granodiorites (E5-1005 and OA-26) were collected close to the contact with the Wolf River Batholith. Their fine-grain size, visible potassium feldspar, and dike-like occurrence suggest that these rocks could be offshoots of the Batholith. In contrast, the tonalites could be lapilli tuffs. Their bimodal grain size is consistent with volcanic rocks. The preferred orientation of the megacrysts could be a flow fabric. Figures 4 and 5 could be interpreted to suggest that the granodiorites

Table 3. Whole-rock analyses of metagranodiorite. The major elements are expressed in mole percent. The CIPW norm is listed.

	P2-124	P2-148	P4-111	P4-117	E5-1005
SIO2	67.81	65.24	69.35	68.49	74.20
TIO2	0.07	0.08	0.07	0.07	0.12
AL2O3	15.47	16.36	15.16	15.72	13.13
FE2O3	0.41	0.29	0.39	0.34	0.20
FEO	2.01	1.43	1.93	1.66	0.99
MNO	0.02	0.01	0.01	0.02	0.01
MGO	1.15	1.35	1.08	1.31	0.39
CAO	2.11	0.95	2.48	2.06	1.10
NA2O	7.75	12.95	6.83	6.80	8.64
K2O	3.16	1.24	2.58	3.41	1.16
H2O+					
H2O-					
P2O5	0.04	0.09	0.12	0.12	0.06
TOTAL	100.00	100.00	100.00	100.00	100.00
Ap	0.11	0.27	0.34	0.33	0.15
Il	0.20	0.21	0.17	0.19	0.32
Mt	0.85	0.62	0.80	0.69	0.40
Or	15.76	6.33	12.57	16.78	5.55
Ab	36.38	62.30	31.35	31.47	38.92
An	10.15	4.06	11.07	9.14	4.80
Hy	2.93	2.76	2.72	2.80	1.11
C	0.88	1.08	2.17	3.22	2.31
Q	30.24	20.41	35.63	33.34	43.02
Total	97.51	98.03	96.81	97.95	96.59

Figure 5. Peacock plot showing calc-alkaline to calcic series of metavolcanics (solid symbols) and metagranodiorites (open symbols). CaO is denoted by circles, alkalis by triangles.


Na2O + K2O (wt %)
CaO
SiO2 (wt. %)
50
60
70
2
4
6
8

are differentiates of the same magma that produced the more mafic volcanics.

I believe the granodiorites and tonalites are deformational variants of the same granodiorite intrusive The potassium feldspar in the granodiorites is interstitial to quartz and plagioclase, and alters to fine, rounded grains before the quartz and plagioclase become altered. The small, roundish crystals that replace the potassium feldspar look just like the fine matrix grains in the tonalites. The tonalites were collected closer to the Eau Claire River shear zone than were the granodiorites. Shear-zone-related deformation and metasomatism would be most intense close to the shear zone. I believe that metamorphic fluids emanating from the shear zone, and slight shear deformation, are responsible for preferentially altering and replacing potassium feldspar before plagioclase or quartz. This process is responsible for changing a granodiorite into a tonalitic quartz-eye porphyry with elongated, sericitized, relict plagioclase megacrysts.

Metagabbro

The metagabbro unit exhibits considerable variation in grain size and texture, from a coarse grained, poikilitic amphibolite to a medium grained, plagioclase porphyry to a fine grained, schistose amphibolite. The coarse grained and poikilitic varieties are rare. In drillcore these varieties exhibit a distinctive, subdued mottling caused by reflections off of amphibole cleavage surfaces. The observed textural variation roughly correlates with the distance from the Eau Claire River shear zone. Finer grained, schistose variants are common in the western half of the study area, proximal to the shear zone. Larger grained, granular and poikilitic variants are common in the eastern half of the study area, distal to the shear zone. The pyrrhotite and magnetite content of these lithologies makes them magnetic. The more schistose variants are the most highly magnetic.

The most common metagabbro is a greenish, medium grained, hypidiomorphic granular to porphyritic rock consisting of dark green, anhedral amphibole and pale green or gray, euhedral to subhedral, plagioclase blocks. The plagioclase proportion varies from 40-90% and creates a broad layering. Accessory pyrrhotite, pyrite and magnetite are disseminated throughout. Abundant epidote, zoisite, chlorite, and quartz may be present. Intergrowths of magnetite and minor pyrite appear on cleavage traces of some altered plagioclase crystals. Quartz veining may be present. Sample EA2-87 (U.W. 1817/12) typifies the common, medium grained, metagabbro lithology. This rock consists of 65% gray, transparent, euhedral and subhedral, blocky to lath-shaped, medium grained, plagioclase phenocrysts in a dark green, aphanitic groundmass with rare, medium, subhedral grains of dark green amphibole. The phenocrysts are often glomerophyric and may exhibit hairline fractures with a dark green filling. Accessory pyrite is disseminated in the groundmass.

Coarse grained, poikilitic varieties are rare. They were observed in drillcore from the eastern half of the study area. In drillcore these varieties exhibit a distinctive, subdued mottling caused by reflections off of amphibole cleavage surfaces. The archetypical example is a poikilitic amphibolite, sample EA5-1072 (U.W. 1817/11). It is dark green with grayish mottling. It consists of 60% very coarse to coarse grains of green amphibole, and 40% medium to coarse, pale gray, translucent, anhedral feldspar grains. On one end of the sample an amphibole oikocryst is optically continuous across the entire width of the BQ core (3.7 mm). This megacryst is studded with relict, anhedral, plagioclase chadacrysts, now consisting of plagioclase, zoisite, epidote and chlorite.

A fine grained, schistose amphibolite is the predominant variety of metagabbro in the western half of the study area. This rock is a strongly magnetic, "salt and pepper" speckled, schistose magnetite-biotite amphibolite. Quartz and pyrrhotite may be present. It may also contain rare lenses of medium grained, anhedral to subhedral, plagioclase phenocrysts set in a dark green matrix. Sample PL7-269 (U.W. 1817/15) is a typical example. It is grayish-green and distinctly speckled when dry. The mineralogy is pyrrhotite-biotite-quartz-magnetite-feldspar-amphibole. Schistosity is poorly developed. In thinsection, stringers of biotite and magnetite are separated by intergrowths of anhedral quartz and green, relict, amphibole grains. One of the more schistose samples is EA2-61 (U.W. 1817/16). It consists of well developed foliae of brown, fine-grained biotite sheathed by dark green laminae of feldspar and amphibole. Anomalously, this sample is not magnetic.

There is a visual similarity between some units logged as metagabbro and others logged as metavolcanic, but a gabbroic protolith is proposed for several reasons. First, the relatively uniform size and unrounded condition of the feldspar grains, and the simple, amphibole-feldspar mineralogy of these rocks, are in sharp contrast to other volcanic rocks in the area. Second, the whole rock analyses and normative compositions are consistent with a gabbroic to ferro-gabbroic composition (table 4 and table A-3). Third, the amphibole-plagioclase rocks seen in drillcore would be gabbros if the amphibole were pyroxene, and the area has undergone greenschist facies regional metamorphism, which may have changed the pyroxene to amphibole. Lastly, drillcore samples reveal gradual transitions in grain size and proportion of feldspar phenocrysts. These transitions are suggestive of a broadly layered pluton. The drillcore samples also reveal transitions from one fabric to another. These transitions are suggestive of shearing.

Table 4. Whole-rock analyses of metagabbroic rocks. Major elements are expressed in mole percent. The CIPW norm is listed.

	P2-211	P2-260	P7-269	P7-275	E2-87
SIO2	45.45	45.96	45.83	45.50	47.47
TIO2	2.61	2.68	2.40	2.50	0.18
AL2O3	14.21	13.85	13.59	13.18	21.79
FE2O3	2.99	3.05	2.98	3.02	1.15
FEO	14.80	15.04	14.74	14.94	5.68
MNO	0.24	0.26	0.25	0.22	0.13
MGO	6.83	7.15	6.39	7.15	6.65
CAO	9.09	8.55	8.12	8.03	10.99
NA2O	2.34	2.35	2.22	2.94	4.40
K2O	0.85	0.55	3.08	1.80	1.49
H2O+	nd	nd	nd	nd	nd
H2O-	nd	nd	nd	nd	nd
P2O5	0.58	0.55	0.41	0.70	0.07
TOTAL	100.00	100.00	100.00	100.00	100.00
Ap	1.87	1.75	1.26	2.27	.21101
Il	8.14	8.38	7.25	7.92	.52752
Mt	7.12	7.26	6.88	7.30	2.53
Or	4.87	3.16	17.05	10.43	7.87
Ab	12.56	12.68	11.57	16.04	21.91
An	31.40	31.28	22.90	24.43	42.02
Di	12.26	10.19	14.98	12.64	13.05
Hy	17.44	18.61	15.77	18.32	8.24
Ol	nd	nd	nd	nd	2.43
Q	5.52	7.26	1.01	2.36	nd
Total	101.17	100.56	98.68	101.71	98.78

One transition that has been observed is a plagioclase porphyry grading into a schist via a flasure porphyry intermediary. The flasure textured metagabbro exhibits lenses of feldspar porphyry with hairline-cracked phenocrysts intercalated with an aphanitic, wispy appearing, dark colored, foliated mortar (EA3-182, U.W. 1817/9). As the width and total proportion of the mortar increases, the rock becomes phyllitic or schistose but still contains widely spaced, porphyritic lenses with sharp boundaries. The transition to schist may occur over intervals of meters to less than 5 cm. In drillcore sample EA-2 at 66' (U.W. 1817/10), randomly orientated euhedral plagioclase grains are set in interstitial green amphibole. As one moves 5 cm down the core axis the phenocrysts gradually adopt a preferred orientation, become stretched, and then smeared into very fine laminae. Some of the well foliated metagabbros display highly contorted, flame-like lamination, suggestive of a plastic state (EA-5, 1060-1090).

Although the foliation of the schistose amphibolite rocks is closer to that of a gneiss than a schist, based on the proportion of platy minerals in the rocks composition, this rock will be referred to as a "salt and pepper" schist or simply a "schist" for the sake of convenience.

Diabase

Several cores are cut by diabase dikes. The dikes range from 2.5 cm to 4.5 m in thickness, but most dikes were from 0.5 to 2 m thick. The dikes have very sharp contacts with their hosts and chilled margins are common.

The dikes vary in quartz content, grain size, texture and fabric. In general they are magnetic, dark colored, aphanitic to fine grained, microporphyritic to porphyritic, biotite-plagioclase diabases with substantial amounts of magnetite. The typical dike has plagioclase phenocrysts in a plagioclase-biotite-magnetite groundmass. The feldspars may show a random orientation or a strong, preferred orientation. Several of the dikes had a strongly lineated, speckled appearance (PL1-589-600). Substantial amounts of magnetite occur as disseminated microcrystalline dust, or narrow rod-like to worm-like bodies, or as fine, subhedral grains. These three morphologies were not observed together in the same thinsection. Less than 5% quartz was present as large and small anhedral and subhedral grains in one of the sampled dikes (PL8-475, U.W. 1817/17). In this rock, a few megacrysts of anhedral magnetite, subhedral quartz, biotite and pyrite, and blocky plagioclase are set in a groundmass of randomly oriented, equigranular, plagioclase laths with interstitial biotite, quartz and magnetite. Whole-rock analyses of several dikes appear in Table 5. Although most of these dikes have been metamorphosed, they are not unusual for Wisconsin (Mudrey and Meyers, 1985).

Table 5. Whole-rock analyses of diabase dikes. Major elements are expressed in mole percent. The CIPW norm is listed.

	P2-570	P4-466	P5-260
SIO2	36.77	42.59	43.43
TIO2	2.94	2.82	2.13
AL2O3	18.94	16.70	13.12
FE2O3	2.76	2.76	2.64
FEO	13.64	13.61	13.03
MNO	0.21	0.20	3.72
MGO	6.23	5.49	6.54
CAO	6.92	6.30	8.66
NA2O	6.09	5.06	4.93
K2O	3.34	2.59	1.47
H2O+			
H2O-			
P2O5	2.17	1.88	0.34
TOTAL	100.00	100.00	100.00
Ap	5.83	5.62	0.97
Il	7.71	8.19	6.02
Mt	5.51	6.11	5.69
Or	16.00	13.79	7.60
Ab	13.96	25.37	24.04
An	15.81	16.78	17.38
Di			20.04
Hy		12.29	0.97
Ol	22.51	5.61	21.29
Ne	7.31		
C	5.11	5.31	
Total	99.75	99.08	104.01

DEFORMATION OF UNITS

A structural analysis of the study area is limited by the paucity of exposed bedrock and the narrow width of the drillcores. Several observations suggest that although cataclasis has taken place in the area, it may be confined to numerous narrow zones. The following paragraphs discuss the observed structures and textural features for each of the dominant lithologies. Details on textures and mineralogy are provided in the previous chapter.

Observed features

Two folds were observed in an outcrop of banded to laminated, aphanitic silicious rock (Ob-13, U.W. 1817/18) (NE/SW/SW sec. 27). They are Z-shaped, asymetrical, tight, Class 3 folds (Ramsay, 1967). The best preserved fold has a fold width of approximately 2.5 cm and a fold height of approximately 3 cm. The axial plane is approximately vertical and trending N. 30 E. One limb was greatly thinned. Extreme limb thinning obscured the nature of the other fold seen at this outcrop. Very small folds were observed in a green phyllite collected from an outcrop in NE/NE/NE sec. 27 and in a phyllitic core sample, PL4-545 (U.W. 1817/19). They were Z-shaped tight folds with fold widths and heights of approximately 2 mm and 5 mm respectively. The fold in the green phyllite was destroyed when the rock fractured during sawing. Curving lines of lineated, green amphibole prisms, believed to be, sheared-off micro-folds, occur in schistose amphibolite in thinsection EA2-158 (U.W. 1817/13). They appear as C- or U-shapes with one stretched limb and the other limb abruptly truncated. These structures could be remnant crenulation but their rarity and isolation suggest otherwise. Only a few were observed, and rarely more than one per slide. If the lineated amphiboles were crenulation, their presence in thinsections would be expected in greater numbers. Crenulation with wavelengths of about 2 mm is common in felsites and phyllites.

Two, white, well-rounded, oblong inclusions of coarse-grained quartz and feldspar (6x10 cm and 1x3 cm) are aligned along the trend of lamination in a fine grained, laminated porphyry in which quartz and feldspar phenocrysts float in aphanitic, dark-colored matrix (NE/NE/SW sec. 27). These inclusions are believed to be boudins formed from a more felsic portion of an originally layered protolith. The same outcrop displays pinch-and-swell structures in quartz layers and lenses. Another boudin, lenticular in cross section and tapering along its length, consists of layers of pink feldspar and white quartz in a host of brownish, crenulated phyllite (NE/SW/SW sec. 27). All of these boudins could have formed from quartzofeldspathic veins of composition similar to coresample E5-1005 (U.W. 1817/7), an almost white, granoblastic metagranodiorite.

A sample of breccia was collected as float from a hole believed to be a prospecting pit or mudpit in SW/NE/SE sec. 26. The sample measures 14 x 17 cm with an almost uniform width of 3 cm, suggesting it came from a narrow vein-like zone. It consists of angular fragments of gray quartz (to 4 cm) in a red and yellow, weathered matrix. Thin zones of breccia, lithologically different than the one found as float, were observed in drill cores (P5-470, 4 cm; P5-260, 1 cm; P5-262, 2.5 cm, magnetic; P6-172, 2 m, schist with sulfide stringers).

Faulting is evident in many drill cores, made apparent by slickensides on fracture surfaces, by offsets in quartz lenses and veins, and by en-echelon offsets in mafic veins. One sample displays razor sharp contacts which neatly terminate clasts and separate foliations that occur at different orientations to the core axis (PL4-125, U.W. 1817/26). A micro-fault was observed in a thinsection of volcanic sediment (Ob-15a, U.W. 1817/25) and numerous 3 mm fault-like offsets appear in the laminations of a felsic layered phyllite (Ob-18, U.W. 1817/21). Conjugate shears are common in silicified units and massive units (PL2-51, U.W. 1817/22). An absolute lack of continuity of units between drillholes frustrated efforts to draw cross-sections and suggests the presence of many faults.

Discussion of Deformation

Although some degree of shearing is strongly suggested by the textures and fabrics of most rocks in the area, shearing seems more pervasive in the western half of the area than in the eastern half. The degree of shearing may be relatively constant over wide intervals of drillcore, or it may change repeatedly within a given rock unit. Gradual change from more- to less- to more-sheared is common. The changes may take place over wide or narrow intervals. Variation in the degree of shearing is recognized megascopically by the size and rounding of grains, and microscopically by granulation of grains and formation of fluxion structures. Changes in degree of shear often occur at protolithologic contacts. These changes are especially abrupt where magnetic schistose amphibolite (sheared gabbro) is in contact with metavolcanics. These abrupt changes could represent sheared and unsheared lenses of rock that have been brought into fault contact. Alternatively, they could represent originally adjacent rock bodies that reacted differently to applied stress because of fundamental differences in their mineralogies.

Some protoliths are more suitable than others for yielding information to substantiate the presence of shearing. This suitability is partially dependent upon the magnitude of the difference in appearance between a given unshared lithology and a cataclasite of similar grain size. Fine-grained volcaniclastics could be sheared but not recognized as such. Their fine grain-size and layered texture would not be greatly altered by shearing. The large, interlocking grains of plutonic rocks are better suited to displaying the effects of shear, simply because their primary grain size, texture and fabric are in great contrast to the sheared equivalent.

Deformation of layered metavolcanics: Proof of shearing is difficult to establish for these fine grained rocks. The primary characteristics of volcanic tuffs and flows, and depositional characteristics of volcaniclastic sediments appear very similar to cataclastic granularity, layering, and stretching and rounding of clasts (Higgins, 1971). Metamorphic recrystallization can easily obliterate many features in fine grained rocks that could have served as evidence for or against shearing.

The contribution of shearing in development of the laminated and lensoidal fabric of the phyllites is believed to be minor in comparison to that which resulted from sedimentary deposition. Because all of the observed features can be explained by a sedimentary depositional environment, evocation of strong cataclasis and mylonitization is not necessary to explain the fabric seen in these rocks. Some cataclasis could be expected at the rates of strain associated with regional folding, thereby imparting some cataclastic features to a rock dominated by sedimentary features. Regional folding is able to produce slippage along pre-existing layering, to bend cleavage and twin planes, and to crack quartz grains. These facts lead to the conclusion that the presence or absence of major shearing in the study area cannot be determined from the layered phyllites alone (U.W. 1817/18A, U.W. 1817/18B, U.W. 1817/18C).

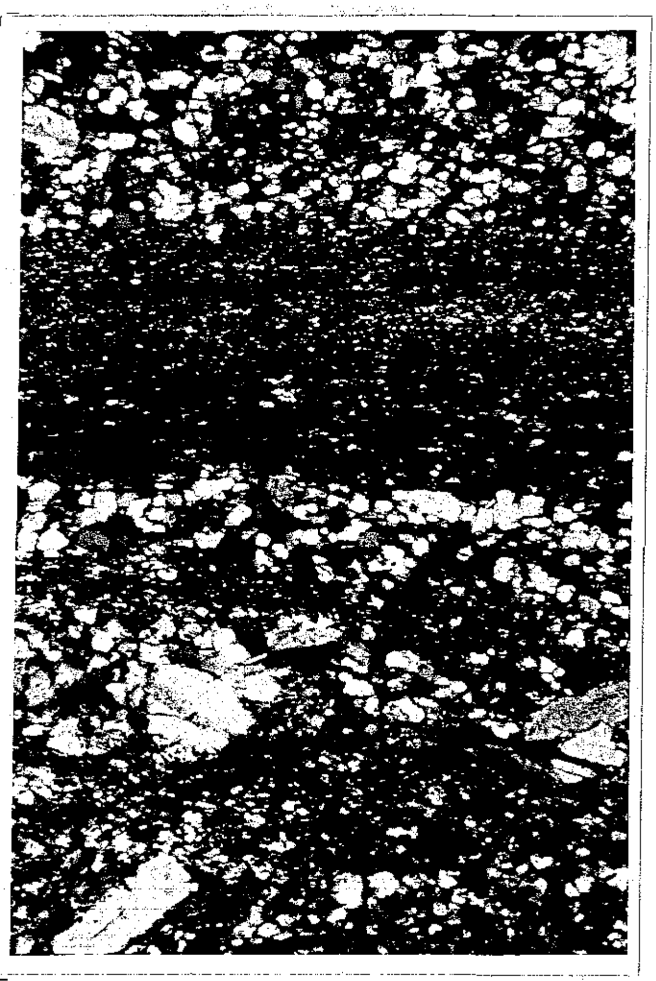


Plate 2. Grain size variation in phyllite from within the Eau Claire River shear zone. Well-sorted finer grained layers are intercalated with poorly sorted layers and lenses (OB-19, U.W. 1817/27).

Deformation of metagranodiorite: The variable textures of the metagranodiorite are suggestive of deformation. The observed parallel orientation of grains could develop during emplacement of a not-quite-consolidated magma (protoclastic gneiss). However, other features observed in the metagranodiorites would not be expected in a protoclastic gneiss and are more suggestive of shearing. These features include a bimodal grain size distribution in which strained, broken, rounded megacrysts float in a much finer grained, granular matrix. This observed texture is similar to the proto-mylonites and mylonite gneisses of Higgins (1971) and suggests that these rocks have been sheared, some to a fairly high degree.

Bell and Etheridge (1973) discuss four progressive stages of shearing. Quartz is the first mineral to show microscopic evidence of shearing. This includes undulose extinction, polygonalization, deformation banding, and eventual growth of new grains with serriate boundaries. More shearing produces quartz ribbons. Feldspar shows less evidence of deformation than quartz under a given degree of strain, but the effects are similar. Feldspar forms subgrains and exhibits grain edge and fracture trace comminution. Recrystallization of feldspar results in smaller grains than in quartz.

Examination of the granodiorites in thinsection reveals many of the mylonitic features indicative of stage two shearing. Nonetheless, I believe the strong fabric of the metagranodiorites is dominantly protoclastic, the rocks having been sheared only slightly. Quartz is more susceptible to granulation upon shearing than is feldspar. A sheared granodiorite should have granulated or ribboned quartz coexisting with less deformed feldspar. These rocks show fracture trace and grain edge comminution, and grain rounding, of both quartz and feldspar, but to only a slight extent. Quartz grains with relict crystal faces are still present in the relatively unsheared rocks (PL2-131, U.W. 1817/4, PL2-124, U.W. 1817/5). The quartz megacrysts in the relatively sheared rocks are not much different than in the relatively unsheared rocks. I believe metasomatism has affected these rocks, causing the alteration of potassium feldspar before plagioclase. Metasomatism could be responsible for recrystallization that appears to be shear-related comminution. Concurrent shearing and metasomatism could produce a hybrid rock exhibiting characteristic features of each process.

Deformation of metagabbro: The best evidence for shearing occurs in the metagabbro where a porphyry grades into a schist via an intermediary texture in which lense-shaped bodies of porphyry float in an anastomosing, vein-like, microgranular, recrystallized groundmass. The anastomosing aphanitic matrix is like the finely comminuted mortar of a sheared environment. The schist exists over a core intersect of at least 5.8 m with intercalated porphyry and semischist extending an additional 21 m. The intercalation of rocks of differing grain size is common. The bounding surfaces of the lensoidal bodies are sharp

(EA-5, 1100-1150'). The "salt and pepper," magnetic schist is frequently of finer grain size near contacts, grading into a coarser grained interior. Bell and Etheridge (1973) found that grain size diminished in areas of greater ductile shear. Perhaps the central portion of the "salt and pepper" schist moved as a unit relative to the exterior portions which would be in friction with the surrounding, less mafic, more resistant lithologies. The surrounding lithologies display gradational contacts presumably caused by shear stress produced from friction with the mobile schist. At the contact the surrounding lithology displays the grain size and "salt and pepper" fabric like that of the schist. This texture grades over a short interval into the characteristic texture of the particular unit. The exact contact is marked by the persistent absence of magnetic attraction, suggesting the lack of in-sheared metagabbro.

Although some shearing is apparent, extensive thicknesses of mylonites were not definitely identified. The rocks from the study area that fall within the Eau Claire River shear zone (LaBerge and Meyers, 1983) derive their grain size and texture from primary volcaniclastic deposition but also show the affects of minor shearing. They are exceedingly fine-grained, phyllitic metavolcanics, admittedly close to being phyllonites. Rounded feldspar microphenocrysts rotated into the foliation with tails of gradually diminishing grain size surrounded by dark colored fluxion structure are definite evidence of shearing. In the same rocks, feldspar laths oriented perpendicular to the layering and foliation suggest the absence of shearing. If these laths are porphyroblasts grown during post-shearing cooling in response to a newly oriented stress regime, I would expect to see fresh growth on the rounded, rotated micro-phenocrysts. Absent such growth, I prefer to call these rocks phyllites rather than phyllonites.

Before examining thinsections of these rocks, I believed that most of the rocks in the study area were significantly sheared, even those lying outside of the "shear zone." After examining thinsections, I believe that shearing does not uniformly affect rocks to produce homogeneous lithologies and textures. Rather, the rocks from the "shear zone" are variously sheared to produce an intercalated series of more- and less-sheared lithologies. Phylonite, phylonitic tuff, and phyllitic tuff is a common sequence. Zones in which lateral movement was concentrated are more sheared than other areas. Lenses of relatively unsheared material are enveloped by more sheared material. A gradational increase in the degree of shearing and proportion of sheared units, from east to west, best explains the observed features in the study area.

MINERALIZATION AND ALTERATION

Visible quantities of metallic minerals occur in every rock unit in the study area except in the Wolf River Batholith adamellite. Veinlets, stringers, disseminated grains and possibly bedded accumulations of metallic minerals show affinities for certain rock units. In order from most to least mineralized, the rock units are layered phyllite, sheared and then unsheared metagabbro, granodiorite, and adamellite.

The dominant metallic species are pyrite (py), magnetite (mag), and pyrrhotite (po), followed by much less common chalcopyrite (cpy), rare sphalerite (sp), and rare galena (ga). Visible gold was not observed in any rock or core sample from the study area. Assays for gold show that volcanic rocks as a group have the highest average gold values (63 ppb, 30 samples), and that epiclastic metavolcanics as a sub-group are even higher (72 ppb, 25 samples). The lava and ash flow metavolcanics averaged 22 ppb (5 samples) (table 6). This quantity of gold is one to two orders of magnitude less than is currently mined, but considerably higher than average gold values for rocks of this type (5 ppb; Gottfried, et al., 1972) (table 7). The highest values seem to show an affinity for contacts between mafic volcaniclastics and quartz-pyrrhotite veins. The highest gold value (590 ppb, E4-377, U.W. 1817/1) came from a quartz + pyrrhotite + pyrite mass in a mafic

Table 6. Gold abundances in ppb as determined by assay of 30 g samples. An abundance of 1 ppb is assigned to each sample that produced a value less than the detection limit (5 ppb).

Metavolcanics	
P1-215	1.00
P2-271	50.00
P5-250	5.00
P5-271	250.00
P5-295	20.00
P5-297	25.00
P5-539	125.00
P5-584	10.00
P7-426	1.00
*P2-309	N/A
*P3-83	15.00
*P5-289	40.00
*P8-500	10.00
P6-49	20.00
E4-377	590.00
*P2-76	15.00
*P6-135	30.00
E5-664	115.00
P1-263	10.00
P1-306	40.00
P2-97	65.00
P2-381	10.00
P5-155	95.00
P5-257	1.00
P5-259	65.00
P5-283	20.00
P5-289	40.00
P5-374	55.00
P5-418	125.00
P5-426	35.00
P5-534	15.00
average	63.00

Metagranodiorites	
P2-124	5.00
P2-148	N/A
P4-111	1.00
P4-117	5.00
E5-1005	5.00
average	4.00

Metagabbros	
P2-211	5.00
P2-260	5.00
P7-269	1.00
P7-275	1.00
E2-87	5.00
average	3.40

Diorite Dikes	
P2-570	1.00
P4-466	1.00
P5-260	1.00
average	1.00

* These metavolcanics are flows, the others are volcaniclastics.

Table 7. Average gold abundance (in ppb)

Rock Type	Study Area	All Rocks[1]
Andesite	63[2]	4.6[3]
Metagabbro	3.4	3.3[4]
Metagranodiorite	4.0	0.8[5]

[1] Data from Gottfried, et al (1972).

[2] Average of all metavolcanics.

[3] Calc-alkalic associations.

[4] Continental tholeiite.

[5] Dacite to rhyodacite.

metatuff that is somewhat similar in appearance to a "salt and pepper" metagabbro.

Gangue of quartz ± epidote ± calcite commonly accompanies the sulfides and magnetite in veinlets, stringers and less common, vuggy zones. Epidote is the most abundant gangue mineral in these vuggy zones. Calcite is either found as a minor constituent of polymineralic veins or as the dominant mineral in veins which are not offset by faulting. Silicified zones occur in most rock units. The widespread sulfides and oxides, the common silicified zones and the vuggy, epidotized zones suggest that a hydrothermal system has been active in the area. A deformational event related to plutonism or shearing may have produced quartz veins and remobilized syngenetic mineralization.

Layered Metavolcanics

Of the three major rock units in the study area, the layered phyllites present the most dramatic display of mineralization and contain the most sulfide minerals. These metavolcaniclastic rocks are repeatedly cut by stringers and veins of metallic minerals, most of which are concordant with the layering. Sparsely disseminated, fine grains, and lensoidal aggregates of metallic minerals, are common. The metallic minerals present in the layered phyllites include pyrite, magnetite, chalcopyrite, pyrrhotite, sphalerite, and galena, in decreasing order of abundance. Mineral textures show both replacement and open-space filling. Quartz and epidote are common gangue minerals, but calcite may also be present. Crosscutting relationships suggest two generations of mineralization or a deformational event during mineralization. Remobilization of existing sulfides could have taken place during either mineralization or deformation. Sulfide and oxide bodies that are conformable with layering could have intruded along paths of least resistance. Intrusion seems obvious in some places, but in other places the sulfides could be bedded. Bedded sulfides would not be unusual in a mafic, volcanic environment.

The most commonly associated phases of mineralization in the phyllites are py $\pm$ gangue, followed closely in abundance by py + mag $\pm$ gangue. Py + cpy $\pm$ gangue is slightly more common than py + mag + cpy $\pm$ gangue. The next most common associations include mag + quartz and py + po $\pm$ gangue. The associations that were rarely seen include ga + py, mag + cpy, cpy + po, and py + cpy + sp, all with associated gangue minerals. Galena and sphalerite were seen in only a few samples and in very small quantities. Galena occurs in stringers of very fine, anhedral grains and aphanitic masses with py + po + cpy + quartz + green amphibole. Sphalerite occurs as resinous, reddish-gray, fine to medium grained aggregates with pyrite. It may also appear as black, crypto-crystalline matrix for pyrite + quartz + calcite in veinlets and irregular masses believed to be deformed veins (*PL4-79, U.W. 1817/24*).

The observed gangue minerals, in decreasing order of abundance, include quartz, epidote, green amphibole, calcite, and rarely chlorite. The quartz is colorless and transparent or gray and cryptocrystalline. The epidote is pale apple-green, generally aphanitic to very fine-grained and anhedral, but in places is medium-grained and euhedral. The amphibole is dark green, aphanitic to fine-grained, slender prisms and needles. The calcite is usually white, rarely pink, fine to medium grained, and subhedral. Calcite is generally absent or very minor but does form the major gangue constituent in veins that are apparently not offset by faulting.

Stringer mineralization is a common feature of the phyllites. The stringers range in width from barely visible to 3 mm and range in concentration from one per centimeter to one per decimeter. Stringers are generally conformable to compositional layering but unconformable stringers do occur. The unconformable stringers are generally confined to sparsely vuggy, granoblastic, silicified zones. Stringer mineralization includes sulfide, oxide, and silicate minerals, one specie of which generally composes 50 to 70% of the stringer. Such proportions are difficult to ascertain, but one specie is clearly dominant. Within the stringers there appears to be no set pattern of spatial relationship between phases. Rarely, the stringers widen sharply to form polygonal clots. The clots are isolated and appear to be randomly oriented. They tend to occur in the sparsely vuggy, silicified zones.

Veins are less common than stringers in the layered phyllites. Veins are distinguished by their continuous nature, relatively uniform width and fairly straight course. The veins as a group range in width from less than 1 mm to more than 3 m, but are commonly within the 1mm-1cm range. Small veins have sulfides and magnetite in greater proportions than gangue, and may consist of magnetite and sulfide without gangue. Large veins typically contain gangue well in excess of sulfide and oxide minerals, and may be barren of opaque minerals except at contacts with the host lithology. Some veins up to 10 cm in width are dominantly composed of calcite. These calcite veins commonly offset intersected stringers, veins, and layering. Because other features do not offset the calcite veins, the calcite veins are believed to be relatively young features.

Pyrite is the dominant non-gangue constituent in most mineralized veins. Magnetite $\pm$ chalcopyrite $\pm$ pyrrhotite may be present. These latter three species generally form clots adjacent to a subhedral pyrite grain. Magnetite commonly forms symmetrical borders around quartz $\pm$ sulfide veinlets. Only rarely is a grain of one metallic specie fully contained within another. On a microscopic scale, it is common to find rounded blebs of the subordinant species partially embedded in, or touching the grain margin of, the dominant specie. In one spectacular occurrence, a large quartz vein is brecciated by a dominantly pyrrhotite vein that partially encloses a 3.5 x 2 cm subhedral grain of pyrite (EA5-664, U.W. 1817/23). Clots of chalcopyrite lie both adjacent to and slightly separated from the pyrite grain. The chalcopyrite penetrates the pyrite grain boundary where it touches small bodies of quartz that are otherwise enclosed by the pyrite. The outer 3 mm of the pyrite grain contains disseminated chalcopyrite grains. Similar megacrysts of pyrite occurred elsewhere in the core but were not sampled. This example of a dominant mineral with marginal growth of other minerals is similar to what can be seen on a smaller scale in other samples.

Gabbros

The rocks believed to be of gabbroic protolith exhibit a change in their metallic mineral content that accompanies their change to a more schistose fabric. The non-schistose metagabbros are mineralized mainly with pyrite whereas the schistose, "salt and pepper" gabbros are mineralized mainly with magnetite and pyrrhotite. Gold assays of both types of metagabbros are uniformly low, only 5 ppb or less.

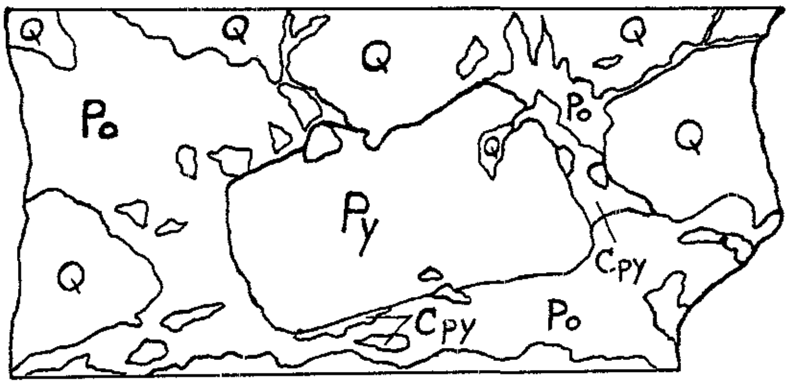


Plate 3. A large quartz vein (Q) is brecciated by a dominantly pyrrhotite (Po) vein partially enclosing a 2 X 3.5 cm pyrite (Py) grain. Chalcopyrite (Cpy) lies adjacent to and partially embays the pyrite grain.

The non-schistose metagabbros contain disseminated pyrite, pyrrhotite and magnetite, and rare disseminated chalcopyrite. Pyrite commonly occurs in the intersticies of the amphibole matrix, appearing as disseminated, fine, euhedral to anhedral grains, and aggregates of fine grains. Pyrite also fills minute fractures in plagioclase laths, and was observed intergrown with amphibole on foliation and fracture surfaces, in places arborescent, in others lineated and resembling slickensides. Pyrite is rarely found as an inclusion in amphibole. A brownish sulfide believed to be pentlandite was seen as a border around pyrite in the central zone of an epidote veinlet in slightly deformed metagabbro.

The schistose "salt and pepper" gabbros exhibit a very different suite of metallic minerals dominated by magnetite and pyrrhotite. These minerals occur as lineated, elongate aggregates of approximately the same size, and in the same orientation as, the coexisting plagioclase and amphibole grains and biotite aggregates. Minor disseminated pyrite $\pm$ chalcopyrite was observed in veinlets of pyrrhotite. These rocks are strongly magnetic except where epidotized. Epidotized schistose gabbro contains veinlets and clots of pyrrhotite and minor blebs of chalcopyrite or pyrite, but magnetite is absent.

Granodiorites

All specimens of metagranodiorite are deformed to some extent except one from drillcore EA-5 at 1005 ft (U.W. 1817/7). There are no metallic minerals in the undeformed sample, but the deformed samples contain pyrite and rare chalcopyrite. The pyrite occurs as both fine to medium, anhedral to subhedral grains, and as irregularly shaped veinlets enclosing rare chalcopyrite. The gangue in the veinlets is chlorite and epidote. A striking characteristic of this rock unit is the dominance of pyrite and the absence of pyrrhotite and magnetite, in contrast to other units.

Most veins and veinlets do not follow a straight course cutting across the fabric. Rather, they meander between clasts in a manner generally concordant with the fabric, suggestive of syndeformational intrusion or remobilization of sulfides. However, some veinlets are more regular in shape. These veinlets cut sharply across the fabric and are clearly open space filling. The rare quartz veins that cut this unit are generally contorted to irregular and contain clots of pyrite. They approximately follow the fabric over most of their course but become obviously disconformable along planes of offset where they change course in a smooth, flowing manner.

Alteration

The age and geologic setting of the rocks in the study area have allowed ample time and opportunity for alteration. Some type of alteration, megascopic or microscopic, was seen in almost every rock examined. The degree to which feldspars have been replaced varies, but few rocks from the area have fresh grains. Most twinned plagioclase is recognizable only as relic grains. Outlines of large relics are discernable in the mosaic of small, untwinned, feldspar grains upon rotation of the microscope stage to the extinction position of the relic grain. Concentric zoning and polysynthetic twinning are evident in some relics through changes in the crystallographic orientations of, and the spacing between, the fine replacement grains of sericite, untwinned feldspar, quartz, and epidote. The observed alteration is not all the result of one event. Hydrothermal alteration assemblages are distinguishable through the mask of the ubiquitous greenschist facies recrystallization just described.

Silicification has taken place in discrete zones within these rocks. In all cases these zones are recognized by a blurring of fabric which produces a mottled appearance in the gabbros and a greenish-gray, homogeneous appearance in the volcanics. In all cases the texture becomes hornfelsic. Grain size is variable. Silicified zones commonly are host to fractures and veinlets that cut the core at random angles.

Epidotization is suggested by variance in the concentration and thickness of epidote veins. In some places they become so numerous and thick that they coalesce to form broad bands of rock consisting of 60 to 80%, apple green, aphanitic to medium grained, subhedral epidote. These zones are marked by numerous vugs, open fractures, and drusy euhedral crystals of epidote, calcite, quartz, and pyrite. The fabric of the protolith is visible in some epidotized zones, generally where they occur in the gabbroic protolith.

Evidence of sericitization is problematic. Sericite is plentiful as a replacement of feldspar and other grains or clasts of unknown heritage, which are now sericitic masses. Quartz and untwinned feldspar commonly accompany the sericite in replaced grains and in the groundmass. This alteration assemblage is to be expected in greenschist facies metavolcanics. Aside from this ever present alteration to sericite, there are several sericite-rich lithologies. These can be described as sericite phyllites, quartz-sericite schists and sericite-rich metavolcanics and metagranodiorites. The latter lithology displays flowing fabric with large, rounded quartz augen. Some of these lithologies may represent zones of hydrothermal sericite enrichment confined to a relatively narrow zone by strong, pre-existing fabric. Others could represent a metamorphosed aluminous protolith such as a pelitic metasediment or felsic volcanic. In the layered phyllites the boundaries of wide sericitic zones are gradational. Narrow, slightly gradational, sericitic zones or layers are also observed in the phyllites. Both the wide and narrow zones could be caused by alteration of more felsic volcaniclastic layers. In the gabbroic and granodioritic protoliths however, the boundaries of the sericitic zones are fairly sharp to sharp. These sharp compositional boundaries are suggestive of infaulting, xenoliths, or roof pendants, but could be sericitized zones confined by elements of the fabric.

Summary

Mineralization in the study area defies a simple explanation. The observed mineralization is easier to explain if two episodes of mineralization are superimposed. Even so, the alternatives are numerous. The largely concordant relations of the mineralization in the volcanics could result from syngenetic, bedded, deposition. Concordancy could also be produced by metasomatism of chemically reactive and porous layers. Foliation planes could exert directional control upon fractures and thus channel migrating fluids. Disseminated sulfides could be syngenetic or epigenetic.

Even if some mineralization is syngenetic, other mineralization certainly is not. Conformable sulfide stringers cross-cut deformed quartz veins along Z-shaped paths, suggesting quartz veining, followed by sulfide stringers, and then a slight shearing movement. Syndeformational mineralization is also suggested by unconformable sulfide and calcite veins that offset other planar features but are not themselves offset. Mineralized breccia zones cutting quartz veins are further evidence of syndeformational mineralization. Evidence of open-space-filling mineralization includes drusy-walled vugs in quartz veins, matched walls on sulfide stringers in silicified zones, and symmetrical banding of vein constituents. Replacement mineralization is indicated by mismatched walls on most stringers, gradational alteration fronts, and opaque minerals encroaching along cleavage planes in feldspar crystals.

The variability of the sulfide and magnetite occurrences make establishing a paragenetic sequence difficult. The inconsistencies may be due to remobilization or to overprinting of late mineralization upon early mineralization. Perhaps pulses of chemically distinct fluids successively mineralized the area, producing the several observed combinations of opaque minerals. Any one of the opaque minerals discussed previously may dominate a given occurrence. Quartz, magnetite, pyrrhotite, and pyrite were each observed to compose veins or veinlets which appeared megascopically pure. The minerals in multi-mineralic veins may occupy long, relatively continuous domains, or may form heterogeneous mixtures of small domains.

Very few consistent relations emerge from close examination. Magnetite is rarely contained by sulfides, but sulfides are commonly contained by magnetite. Pyrite and pyrrhotite generally occur in adjacent positions and rarely contain inclusions of the other species. A notable exception is the high-gold pyrrhotite vein containing very coarse euhedral pyrite crystals (EA5-664, U.W. 1817/23). Chalcopyrite inclusions commonly occur in pyrite, magnetite and pyrrhotite, and are located on or near the margin of the host grain. Galena and sphalerite are too rare to comment on, except to point out their presence in one relatively high-gold sample (115 ppb, EA5-664, U.W. 1817/23). Crustiform banding is absent, but where magnetite is present, magnetite commonly forms a symmetrical border between the sulfides and the wall rock, and may form a border around an otherwise barren quartz vein.

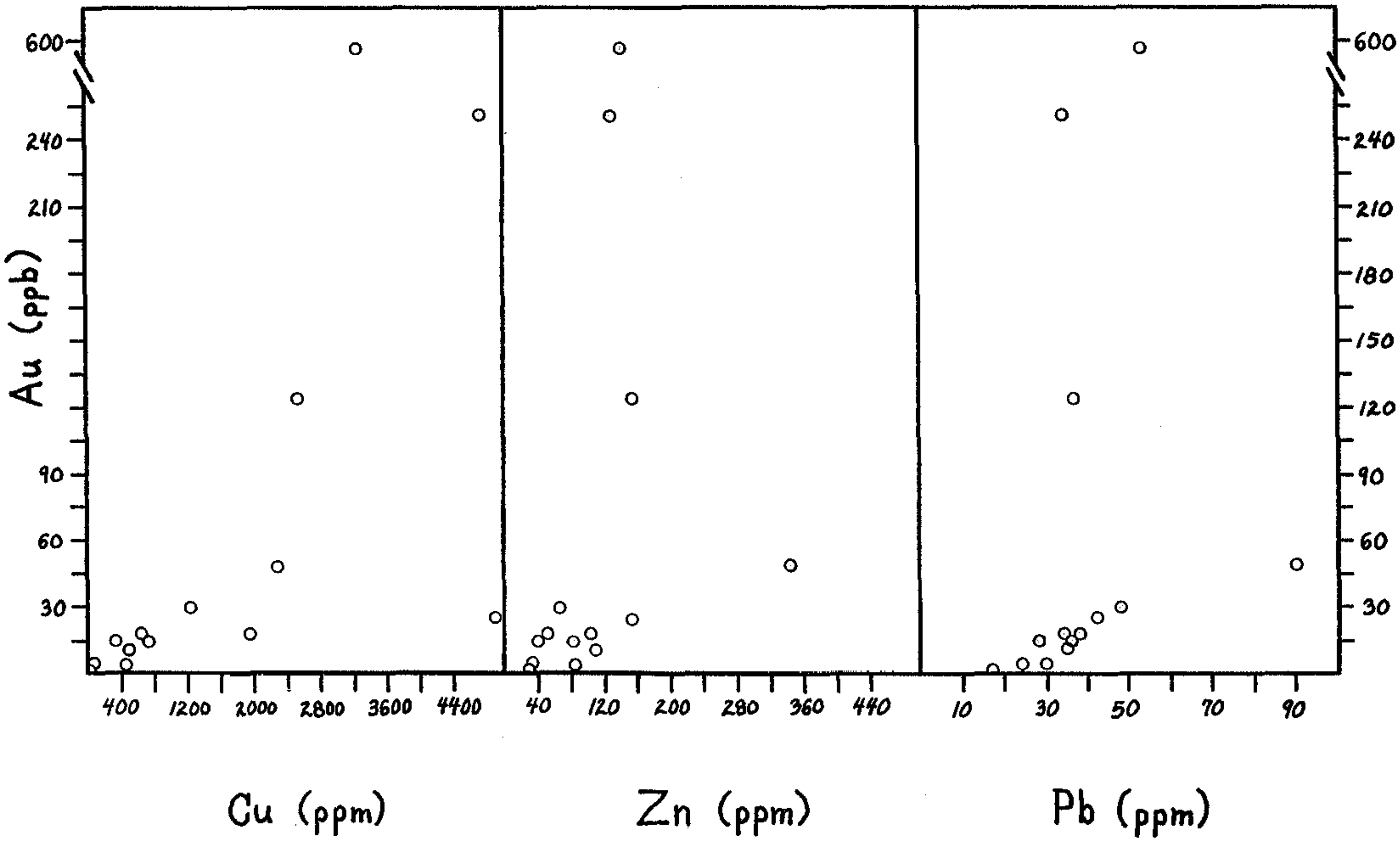
DISCUSSION

The source of the fluids that mineralized the study area is unknown. The data resulting from this investigation suggest three possibilities. First, a sub-volcanic pluton could establish a hydrothermal cell to leach the volcanic pile and precipitate sulfides at or near the sea floor. Second, volatiles escaping a magma chamber could send fluids streaming upwards along paths of least resistance. Third, tectonic forces could cause shearing and the shear zone could become the conduit for metamorphic, magmatic or hydrothermal fluids which would metasomatize permeable and sheared lithologies. The presence of a shear zone and several plutons in the study area make all three possibilities viable. The presence of both mineralized and barren quartz-vein-systems suggests the plausibility of two distinct sources of mineralizing fluids.

The trace element chemistry of the mineralization is enlightening, but does not unequivocally establish a correct mineralization model. A comparison of gold abundances shows that the volcanic rocks in the study area have 12 times the average gold values of similar rocks, but that the other rocks in the study area are about average (Table 7). The mafic volcanics have a higher gold content than the intermediate volcanics, consistent with data for average rocks (Gottfried, et al., 1972). This relationship could mean that mafic volcanics have a higher, average, primary gold content than other rocks, or that secondary concentration mechanisms preferentially deposit gold in mafic volcanics. The former was demonstrated by Gottfried, et al., by carefully selecting samples that were not altered and did not show signs of secondary gold enrichment. A variation of the latter is known to occur in deposits in Canada, where iron formations or other rocks are chemically favorable to gold mineralization (Boyle, 1979). The volcanic rocks from the study area are all altered, and the highest gold values were obtained from rocks with quartz and sulfide veins or stringers. Thus, the anomalously high gold content could be the result of both syngenetic and epigenetic enrichment.

Figure 6 is a plot of gold values versus chalcophile trace element values from the volcanics in the study area. These volcanics have been hydrothermally altered and most contain stringers and veins of quartz + sulfide + magnetite. The figure demonstrates positive correlations between Au and Cu, Zn, and Pb. The magnitudes of the correlations suggest that gold is most closely associated with copper. A similar relationship between gold abundance and copper abundance was observed in unaltered volcanic rocks by Gottfried, et al. (1972). This correlation is also suggested by the observation that most samples without visible chalcopyrite were low in gold content. A notable exception is the sample containing the most gold (EA4-377, U.W. 1817/1) which contains no visible chalcopyrite.

Figure 6. Gold abundance relative to base metal abundance in metavolcanic rocks.



Each plot in Figure 6 demonstrates a divergence, or perhaps two distinct trends. This branching could be attributed to successive pulses of different mineralizing fluids. An overprinting of a Au-Cu pulse upon pre-existing Cu-Zn-Pb mineralization would raise the gold and copper contents of the rocks encountered without elevating the zinc or lead contents.

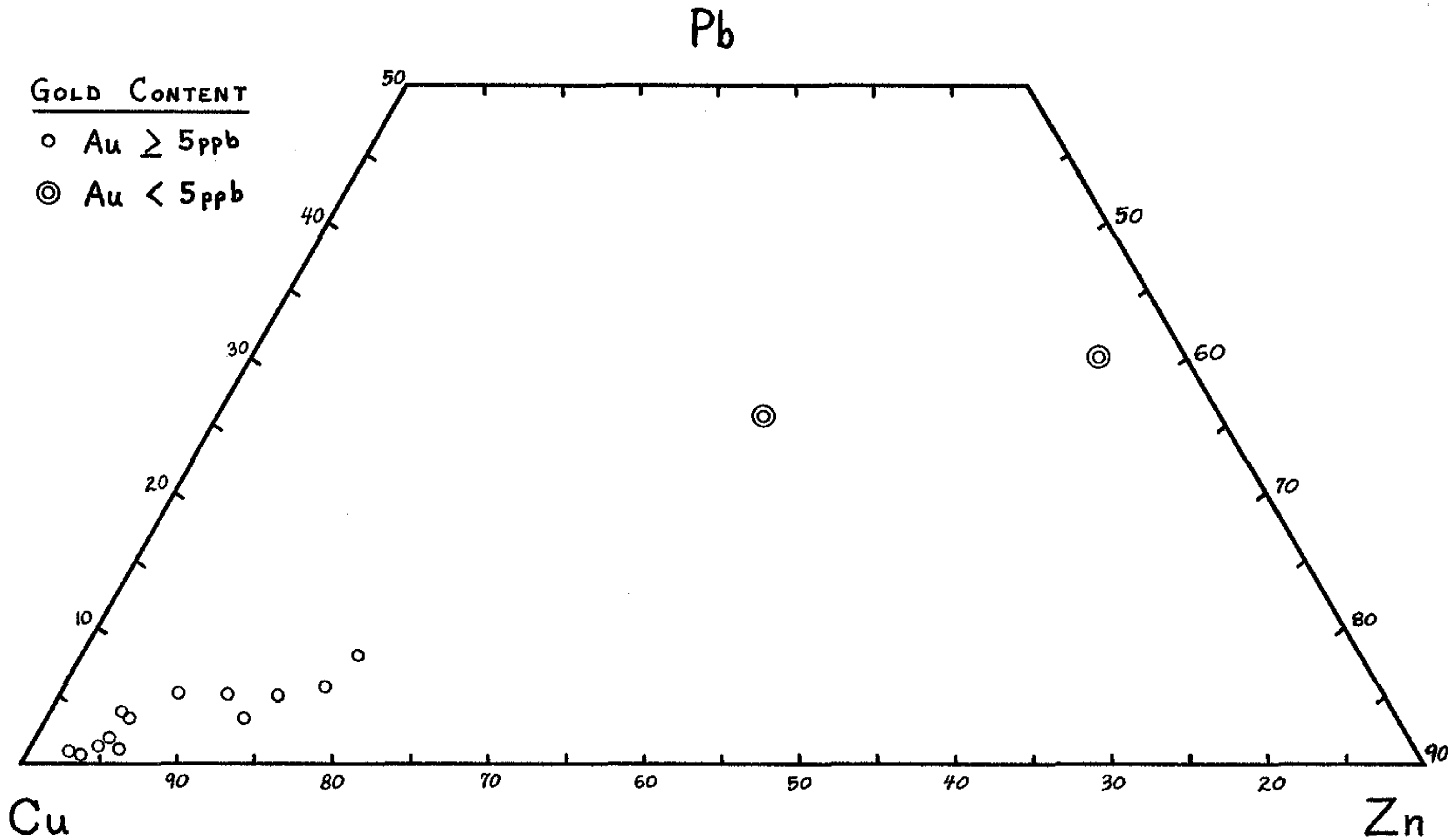
There is a positive correlation between gold and mafic volcanic rocks shown by Table 6. This relationship suggests that gold was either remobilized from the volcanic rocks or precipitated from ore-bearing solutions as a result of wall-rock alteration reactions with the volcanic rocks. If gold had been introduced with the quartz, the quartz veins in non-volcanic rocks would contain similar quantities of gold as those in volcanic rocks, assuming deposition indiscriminate to the chemistry and physical nature of the wall rock. This was not demonstrated in the analyses. Even the rocks chemically similar to mafic volcanics, such as metagabbros, mineralized with quartz-sulfide veins, have lower average gold values than the volcanics.

The dominance of copper and zinc over lead is consistent with the observed elemental ratios in volcanogenic massive sulfide deposits (Franklin et al., 1981). These deposits are either Cu + Zn, Zn + Cu or Zn + Pb, but never Cu + Pb. If the "ore" minerals in the study area were deposited with the volcanics syngenetically, or leached and deposited epigenetically, the volcanogenic mineralizing process was not chemically unusual. The paleo-environment could have been favorable to the formation of a Zn-Cu or Cu mineral deposit, such as those near Crandon, Rhinelander, and Ladysmith, Wisconsin.

Figure 7 shows the relative abundances of Cu, Zn and Pb in the volcanics from the study area. The abundances have been normalized to 100% and plotted on a ternary diagram. The Cu dominance is obvious, and would be expected in the high-temperature, stringer zone of a Cu-Zn volcanogenic massive sulfide deposit. The linear trend shown on the figure is suggestive of zoning, however the structural complexity of the study area prevents the definite establishment of a mineral or elemental zonation pattern.

The great amount of mineral exploration activity that has taken place in the study area seems unwarranted by the low gold values of the rocks analyzed for this study. Table 1 lists known drilling information from the study area and vicinity. Some of the company records show that these companies have explored the area with the benefit of drilling information developed by their predecessors. Sharing exploration information reduces risk, thereby increasing the attractiveness of an exploration target. The economics of mineral exploration are beyond the scope of this project, but basically, the more that is known about a mineral occurrence, the more accurately one may calculate an economic level of exploration investment (Snow and

Figure 7. Relative abundance of base metals in metavolcanic rocks.



MacKenzie, 1981). Nevertheless, funds will generally not be spent on additional drilling unless the probability of economic discovery at a given level of investment exceeds such probabilities for alternative ventures. For five successive companies to explore this area almost continuously for 20 years, there must be significant potential for an economic discovery. Using the continued expenditure of exploration funds as an indication of potential, I was led to believe that private assays had resulted in significantly greater gold abundances than those reported in this investigation. My belief was confirmed by a recent disclosure on the study area that revealed the presence of gold at 9.2 g/ton (9200 ppb) and 1.3% copper over a 3 m interval (Werniuk, 1987). The gold was described as being located in a "chert horizon" in mafic volcanic rocks.

The mineralization and geologic setting of this gold occurrence are similar to other occurrences described by Boyle (1979). One category of deposit is described by Boyle as "gold-silver .... stockworks, lodes, mineralized pipes and irregular silicified bodies, in fractures, faults, shear zones, sheeted zones and breccia zones essentially in volcanic terranes" (p. 251). Likely host rocks are Precambrian tuffs, agglomerates, sediments and interbedded flows and iron formation. Ore minerals generally occur as intimate intergrowths. Recrystallization and replacement features are abundant. Relatively pure native gold is present. Pyrite, pyrrhotite and arsenopyrite are common. Argentiferous galena, sphalerite and chalcopyrite are ubiquitous but only in small quantities. Quartz is the most abundant gangue mineral. Alteration is extensive and complex. The deposits may pass downwards into barren quartz and carbonate veins with scattered pyrite, pyrrhotite and base-metal sulfides. Deposits of this type include those of the Yellowknife district, Northwest Territories; Red Lake district, Ontario; the Kerr-Addison and Chesterville Mines of the Kirkland Lake district, Ontario; and the Senator Rouyn mine of the Noranda-Rouyn district, Quebec (Boyle, 1979).

Another similar category of gold deposits discussed by Boyle consists of, "gold-silver ... veins, lodes, stockworks and silicified zones in a complex geological environment comprising sediments, volcanics and various igneous intrusives and granitized rocks," (p. 290, 1979). Deposits of this type are much younger than Precambrian, often Tertiary. The mineralization occurred after igneous intrusive and granitization activity. Examples of this type of deposit include: the Alaska Juneau Mine, Alaska; Grass Valley district, California; Rossland camp, West Kootenay district, British Columbia; and the Northern Empire Mine, Little Long Lac district, Ontario (pp. 290-291).

Although the aforementioned categories of deposits have certain features in common with the study area, there is a more likely explanation for this deposit. I believe my examination of this area has revealed the stringer and alteration zones of a hydrothermally produced volcanogenic massive sulfide deposit. Conformable, bedded, syngenetic sulfides are common but volumetrically minor compared to the interbedded rock. These sulfides may be the result of the early stages of this hydrothermal system, or may be from a previously active, distal system. The stockwork and the Cu-dominance is the result of a more recent, proximal system which is responsible for some of the alteration assemblages observed. Other alteration is due to regional metamorphism. Still other alteration, and the large quartz veins, are probably related to the emplacement of the Wolf River Batholith. If the shear zone was active during mineralization, it could have vented the ore-bearing solutions over a wide area, resulting in sulfide deposition insufficient to form a "massive" sulfide deposit.

Significant questions as to the chronology of certain events following the sulfide mineralization remain. Uncertainties include the timing of tilting of the units to a near vertical position, shearing of the western portion of the area, intrusion of large quartz veins, and faulting. I believe these events occurred in the order presented, except that some shearing appears to have also occurred before and during mineralization. The most crucial event, the deposition of gold-bearing mineralization, has proved elusive as previously discussed. It is probably the result of both syngenetic enrichment in mafic volcanic rocks and epigenetic deposition in the stringer zone of a volcanogenic massive sulfide deposit.

For those who would or must continue this examination, I suggest the following:

1) the examination of additional drillcores and a more thorough geochemical program will be necessary to understand the gold mineralization;
2) the chemical and physical relationships between the large and small quartz veins must be investigated;
3) the hydrothermal, kinetic and contact metamorphic alteration assemblages must be clearly differentiated; and
4) the supposed protoliths and their respective deformed and/or altered equivalents must be determined with greater precision.

I suspect that much inferred faulting and inability to correlate units between drillholes may be due to the complex result of superimposed cataclastic deformation, contact metamorphism and hydrothermal metamorphism. I do not dismiss the possibility that some of the "sheared" rocks are actually the unsheared products of hydrothermal alteration. I admit to the possibility that the "gabbro" is really contact metamorphosed volcanic rock, not plutonic rock. I think everyone who has worked on these rocks will harbor more differences of opinion than agreements, but will concur on one statement, namely, the area is very complex.

CONCLUSION

The study area is dominated by phyllitic to phyllonitic, mafic and intermediate, subaluminous, calc-alkaline series volcaniclastic rocks, mostly andesites. These rocks have been tilted to a vertical position and metamorphosed to at least the lower greenschist facies of low grade metamorphism. Compositional determinations on the ubiquitous, dark-green amphibole are needed to establish these rocks as upper greenschist, or transitional to amphibolite facies. The volcanics have been intruded by gabbro and granodiorite plutons, mafic dikes, quartz veins, and by the Wolf River Batholith.

Structural relations in the area are made tenuous by a lack of outcrop, by shearing and faulting, and by insufficient drillcore to map intrusive relationships. Mylonitic and other textures indicative of shearing show that shearing was most intense, and affected the greatest volume of rock, in the western part of the area, from which no drillcores are available. The fine grained, partially recrystallized, volcaniclastic rocks in the western part of the area could be expected to have primary textures that look very similar to a mylonitic texture. Feldspar phenocrysts oriented sub-perpendicular to lamination indicate incomplete mylonitization within the sheared lithologies. Interlayering and intercalation of more- and less-sheared rocks is common. Shearing has affected the gabbro and granodiorite, but not the Wolf River Batholith. Shearing appears to have been concurrent with one stage of mineralization, but may have simply remobilized pre-existing mineralization. Mineralization also occurred after deformation.

Chemical analyses show a close association between gold and copper, and a gold affinity for volcanic rocks. The volcanic rocks analyzed averaged 63 ppb gold, 12 times the average value for rocks of this type. A ternary plot of the relative abundances of Cu, Zn and Pb, indicates that the study area may lie within the Cu-rich zone of a zoned Zn-Cu massive sulfide deposit. Alternatively, the massive sulfide deposit could be of the dominantly Cu type. The dominant mineralization in the volcanics consists of disseminated pyrite and stringers of pyrite $\pm$ pyrrhotite $\pm$ magnetite with subordinate chalcopyrite. Quartz $\pm$ epidote $\pm$ calcite is the common gangue assemblage. Silicified, epidotized and sericitized lithologies do occur, but a pattern of zonation was not apparent.

The level of mineral exploration drilling in the study area has been anomalously high for the state of Wisconsin. In 20 years, four companies have drilled 60 holes within a 6 square mile area. Additional holes drilled nearby by a fifth company intersected meta-sedimentary and meta-igneous rocks containing up to 50% pyrrhotite (Hepp, unpublished). Exploration activity is spurred by gold assays ranging up to 9200 ppb, greatly exceeding the 590 ppb gold obtained as part of this study. The study area shows strong potential for hosting a gold-rich volcanogenic massive sulfide deposit, and lesser potential for hosting a gold-quartz vein deposit related to granite emplacement, or a shear-zone-related gold deposit.

The exact nature of the mineralizing system(s) is unknown. A satisfactory model must explain certain observations:

1) disseminated, bedded, replacement and open-space-filling mineralization occur in the same rocks;
2) some stringers and veins have been deformed, others have not;
3) vein and stringer mineralization is not consistent mineralogically or texturally;
4) the diversity of the ore mineral assemblage varies with lithology (volcanics > gabbro > granodiorite);
5) gold is most plentiful where mineralized quartz veins cut mafic volcanics, and commonly below detection limits where mineralized quartz veins cut other lithologies.

A three-stage mineralization model is proposed. The first stage is the syngenetic, subaqueous deposition or enrichment of sulfides and gold in intermediate and mafic volcanics. The second stage involves an epigenetic, volcanogenic, hydrothermal process which is interrupted by a deformational event that causes sudden fracturing and forms a closely-spaced quartz-sulfide-magnetite stockwork. The third stage, occurring after regional folding, involves faulting and the intrusion of large, barren, quartz veins, probably contemporaneous with the emplacement of the Wolf River Batholith. The presence of mineralization on fault planes and as breccia matrix indicates the presence of mineralizing fluids during structural deformation. It does not appear that the shear zone played a role in the mineralizing process, such as supplying the conduit for gold-bearing fluids, or providing a source of metamorphic fluids to transport locally remobilized gold to receptive sites in the mafic volcanic rocks. It appears more likely that the shear zone is just another result of the tectonic forces responsible for the volcanic and plutonic activity in the area. Petrographic and geochemical evidence suggest that this gold occurrence formed in the root zone of a *Cu-Zn* or *Zn-Cu* volcanogenic massive sulfide deposit.

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APPENDIX

Table A-1. Whole-rock and trace element analyses of metavolcanic rocks. Major elements are in weight percent. All trace elements in ppm except gold (ppb). Any value less than the detection limit is listed as 1.00.

	P1-215	P2-271	P5-250	P5-271	P5-295	P5-297	P5-539	P5-584	P7-426	P2-309
SIO2	62.10	51.70	56.60	57.60	50.10	44.00	55.20	51.90	67.90	54.30
TIO2	0.75	0.66	0.56	0.38	nd	0.65	0.56	0.58	0.60	0.65
AL2O3	16.80	14.70	12.40	10.50	12.50	13.90	10.40	13.30	14.00	13.40
FE2O3	6.21	15.00	9.90	12.50	13.20	14.30	12.30	10.90	4.39	12.90
FEO	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
MNO	0.07	0.11	0.21	0.17	0.19	0.15	0.20	0.21	0.04	0.17
MGO	2.75	7.07	8.07	5.34	10.50	13.80	6.69	9.00	2.86	6.23
CAO	6.58	0.61	9.03	9.05	7.61	2.38	8.45	6.64	1.44	8.73
NA2O	4.16	2.69	2.36	1.70	1.77	1.75	1.55	2.42	4.27	3.18
K2O	0.72	4.38	1.12	0.78	1.20	2.19	0.79	1.41	1.81	0.24
H2O+	0.15	3.75	1.30	2.00	1.70	5.40	2.70	1.90	0.30	1.20
H2O-	0.15	nd	nd	nd	nd	nd	nd	nd	nd	nd
P2O5	0.18	0.01	0.11	0.09	0.16	0.21	0.30	0.17	0.25	0.03
TOTAL	100.62	100.68	101.66	100.11	98.93	98.73	99.14	98.43	97.86	101.03
au	1.00	50.00	5.00	250	20.00	25.00	125	10.00	1.00	nd
cu	36.00	36.00	470	4750	1970	4720	2560	505	9.00	614
ni	14.00	49.00	67.00	50.00	95.00	89.00	53.00	85.00	2.00	33.00
zn	33.00	345	81.00	134	102.00	154	153	109.00	31.00	79.00
pb	24.00	91.00	30.00	35.00	34.00	154	37.00	35.00	17.00	35.00
as	9.00	105.00	1.00	1.00	1.00	42.00	1.00	1.00	1.00	1.00
v	139	nd	nd	nd	nd	314	nd	nd	nd	nd
cr	12.00	nd	nd	nd	nd	509	nd	nd	nd	nd
mn	776	nd	nd	nd	nd	1430	nd	nd	nd	nd
co	13.00	nd	nd	nd	nd	63.00	nd	nd	nd	nd
mo	3.00	nd	nd	nd	nd	4.00	nd	nd	nd	nd
sb	nd	8.00	1.00	1.00	1.00	nd	1.00	1.00	1.00	7.00

Table A-1. Continued

	P3-83	P5-289	P8-500	P6-49	E4-377	P2-76	P6-135
SIO2	50.90	50.80	51.20	nd	nd	nd	nd
TIO2	0.67	0.66	0.74	nd	nd	nd	nd
AL2O3	14.90	13.60	13.30	nd	nd	nd	nd
FE2O3	12.20	12.40	12.10	nd	nd	nd	nd
FEO	nd	nd	nd	nd	nd	nd	nd
MNO	0.22	0.20	0.17	nd	nd	nd	nd
MGO	7.56	7.90	8.08	nd	nd	nd	nd
CAO	12.00	9.90	9.79	nd	nd	nd	nd
NA2O	0.89	2.82	0.83	nd	nd	nd	nd
K2O	0.26	0.25	1.07	nd	nd	nd	nd
H2O+	1.65	0.70	1.20	nd	nd	nd	nd
H2O-	nd	nd	nd	nd	nd	nd	nd
P2O5	0.08	0.10	0.35	nd	nd	nd	nd
TOTAL	101.33	99.33	98.83	nd	nd	nd	nd
au	15.00	40.00	10.00	20.00	590	15.00	30.00
cu	339	nd	nd	629	3290	731	1240
ni	47.00	nd	nd	43.00	80.00	35.00	76.00
zn	81.00	nd	nd	54.00	145	40.00	64.00
pb	36.00	nd	nd	37.00	54.00	28.00	49.00
as	1.00	nd	nd	1.00	1.00	1.00	12.00
v	nd	nd	nd	293	74.00	307	225
cr	nd	nd	nd	104.00	18.00	81.00	73.00
mn	nd	nd	nd	1981	1458	956	1324
co	nd	nd	nd	56.00	153	50.00	73.00
mo	nd	nd	nd	2.00	4.00	4.00	24.00
sb	1.00	nd	nd	nd	nd	nd	nd

Table A-2. Whole-rock and trace element analyses of metagranodioritic rocks. Major elements are in weight percent. All trace elements are in ppm except gold (ppb). Any value less than the detection limit is listed as 1.00.

	P2-124	P2-148	P4-111	P4-117	E5-1005
SIO2	71.08	70.50	71.70	71.90	76.60
TIO2	0.10	0.11	0.09	0.10	0.17
AL2O3	13.76	15.00	13.30	14.00	11.50
FE2O3	2.84	2.08	2.69	2.35	1.37
FEO					
MNO	0.02	0.01	0.01	0.02	0.01
MGO	0.81	0.98	0.75	0.92	0.27
CAO	2.06	0.96	2.39	2.02	1.06
NA2O	4.19	7.22	3.64	3.68	4.60
K2O	2.60	1.05	2.09	2.81	0.94
H2O+	1.60	0.80	2.10	2.10	0.50
H2O-					
P2O5	0.05	0.12	0.15	0.15	0.07
TOTAL	99.11	98.83	98.91	100.05	97.09
AU	5.00		1.00	5.00	5.00
LI		4.00	9.00	18.00	
BE		1.00			
RB		21.00	34.00	51.00	31.00
SR		125	226	232	63.00
NB		1.00			
BA		525	322	464	103.00

Table A-3. Whole-rock and trace element analyses of metagabbroic rocks. Major elements are in weight percent. All trace elements are in ppm, except gold (ppb). Any value less than the detection limit is listed as 1.00.

	P2-211	P2-260	P7-269	P7-275	E2-87
SIO2	47.50	47.70	46.83	48.00	50.84
TIO2	3.63	3.70	3.26	3.51	0.26
AL2O3	12.60	12.20	11.78	11.80	19.80
FE2O3	20.80	21.00	20.26	21.20	8.18
FEO	nd	nd	nd	nd	nd
MNO	0.30	0.32	0.30	0.27	0.16
MGO	4.79	4.98	4.38	5.06	4.78
CAO	8.87	8.28	7.74	7.91	10.99
NA2O	1.26	1.26	1.17	1.60	2.43
K2O	0.70	0.45	2.47	1.49	1.25
H2O+	0.10	0.25	0.50	0.15	1.35
H2O-	nd	nd	nd	nd	nd
P2O5	0.72	0.67	0.49	0.87	0.09
TOTAL	101.27	100.81	99.18	101.86	100.13
AU	5.00	5.00	1.00	1.00	5.00
CU	46.00	46.00	nd	52.00	nd
NI	30.00	23.00	nd	27.00	nd
ZN	232	230	nd	171	nd
PB	115	69.00	nd	57.00	nd
AS	1.00	25.00	nd	1.00	nd
V	nd	nd	nd	nd	nd
CR	nd	nd	nd	nd	104.00
MN	nd	nd	nd	nd	1456
CO	nd	nd	nd	nd	13.00
MO	nd	nd	nd	nd	2.00
SB	12.00	1.00	nd	1.00	nd

Table A-4. Whole-rock and trace element analyses of diabase dikes. Major elements are in weight percent. All trace elements are in ppm except gold (ppb). Any value less than the detection limit is listed as 1.00.

	P2-570	P4-466	P5-260
SIO2	38.90	44.20	47.12
TIO2	4.14	3.89	3.07
AL2O3	17.00	14.70	12.08
FE2O3	19.40	19.00	19.01
FEO	nd	nd	nd
MNO	0.26	0.24	4.76
MGO	4.42	3.82	4.76
CAO	6.83	6.10	8.77
NA2O	3.32	2.71	2.76
K2O	2.77	2.11	1.25
H2O+	0.05	0.10	0.25
H2O-	nd	nd	nd
P2O5	2.71	2.31	0.43
TOTAL	99.80	99.18	104.26
AU	1.00	1.00	1.00
CU	310	27.00	nd
NI	9.00	25.00	nd
ZN	191	256	nd
PB	45.00	51.00	nd
AS	1.00	1.00	nd
V	nd	nd	nd
CR	nd	nd	nd
MN	nd	nd	nd
CO	nd	nd	nd
MO	nd	nd	nd
SB	1.00	1.00	nd