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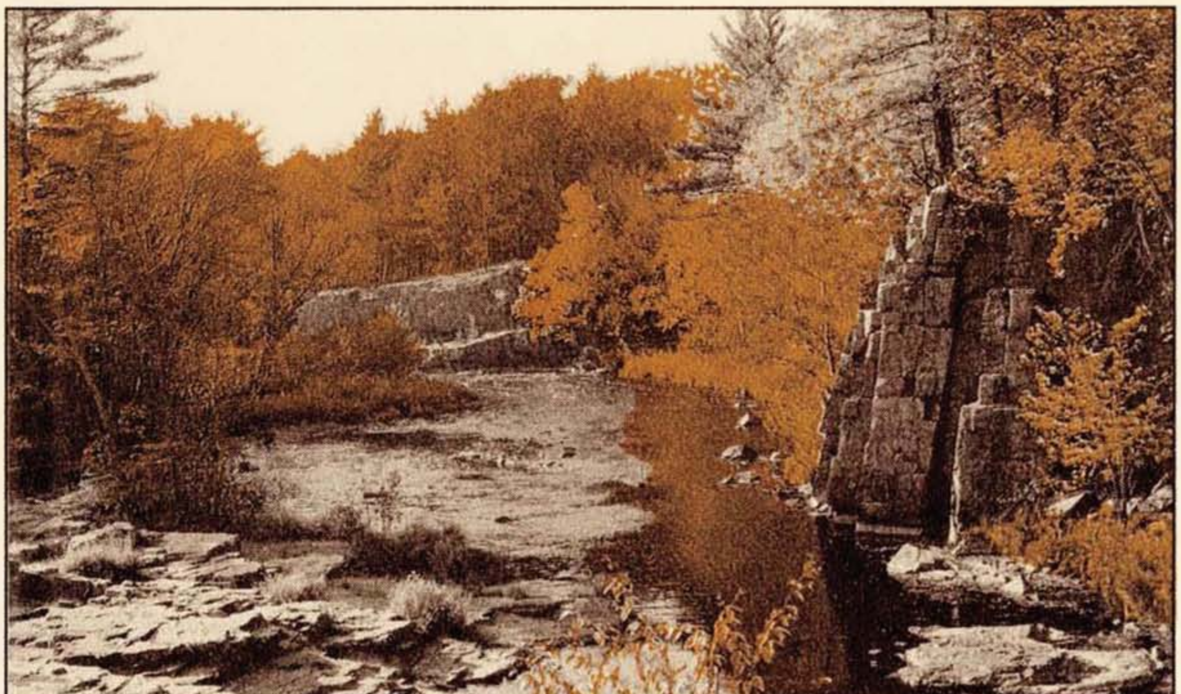
by
Gene L. LaBerge and Paul E. Myers



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PREFACE

This report and the accompanying map (Plate 1) are a product of a long-range program of the Geological and Natural History Survey (GNHS) to map in detail the geology of Wisconsin. The study was done by Professors Gene L. LaBerge, UW-Oshkosh, and Paul E. Myers, UW-Eau Claire while employed on a part-time basis with the GNHS from 1969 thru 1976. Prior to this survey the geologic basis for Marathon County was generally limited to the 1907 work of Weidman.

The regional compilation work of Carl E. Dutton of the U.S. Geological Survey, completed in 1970 under the state/federal cooperative program, and the growing interest in metallic mineral potential of the Precambrian rocks in the late 1960s influenced LaBerge and former State Geologist George F. Hanson to initiate the project.

The report and maps provide a comprehensive summary of the geology of Marathon County. They document the distribution and character of exposed bedrock geologic units, emphasizing the Precambrian crystalline rocks but including the overlying sandstones and surficial deposits. Many of these units have economic significance as sources of aggregate and dimension stone, while others may have potential as sources of metallic minerals ranging from base metals to rare earth elements. The maps provide a valuable source of information for geologists, engineers, planners, the mineral and construction industries, county and local units of government, and land owners who may be concerned with mineral resources, water supply, construction siting, utility routing, waste disposal, and other issues.

Plate 2 of this report is a summary compilation of the Wisconsin Aeromagnetic Map Series by Professor John H. Karl, UW-Oshkosh. The aeromagnetic work, begun in 1973, was coordinated by the GNHS with funding from the GNHS, N. L. Industries and the Upper Great Lakes Regional Commission.

As with any geologic mapping endeavor, interpretations have evolved as information has accumulated on the Precambrian rocks of Central Wisconsin. The tectonic interpretations are those of the authors based on their field work up to 1976.

Dr. Meredith E. Ostrom
State Geologist and Director

PRECAMBRIAN GEOLOGY OF MARATHON COUNTY, WISCONSIN

by
Gene L. LaBerge and Paul E. Myers

ABSTRACT

Systematic geological mapping in Marathon County has disclosed a wide variety of rock types which were formed over a long period of time. Although exposures are not abundant, the distribution of rock types and the consistent structural pattern permit interpretation of the relationships among the various rock units.

The oldest rocks are quartzofeldspathic gneisses and amphibolites exposed in the northwestern and southern parts of the county. Migmatitic gneisses are present locally. The rocks have been intensely deformed, and metamorphosed to amphibolite facies. The age of these rocks has not been established in detail by radiometric methods, they are believed to be either Early Proterozoic or Archean, or a mixture of Archean and Early Proterozoic.

Unconformably overlying the amphibolite-facies rocks is a sequence of greenschist-facies mafic to felsic volcanic rocks that have well-preserved primary textures and structures of probable Early Proterozoic age. The presence of pillow lavas, bedded tuffs and interbedded sedimentary rocks indicates a dominantly submarine environment; however, subaerial welded tuffs, lahars and flow banded rhyolites occur in the Wausau-Brokaw area. Available chemical analyses suggest that the volcanic rocks are of calc-alkaline affinity.

The volcanic rocks were syntectonically intruded by numerous epizonal plutons. The plutons tend to be zoned with xenolith-rich quartz dioritic margins which grade inward through a quartz monzonite zone to a granitic core. In general, the quartz diorites and quartz monzonites are more foliated than the granitic cores.

Middle Proterozoic rocks include the western part of the Wolf River batholith, which underlies approximately the eastern one-quarter of Marathon County, and two syenite plutons west of the Wisconsin River at Wausau. The Wolf River batholith in Marathon Co. consists of a northern segment of coarse grained hornblende granite and a southern segment of finer grained porphyritic quartz monzonite. The batholith shows evidence of little deformation, except along the Little Eau Claire River valley, and has a narrow contact metamorphic aureole along its western margin. The syenite plutons are concentrically zoned, oval, plug-like

bodies. The larger Wausau pluton consists mainly of syenite and quartz syenite, and contains a semi-circular ring of large quartzite xenoliths, including Rib Mountain, Hardwood Hill and Mosinee Hill. The Ninemile granite pluton forms the core of the Wausau pluton, and forms a large lobe that extends southwest of the syenite body. Numerous grus pits have been developed southwest of Rib Mountain in the disintegrated outer margin of the Ninemile pluton. The smaller Stettin pluton, northwest of the Wausau pluton, is more alkalic, with a border zone and a core containing nepheline syenite. Both syenite plutons and the Wolf River bathlith intruded the older volcanic-plutonic complex about 1,500 Ma. A number of east to northeast trending diabase dikes in Marathon County are of probable Middle Proterozoic age.

Structural features in Marathon County consist of several large, nearly vertical fault zones that separate the amphibolite-facies gneisses from the greenschist-facies volcanic and plutonic rocks. These fault zones include the northeast-trending Athens fault in the northwestern part of the County, and the Eau Claire River and the Eau Pleine fault zones that form the eastern and southern boundaries of the greenschist-facies volcanic rocks that underlie most of Marathon County.

The greenschist-facies volcanic rocks appear to form a broad, complex, northeast-trending synclinal structure in much of the County. However, the volcanic rocks have been extensively disrupted by intrusions, and may have been repeated by faulting. Lack of exposure precludes resolving the detailed structure.

Upper Cambrian sandstones that unconformably overlie the Precambrian rocks are present as widely scattered outliers in southeastern and southwestern Marathon County.

Pleistocene deposits in the county include material deposited from three different ice sheets. The Wausau Member of the Marathon Formation in the southcentral part of the County is the oldest glacial material. It is overlain in the northern and western parts of the county by till of the Lincoln Formation of probable early Wisconsinan age. The eastern part of Marathon County is underlain by late Woodfordian till deposited by the Green Bay lobe of the Lake Michigan Glacier.

INTRODUCTION

The primary purpose of this survey was to determine the distribution and age relations of Precambrian rocks in Marathon County and gather basic geologic data needed to assess their resource potential. Marathon County was chosen because previous work indicated that bedrock exposures were probably sufficient to determine relationships between rock units and ultimately to extrapolate the geology into areas of poor exposure. Regional geological mapping for this project was conducted during the summers of 1969 through 1976. Figure 1 is a location map and shows the areas of mapping responsibilities.

Access

Marathon County is located in north central Wisconsin with Wausau as the county seat and the main population center (fig. 1). Athens, Brokaw, Edgar, Mosinee and Stratford are smaller towns in the central and western parts of the county. The main highways include U.S. Highway 51, State Highways 13, 29, 52, 97, 107 and 153. Extensive farming has resulted in most of the land being cleared of forests, the development of an excellent system of county and town roads, and widespread private ownership of land. The county is drained by the Wisconsin River and its tributaries: the Trappe, Rib, Eau Claire, Little Eau Claire, Plover, Eau Pleine and Little Eau Pleine Rivers.

Topography

Most of Marathon County is a gently rolling plain, although the central part of the county is more hilly, presumably due to recent downcutting by the Wisconsin River and its tributaries. The Rib, Eau Pleine and Eau Claire River valleys were incised to bedrock due to high discharge during the Pleistocene when they were major drainageways for the melting glaciers to the north and east. Alluvium carried into the Wisconsin River at Wausau by the Eau Claire and Rib Rivers has resulted in a gently sloping alluvial plain that rises from 366 m at Wausau to about 375 m near Callon eight km east of Wausau and 378 m at Rib Falls about 22 km to the west. The alluvial fill extends from Mosinee north to Wausau, and sporadically north from there to the Lincoln County line. The southeastern part of Marathon County has a series of prominent northeast-trending, bouldery till ridges produced by the last advance of ice into the county.

Previous Geological Work

The county was originally mapped by Weidman (1907) as part of a regional survey of north-central Wisconsin. Parts of the county mapped during a land classification survey by the Wisconsin Geological and Natural History Survey during the 1920's are available as township maps at the Survey office. Hole (1943) concluded that there were four till sheets in and around Marathon County. Thwaites (1943) showed that much of the county previously mapped as part of the driftless area contained glacial deposits, and thus had been glaciated. Emmons and Snyder (1944) examined aspects of the structure in the Wausau area. Vickers (1956), Allingham and Bates (1961), and Henderson and others (1963) published results of geophysical studies, mainly on the syenites west of Wausau. With growing interest in Wisconsin's mineral potential, Dutton and Bradley (1970) compiled the information on Precambrian rocks in Wisconsin available in the files of the Survey. LaBerge and Weis (1968), Weis and LaBerge (1969), and LaBerge and Myers (1973) examined some of the igneous rocks and structural features in Marathon County. LaBerge (1972, 1977, 1980), LaBerge and Myers (1976) and LaBerge and Mudrey (1979) reported on various aspects of the geology and tectonics of central Wisconsin. Other studies that have contributed to this project include the Bouguer anomaly gravity map of Wisconsin by Ervin and Hammer (1974); aeromagnetic maps by Karl and Friedel (pl. 2), Zietz, Karl and Ostrom (1978); radiometric dating by Van Schmus (1976, 1980) and Van Schmus and others (1975 a,b,); studies of the Pleistocene geology by Mickelson and others (1974); Bell and Sherrill's (1974) report on the water availability and additional areas of Paleozoic rock; studies by Anderson (1975), Maass and Medaris (1976), Maass and Van Schmus (1980), the reports by Morey and Sims (1976), Sims (1976), Sims and others (1978),

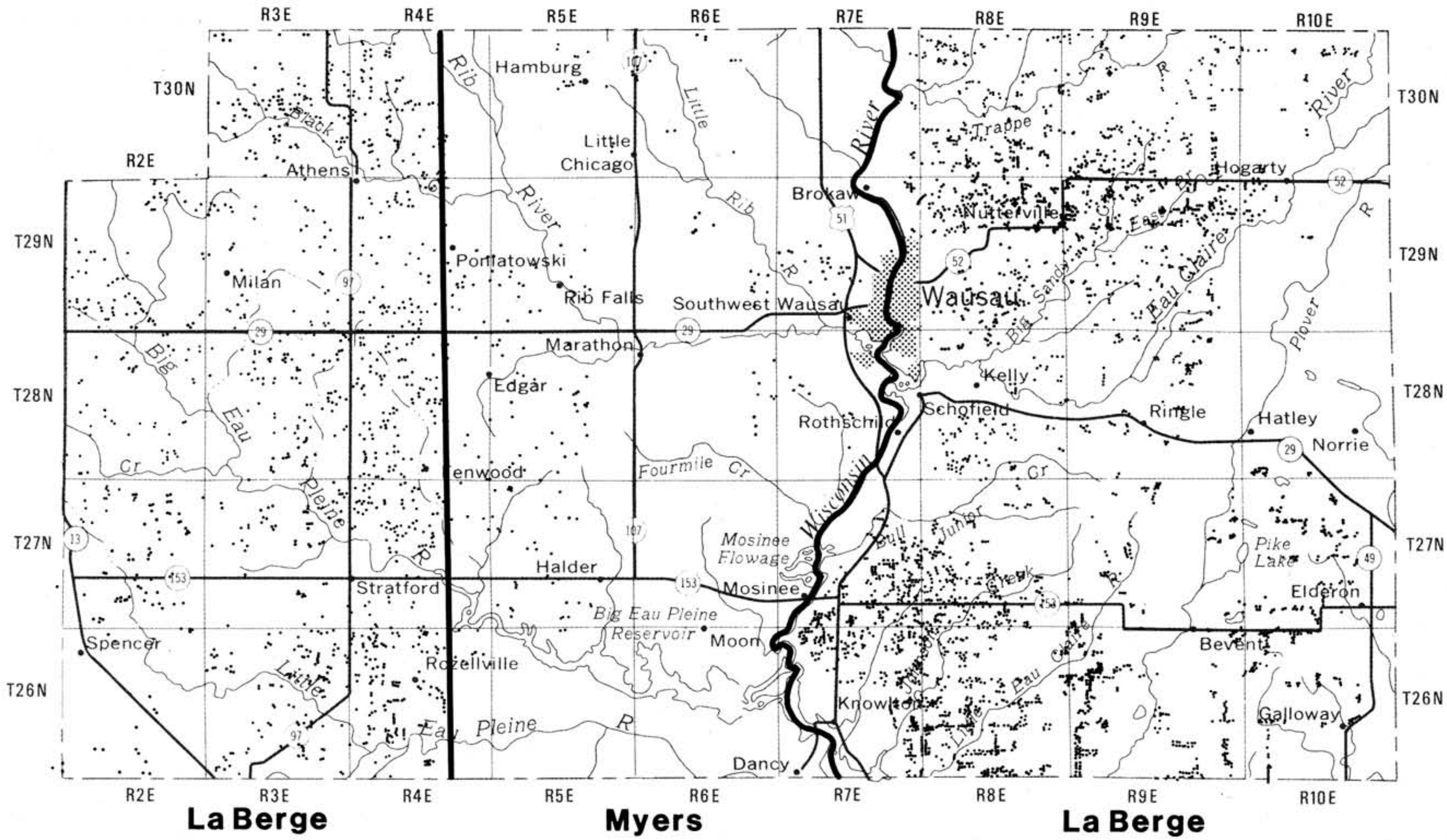

Figure 1.--Index map showing localities mentioned in text, rockpiles and areas for principal mapping responsibility.

Myers (1974, 1976), and Sood and others (1980).

Mapping Methods

Traditional and non-traditional mapping included study of natural and man-made outcrops, and provided the only direct information about bedrock lithology and structure. The best exposures are along roads and major stream valleys. Excavations were utilized when possible. Since glacial cover is thin over most of the county, information on the distribution of rock types was also derived from examination of numerous rockpiles on farms in the area. Angular bedrock fragments brought to the surface by frost action and uprooting of trees are mixed in the glacial veneer and constitute a major component of rocks collected from fields and piled by farmers. Whereas glacial boulders are rounded and of varied composition, bedrock fragments are angular and of uniform rock types. Although rockpiles in areas covered by thin drift contain enough indigenous rock types to permit mapping, thicker drift has obscured all but major bedrock units. The trend and distribution of some units were determined in part by extrapolation with the aid of magnetic or gravity data or both. However, most of the county was mapped before geophysical data were available. Location of outcrops and rockpiles used in this study are found on Plate 1 and Figure 1, respectively. The principal subdivisions of geologic time used in this report are summarized in table 1.

TABLE 1.--Principal subdivisions of Precambrian time as used by the Wisconsin Geological and Natural History Survey

Eon	Era	Period
Phanerozoic	Paleozoic	Cambrian
----------	570 million years	----------
		Late Proterozoic
		------ 900 million years ------
	Proterozoic	Middle Proterozoic
		____ 1,600 million years -----
Precambrian		Early Proterozoic
	____ 2,500 million years	----------
		Late Archean
	Archean	

Acknowledgments

We thank Carl E. Dutton for his major role in introducing us to the area and his aid in initiating the project. We appreciate the continued support of George F. Hanson (former Director of the Survey) and M.E. Ostrom (present Director) during the years in which the mapping and laboratory work was performed. The University of Wisconsin Board of Regents' research grants and Faculty Development grants to Gene L. LaBerge at University of Wisconsin-Oshkosh paid for some of the early field work and the chemical analyses presented herein. Finally, we thank the many colleagues with whom we have discussed various aspects of the geology for their contributions to our present understanding.

Financial support from the Wisconsin Geological and Natural History Survey permitted Gene L. LaBerge in 1970 attend a National Science Foundation institute on volcanic rocks, and in 1974 to participate in the Brevard Zone Penrose Conference.

Earlier versions of the manuscript were read by Bruce A. Brown, Jeffrey K. Greenberg, M.G. Mudrey, Jr., and Klaus Schulz. Their comments have been most helpful in improving the manuscript and are acknowledged with gratitude.

GENERAL GEOLOGY

Marathon County is situated near the southern margin of the exposed Precambrian Shield. Its regional setting in the Precambrian of Wisconsin is shown in figure 2. The bedrock geology is predominantly Precambrian igneous and metamorphic rocks with a few scattered outliers of Paleozoic sandstone that unconformably overlie the Precambrian rocks (pl. 1).

Marathon County is underlain mainly by a sequence of volcanic rocks that range in composition from basalt to rhyolite that have been metamorphosed to greenschist facies and intruded by numerous granitic plutons (fig. 3). The volcanic sequence now exists as isolated pendants and blocks. The widespread development of intrusion breccias, low metamorphic grade of the volcanic rocks, and presence of similar foliation in the plutonic and volcanic rocks suggests shallow, syntectonic intrusion of the plutons. Available radiometric ages indicate that the volcanic-plutonic sequence formed in Early Proterozoic time.

This metavolcanic-plutonic terrane is bounded on the north, west and south by gneisses, amphibolites and migmatites that have undergone amphibolite facies metamorphism, and intense deformation. The gneisses underlie substantial areas around Marathon County which have also been intruded by Early Proterozoic plutons.

The boundaries between the greenschist facies and amphibolite facies rocks are major cataclastic zones[1] that

[1] In this publication the terms "fault" and "cataclastic zone" are defined and used as follows. A fault is a fracture along which there is demonstrable displacement and negligible development of cataclastic features. A cataclastic zone is a zone of crushing and development of interlensing foliation with or without demonstrable displacement. For a more thorough description of the characteristic features and rock types of cataclastic zones, see p. 59 of manuscript.

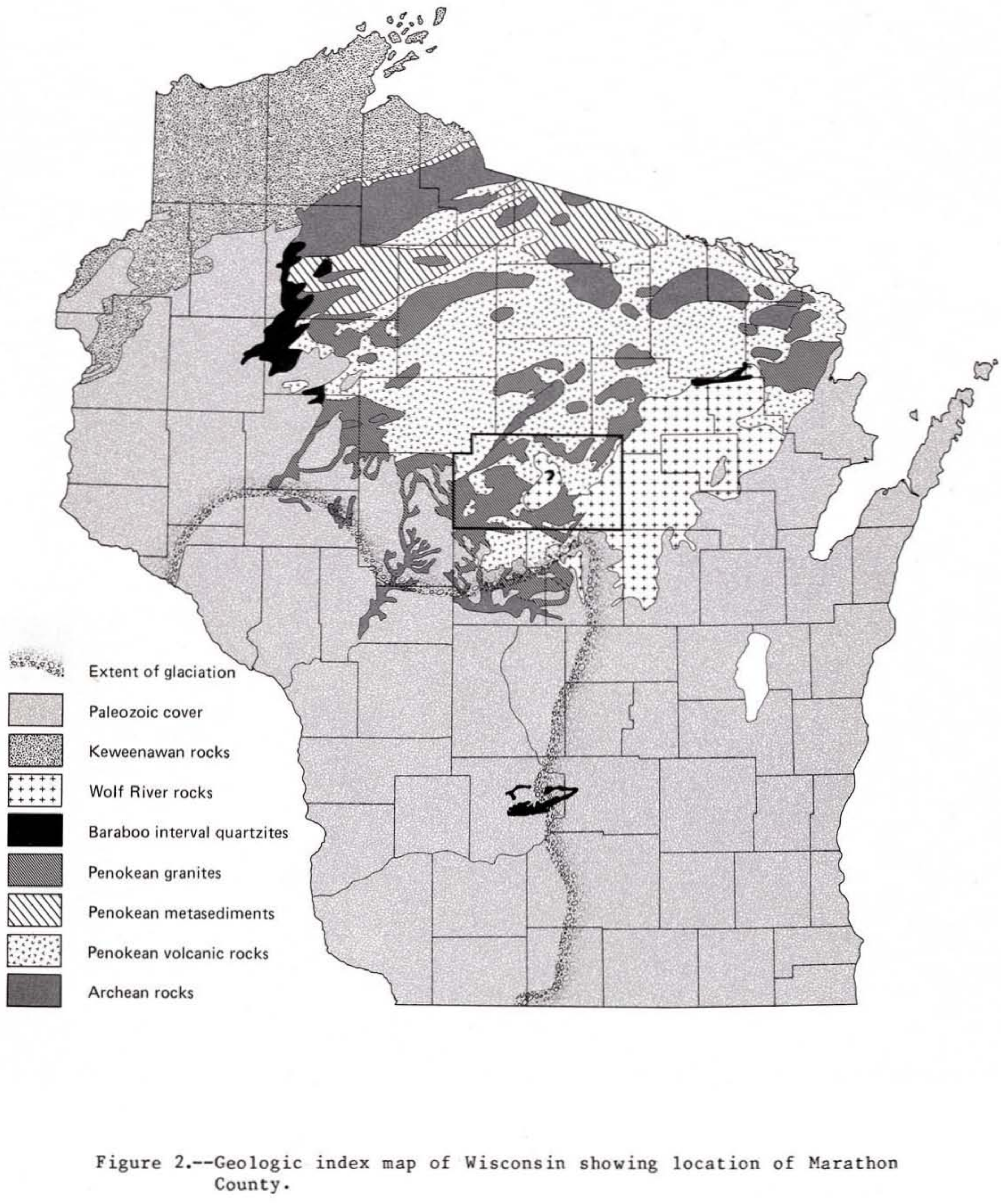

Figure 2.--Geologic index map of Wisconsin showing location of Marathon County.

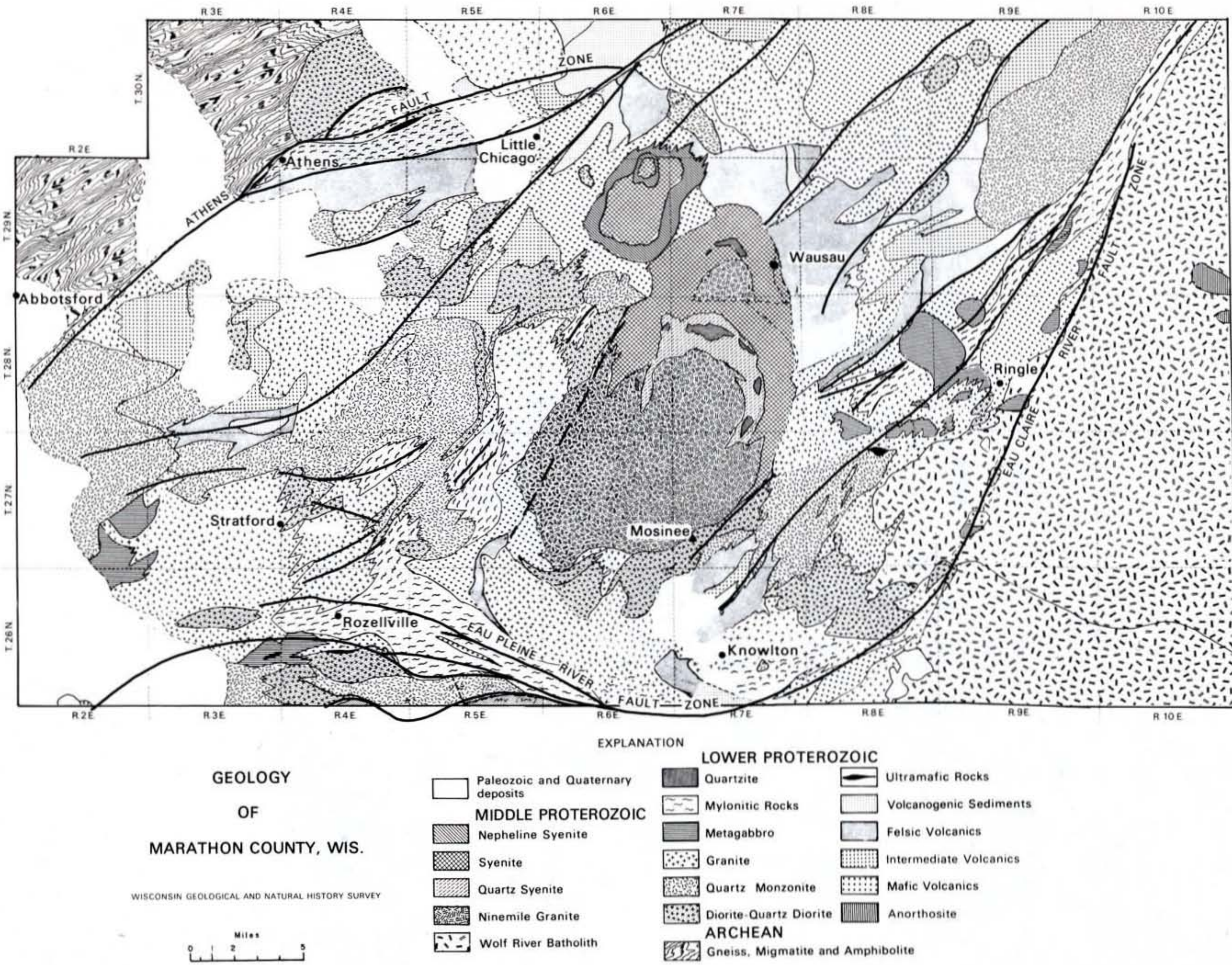

Figure 3.--Summary geologic map of Marathon County showing major lithic units and cataclastic zones.

have been traced for more than 100 km (fig. 2). These major cataclastic zones are the dominant structural feature in the county. Similar cataclastic zones within the greenschist facies rocks suggest deformation before, during and after emplacement of the plutonic rocks.

Eastern Marathon County is underlain by the Wolf River Batholith, a large anorogenic pluton of Middle Proterozoic age (Van Schmus and others, 1975a). The circular Wausau and Stettin syenite bodies west of Wausau are probably related to the Wolf River Batholith (Myers, 1976). Several diabase dikes cut all the older rock types and are probably of Middle Proterozoic age.

Small outliers of Paleozoic sandstone are exposed in southeastern Marathon County. They consist of moderately well-sorted, well-rounded, buff to brown, quartz arenite cemented by silica. The thorough cementation and pronounced color banding 1 to 2 cm thick make this an attractive quarry stone. Similar sandstone outliers are reported in southwestern Marathon County by Bell and Sherrill (1974), but the only exposure found in that area is near the southwestern corner of the county. Numerous boulders of orthoquartzite conglomerate suggest a basal conglomerate unit. The lack of fossils in these rocks makes it uncertain how they are correlative with the Mt. Simon or Galesville sandstones to the south and west.

Three separate Pleistocene till sheets were recognized by us in 1971 (see p. 68 of manuscript). Mickelson and others (1974) showed that the Wausau till is probably pre-Wisconsinan, the Merrill till is early Wisconsinan and till from the Green Bay Lobe is late-Woodfordian. Alluvial fill along the Wisconsin and Rib Rivers provides the major aquifers and sand and gravel deposits in the area.

Table 2 summarizes the geological events and features discussed in this report.

ARCHEAN OR PROTEROZOIC

Northwestern Marathon County

Medium- to coarse-grained quartzofeldspathic biotite- and hornblende-bearing gneisses, amphibolites and migmatites underlie the northwestern corner of Marathon County and occur as isolated blocks along the southern edge of the county (pl. 1). Gneisses and amphibolites (units gn and gdgn of pl. 1) are the dominant rock type north of a line from Colby through Athens to Merrill in Lincoln County. They are sparsely exposed along some of the streams in the area and are present locally as numerous large frost-heaved blocks. The gneisses range in composition from granitic to basaltic (amphibolite). Some are well foliated or lineated or both but are not compositionally layered. Others have pronounced compositional layering from 1 mm to several centimeters thick, and in places (as along the Rib River south of Goodrich in Taylor Co.) the compositional layering may be many meters thick. Some of the non-layered gneisses contain blocks of amphibolitic material and have the appearance of a metamorphosed intrusion breccia (fig. 4). Amphibolitic and quartz dioritic gneisses are exposed in several places along the Rib River within and immediately north of Marathon County. They are also exposed west of Athens along the Marathon-Taylor County Line. Gra-

TABLE 2.--Outline of geological events recognized in central Wisconsin

Interval of geologic time	Geologic event
Pleistocene	Deposition of glacial deposits
Paleozoic	Deposition of Late Cambrian sandstone outliers
Middle Proterozoic	Intrusion of diabase dikes (1,200 Ma?) Intrusion of quartz porphyry plugs Emplacement of Wolf River rocks (1,500 Ma)
Early Proterozoic	Emplacement of post-tectonic plutons (1,765 Ma) Emplacement of syn-tectonic plutons (1,850 Ma) Faulting Deposition of volcano-sedimentary sequence (1,900 Ma) Metamorphism to amphibolite facies (?) Deposition of early volcano-sedimentary sequence
Archean	Formation of gneisses, migmatites, and amphibolites, some greater than 2,800 Ma

Figure 4.--Gneissic rocks consisting of mafic blocks included in a more granitic host at Goodrich Dells, Lincoln County (SE¼NE¼ sec. 25, T. 31 N., R. 4 E.).

nitic gneisses are exposed in places northwest of Athens along Black and Beaver Creek. The granitic gneisses have compositional banding several centimeters thick and commonly contain dikes and veins of granite and pegmatite several centimeters wide. Some of these rocks are here referred to as migmatitic gneisses. The relationship between the granitic gneisses and amphibolites is not known since no exposures containing both rock types were found. An uncommon phase of the gneissic rocks is exposed along Black Creek west of the bridge on Highway 97 in Athens. Rocks at this locality include a felsic rock that appears to be a metadacite tuff, an amphibolite dike(?) and farther upstream a mylonitized granitic gneiss (LaBerge and Palmer, 1980).

Petrographically, grain size of the gneisses range from 0.5 mm to 2 cm and have a lepidoblastic to granoblastic texture. The amphibolitic and quartz diorite gneisses (gdgn) consist of 40 to 50 percent plagioclase (An_{45-50}), 10 to 40 percent blue-green hornblende, 10 to 30 percent quartz, 0 to 15 percent brown biotite, and minor garnet. the granitic gneisses (gn) contain 20 to 40 percent microcline porphyroblasts and matrix, 10 to 30 percent plagioclase, 15 to 30 percent quartz, and 5 to 10 percent brown biotite. Granitic veins in the migmatitic gneisses are composed mainly of microcline and quartz.

Some of the gneisses in northwestern Marathon County have a cataclastic texture superimposed on the gneissic banding and foliation, particularly along the major fault boundary that marks the southern edge of the gneisses. The cataclastically deformed gneisses contain lenticular eyes (augen) of microcline, plagioclase and quartz up to 1 cm long separated by thin layers of much finer grained material. Biotite commonly is concentrated in the fine-grained zones, and produces a wavy compositional layering. In some samples the matrix is recrystallized reducing the inequigranularity of the rock.

The gneisses were locally intruded by granitic rocks in parts of the county. For example, a relatively homogeneous slightly foliated granodiorite (unit gdgn) underlies at least 42 km^2 in T. 30 N., R. 4 E. northeast of Athens. Although the contact between the granodiorite and the gneisses (unit gn) is not exposed, it is probably a pluton in the gneissic rocks. Along the Rib River (secs. 18 and 19, T. 30 N., R. 4 E.) the body appears to truncate the strongly foliated rocks to the west.

Southern Marathon County

Gneissic rocks in southern Marathon County occur as an elongate block about 21 km long and 6.5 km wide along the county line east of Marshfield (units gdgn, gn and qmgn), and as a wedge-shaped area about 9 km long in R. 8 E. east of Lake DuBay (unit amp). The latter area of gneissic rocks extends south into Portage County.

A composite block of gneissic rocks east of Marshfield is bounded on the north by a zone of cataclastic rocks several km wide along the Eau Pleine River valley. Gneissic rocks of diverse composition occur as separate large fault bounded lensoidal blocks. The northernmost unit is an amphibolite (unit amp) 1 km wide and 6.5 km long derived from a deformed gabbroic rock (sec. 19, T. 26 N., R. 4 E.). Much of the body is non-foliated, coarse-grained (5 mm) hornblende and plagioclase with an igneous-appearing texture. This phase is cut by zones 5 mm to several meters wide of fine-grained, laminated amphibolite that presumably represent recrystallized shear zones within the gabbro. Transition zones several centimeters wide are present between the coarse and fine-grained zones, and lensoidal patches of coarse-grained amphibolite are enclosed in the laminated zones (fig. 5).

South of the amphibolite, but separated from it by a massive talc-serpentine body (unit um) with several foliated and slickensided zones, is a foliated quartz diorite (unit gdgn) 2 to 3 km wide and 11 km long. The quartz diorite has closely-spaced (1 to 2 mm) foliation planes defined by biotite near the northern edge of the body (adjacent to the ultramafic body). Foliation dips nearly vertically, and sparce mineral lineations and fold axes in the foliation plunge 85° N. 90° E. to N. 85° W. Foliation planes are more widely separated (1 cm) away from the margin. Much of the remainder of the

Figure 5.--Amphibolite derived from a gabbro. Note the lenticular patches with relict igneous-appearing texture separated by braided zones of foliated amphibolite. From along the Little Eau Pleine River (NW¼SW¼ sec. 24, T. 26 N., R. 3 E.).

body has braided shear zones 1 to 5 cm wide of finer grained, more foliated quartz diorite that have the distribution and appearance of recrystallized shear zones. The overall uniformity of the foliated (gneissic) quartz diorite (gdgn) suggests that it is a metamorphosed plutonic rock. East of the amphibolite unit the gneissic quartz diorite is bounded on the north by pillowed metabasalts and another ultramafic body. A foliated quartz monzonite (qmgn) south of the gneissic quartz diorite (1 to 3 km wide by 17 km long) has a textural uniformity suggesting a quartz monzonite protolith. The southern edge of this body is finer grained (0.5 to 1 mm), banded with layers 1 to 2 mm thick and has prominent mineral streaking and a sugary texture. This is probably a recrystallized mylonitic zone.

A small wedge (0.5 by 1 km) of compositionally banded, coarse-grained granitic gneiss (gn) is exposed south of the gneissic quartz monzonite (in the SW¼ sec. 31, T. 26 N., R. 4 E.). It consists of 5 to 10 mm grains of quartz, microcline and plagioclase in 1 to 3 cm layers alternating with biotite-bearing layers 1 to 2 cm thick (fig. 6). Numerous veins 1 to 4 cm wide of granitic or pegmatitic material cut the layering. The fault boundary of the northern edge of this unit is expressed as a 50- to 100-m wide zone of fine-grained, finely banded gneiss with a saccharoidal texture that appears to be a recrystallized mylonite zone. A zone of ferruginous quartz (unit qz) about 100 meters wide separates the banded gneiss from the foliated quartz monzonite. It is not known whether this quartz rock was quartzite or a ferruginous (pyritic?) vein quartz before deformation and metamorphism.

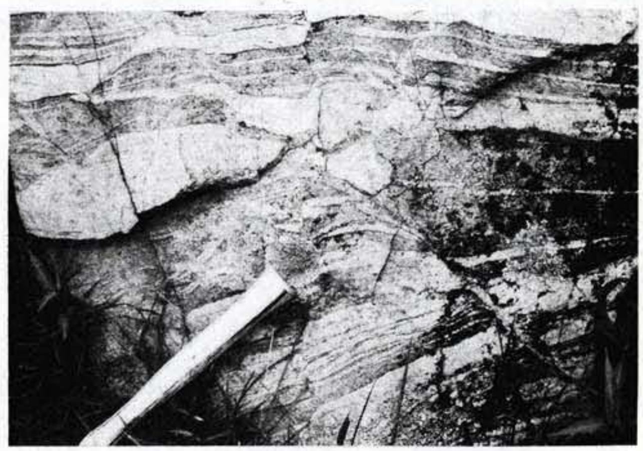

Figure 6.--Banded granitic gneiss from east of Marshfield (SW¼ sec. 31, T. 26 N., R. 4 E.).

This block of gneissic rocks is bounded on the south by mafic metavolcanic rocks that have not been metamorphosed to amphibolite facies, and thus appear to be of lower metamorphic grade than the rocks within the gneissic block. The contact between the gneissic rocks and the volcanic rocks was not found, but it is believed to be a fault, similar to that along the northern edge of the gneisses.

The gneissic units and the metavolcanic rocks are all intruded and truncated in T. 26 N., R. 3 E. by a nonfoliated quartz monzonite (gm). Numerous small granitic dikes and veins and small, poorly exposed pegmatites are present around the margins of the pluton. Truncation by the quartz monzonite of the magnetic trends produced by the mafic rocks can be seen on the aeromagnetic map of the area just east of Marshfield (pl. 2). The lack of deformation and metamorphism in this pluton indicates that it was emplaced after the faulting that juxtaposed the various gneissic rocks.

The gneissic rocks east of the Wisconsin River at Lake DuBay (T. 26 N., R. 8 E.) consist of banded and foliated amphibolite (amp) on the northern edge of the area. The layering and fine grain size of these rocks suggests derivation from basalt or in an environment of intense deformation. These rocks are bounded on the south by prominently banded granodioritic to granitic gneisses (ggr) that were exposed briefly in roadcuts and borrow pits during construction of U.S. Highway 51 in 1972. Temporary exposures of gneisses extended south into Portage County approximately 6 km to SW¼ sec. 25, T. 25 N., R. 8 E. where the gneisses and amphibolites are truncated by rocks of the Wolf River batholith, which also forms the eastern boundary of the gneisses in Marathon County. Much of the gneiss in this part of Marathon County has been cataclastically deformed along a major fault zone discussed later in this report (p. 64). We assume that the two areas of gneiss along the southern edge of Marathon County are part of the same terrane although they may not form a continuous block of gneisses. They are probably segmented by faulting.

Eastern Marathon County

Several areas of amphibolite are present along the major cataclastic zone that extends along the Eau Claire River. An amphibolite lens is surrounded by greenschist facies rocks in the town of Easton (SE¼SW¼ sec. 27, T. 29 N., R. 9 E.); foliated amphibolite is also present immediately east of Eau Claire Dells (SW¼SE¼ sec. 7, and NW¼NE¼ sec. 18, T. 29 N., R. 10 E.); and amphibolite is indicated by abundant angular float boulders near the northeastern corner of the county (SW¼ sec. 2, T. 30 N., R. 10 E.). These occurrences may represent blocks that have been tectonically brought up from an amphibolite terrain at depth by movements along this major cataclastic zone. A block of quartzofeldspathic gneiss (unit gn) east of Rothschild (secs. 21, 22, 27 and 28, T. 28 N., R. 8 E.) also appears to be tectonically transported upward from an amphibolite facies basement.

Regional Relations

Reconnaissance geologic mapping to the west and north of Marathon County suggests that the gneisses are part of a high-grade metamorphic terrane that extends at least 100 km to the west, and at least to Prairie Dells in Lincoln County (about 13 km northeast of Merrill). The gneisses closely resemble those of the Chippewa Amphibolite Complex described by Myers (1974), and Myers and others (1980) from exposures along the Chippewa and Eau Claire Rivers. Known exposures of Precambrian rocks between Marathon County and Chippewa and Eau Claire Counties are dominantly high-grade metamorphic rocks. The gneissic rocks have a distinctive aeromagnetic pattern of gently curving anomalies, compared with a bird's eye pattern of magnetic highs and lows in the remainder of Marathon County (Zeitz and others, 1978). The Bouguer anomaly gravity map of Ervin and Hammer (1974) shows the gneisses as distinct areas of zero to -40 mgal, compared with -40 to -90 mgal in the remainder of Marathon County. The known geology, aeromagnetics and gravity thus suggest that the gneisses in Marathon County are part of a larger gneissic terrane.

Gneissic rocks in and on the periphery of Marathon County are strongly lineated, with mineral lineations and fold axes plunging 20 to 60 degrees west in the plane of the foliation (fig. 2). For example, lineations and fold axes along the Rib River near Goodrich in Taylor County plunge 30 to 40 degrees west; fold axes in gneisses near Marshfield plunge 20 degrees west; strong mineral lineation in amphibolites along the Little Eau Claire River in southeastern Marathon County plunge 60 degrees southwest; fold axes in migmatitic gneisses at Greenwood, Clark County plunge 35 degrees west; and fold axes at Neillsville in Clark County plunge 70 degrees west. This structural uniformity suggests that all of these rocks could have been deformed together during a single deformational episode.

Van Schmus (written communication, June 12, 1981) reports a preliminary U-Pb zircon age of 2,800 Ma from the gneisses in sec. 31, T. 26 N., R. 4 E. Van Schmus and Anderson (1977) reported an age of more than 2,800 Ma for migmatitic gneisses at Pittsville (25 km south of Marathon County). Structural studies and radiometric dating of gneisses at several localities in central Wisconsin led Maass and Medaris (1976) to conclude that the gneisses in central Wisconsin are mainly of Proterozoic age. Myers (1978) and Myers and others (1980) showed that amphibolites and gneisses in Eau Claire and Chippewa Counties had undergone two periods of metamorphism and deformation prior to being included in 1,850 Ma old plutons. These data suggest that there are gneisses of more than one age in the region. This is discussed further under the section on structure (p. 78 of manuscript).

LOWER PROTEROZOIC

Radiometric Ages

Radiometric ages have been published on five units in the lower Proterozoic rocks of Marathon County. All ages have been recalculated with constants proposed by Steiger and Jager (1977).

Van Schmus (1980) reports a U-Pb zircon age from a rhyolite porphyry (No. VS-73-17) from Wausau of 1,859±20 Ma. Recalculation of Rb-Sr whole-rock data of Van Schmus and others (1975b) yields an age of 1,648 Ma with $^{87}Sr/^{86}Sr_i$ of 0.704 for five metavolcanic rocks from Marathon County. Elimination of D-1362, an aberrant high-Rb/Sr sample, results in an age of 1,868 Ma with an initial of 0.7017.

Other U-Pb zircon ages include the quartz monzonite near Kalinke (unit kqm) (Van Schmus, 1980, no. VS-73-16), and a quartz diorite near Mosinee (unit qd) (Van Schmus, 1980, no. VS-73-18); both ages are between 1,825 to 1,840 Ma. An attempt was made to calculate a

Rb-Sr age from data of the granite on Granite Heights by Van Schmus and others (1975b). The apparent age is 1,570 Ma with an initial strontium ratio of 0.707.

These data and field relations suggest that the low-grade volcanic rocks are about 1,860 to 1,870 Ma and were intruded by the granitic rocks about 1,825 to 1,840 Ma. The younger calculated ages of 1,650 to 1,600 Ma are wide-spread in the Lake Superior region, and are presently interpreted to represent a thermal event that reset the Rb-Sr ages (Van Schmus, 1976). The nature and extent of this event are poorly understood.

Metavolcanic Rocks

Volcanic rocks that range in composition from basalt to rhyolite and which have been subjected to greenschist facies metamorphism are widely distributed in Marathon County. Observed rock types include pillow lavas, massive flows, flow breccias, tuffs and volcanogenic sediments. Primary textures and structures are generally well preserved, except where the rocks have been highly deformed, or adjacent to larger plutons, where metamorphic effects have obscured the primary features. The volcanic sequence has been extensively disrupted by faulting and intrusion, and is now preserved as a number of xenoliths, screens and pendants surrounded by plutonic rocks. This, coupled with generally poor exposure, precludes establishing the original volcanic stratigraphy. Age determinations of rhyolites on the east edge of Wausau indicate that the volcanic rocks in this area are 1,860 Ma (p. 14 of manuscript).

Mafic Metavolcanic Rocks

Basaltic rocks (unit mv), including tuffs and pillowed and massive flows, are exposed in several large areas in eastern, northern and southern Marathon County, and in a number of smaller roof pendants. Pillow lavas are exposed along Artus Creek (NW¼NE¼ sec. 29, T. 29 N., R. 6 E.) (fig. 7), along Highway A (SW cor. sec. 27, T. 30 N., R. 6 E.), along Highway N (SE¼ sec. 31, T. 29 N., R. 9E.), south of Rozellville (NE¼SE¼ sec. 21, T. 26 N., R. 4 E.), and along Troy Avenue (SE¼SE¼ sec. 12, T. 29 N., R. 7 E.). Highly deformed pillows (unit am) are exposed in the NE¼SW¼ sec. 12, T. 30 N., R. 8 E. Pillowed basalts were also exposed briefly in a roadcut in Schofield where Highway 29

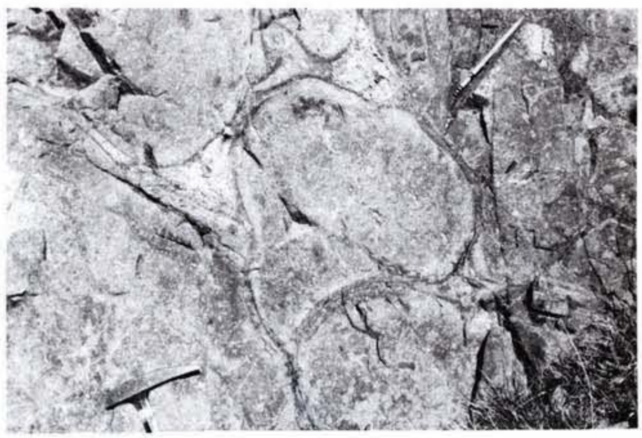

Figure 7.--Photograph of basaltic pillow lavas exposed along Artus Creek (NW¼NE¼ sec. 29, T. 29 N., R. 6 E.). Pillow tops indicate younging to the upper right (southeast).

crosses the Wisconsin River (NE¼SE¼ sec. 24, T. 28 N., R. 7 E.) and during installation of sewer lines in adjacent areas in Schofield. Pillow lavas are present in rockpiles derived from the NE¼ sec. 26, T. 29 N., R. 9 E. Selvages of the pillows are commonly composed of epidote whereas the interior of the pillows are composed of actinolite, plagioclase, epidote, quartz, and some chlorite or carbonate. Massive, porphyritic and amygdaloidal basaltic rocks are also common and widespread with the pillow lavas and in other areas on the map indicated as mafic volcanic rocks (unit mv).

The mafic volcanic rocks vary considerably in mineralogy and texture. Some are composed mainly of plagioclase and amphibole pseudomorphous after pyroxene, with minor chlorite, epidote, carbonate and quartz, and retain a distinct subophitic to intergranular or trachytic igneous texture (fig. 8). Others consist dominantly of randomly oriented actinolitic hornblende with strongly serrate crystals, and may contain considerable epidote as well as sodic plagioclase, actinolitic hornblende, chlorite and quartz. Epidote generally occurs as veins and irregular patches with a granoblastic texture. Amoeboid pale yellow-brown garnets are present locally in epidote rich veins, as at Artus Creek (NW¼NE¼ sec. 29, T. 29 N., R. 6 E.). Vesicle fillings

Figure 8.--Photomicrograph of a mafic metavolcanic rock showing preservation of the igneous texture. Mineralogy consists of greenschist facies minerals.

include fine or coarse grained epidote, granular amphiboles, some with concentric layers, fine or coarse grained quartz, or carbonate, or chlorite, or mixtures of several of these minerals.

There is a wide range in the degree of preservation of primary igneous textures in the metabasalts, although they have largely been altered to greenschist facies minerals. Primary textures are generally preserved in the larger areas of metabasalts. Some samples from the same outcrop area may contain well preserved and poorly preserved igneous textures. However, along the major fault zones, the mafic metavolcanic rocks have been converted to strongly foliated rock. In the fault zone along the Eau Claire River in eastern Marathon County, the metabasalts are foliated and compositionally banded with a lepidoblastic to granoblastic texture. Actinolitic hornblende (Z:C=15°-17°) occurs in both sub-parallel and radiating clusters of up to 3 mm. Relict igneous textures are well preserved in the mafic volcanic rocks exposed on both sides of the fault zone. Thus, the obliteration of igneous textures is confined to the zone, and does not represent a regional metamorphic phenomenon.

A contact metamorphic overprint is present in some of the mafic volcanic rocks near larger intrusions. Along the western edge of the Wolf River Batholith, it consists of 2 to 10 mm rosettes of actinolite or hornblende, or aggregates of pyroxene that mask the earlier foliation. Adjacent to the intrusion, grain size in the metavolcanic rocks increases to about 2 mm, and the rocks have a lepidoblastic to granoblastic texture. The occurrence of garnets is spatially related to plutons (near the Wolf River batholith at Eau Claire Dells, and at Artus Creek, NW¼NE¼ sec. 29, T. 29 N., R. 6 E.) and their occurrence in veins and patches of granoblastic epidote at Artus Creek suggests that the garnets are the result of contact metamorphism.

Intermediate Metavolcanic Rocks

In some roof pendants intermediate metavolcanic rocks (unit iv) occur between mafic and felsic rocks. Intermediate metavolcanic rocks are also locally interbedded with graywacke and conglomerate suggesting subaqueous deposition. In eastern Marathon County, andesites are interbedded with dacites, and the sequence becomes progressively more felsic to the northwest. The original extent and thickness of units are unknown.

The andesites are commonly porphyritic with phenocrysts of hornblende and plagioclase ranging up to 1 cm. In general, the andesites (where recognized) appear to be less chloritic and more fragmental than the basalts. Fragmental and massive rocks of presumed andesitic composition are present near Big Sandy Park (sec. 19, T. 29 N., R. 9 E.), south of the Central Wisconsin Airport near Mosinee, along the Rib River east of Athens (W½ sec. 9, T. 29 N., R. 5 E.) and southwest of the intersection of Highways 97 and 29 (secs. 11, 14, 24 and 26, T. 28 N., R. 3 E). At all these locations the major rock type is a tuff with rhyolite to andesite fragments up to 5 cm in diameter in an andesitic matrix.

At most locations the andesites exhibit considerable deformation, with volcanic fragments usually markedly lineated or flattened or both. At some locations the clasts are elongated up to five times their short dimension (fig. 9). Phenocrysts of hornblende

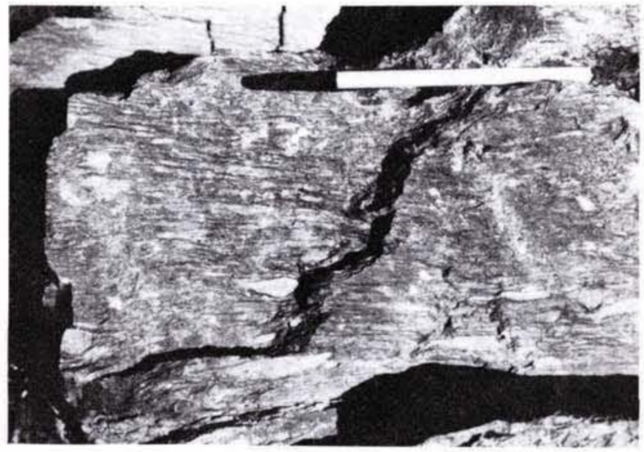

Figure 9.--Photograph of an andesite tuff consisting of clasts of andesite and rhyolite in a fine-grained andesitic matrix. Clasts range up to 7 cm, and most are flattened due to subsequent deformation.

and plagioclase are locally boudinaged, with hornblende generally being much more elongated than the plagioclase.

Felsic Metavolcanic Rocks

Felsic volcanic rocks (unit fv) underlie that part of Wausau east of the Wisconsin River, occur extensively in eastern Marathon County, and in several roof pendants elsewhere in the county. A wide variety of volcanic rock types are represented, including water-laid (bedded) tuffs, welded tuffs, pyroclastic breccias, flow breccias, massive and flow banded rhyolites, lahars and several types of volcanogenic sediments. Lithic tuff with some interbedded volcanogenic sediment is the most common rock type and consists of angular volcanic fragments from 1 cm to a fraction of a millimeter along with rounded quartz grains (fig. 10). This type of rock is extensively exposed in and east of Wausau. Pyroclastic breccia (fig. 11) with clasts up to 20 cm are present east of Wausau (NE cor. sec. 36, T. 29 N., R. 8 E.) and south of Mosinee (W¼ cor. sec. 4, T. 26 N., R. 7 E.). These breccias were probably deposited proximal to vents.

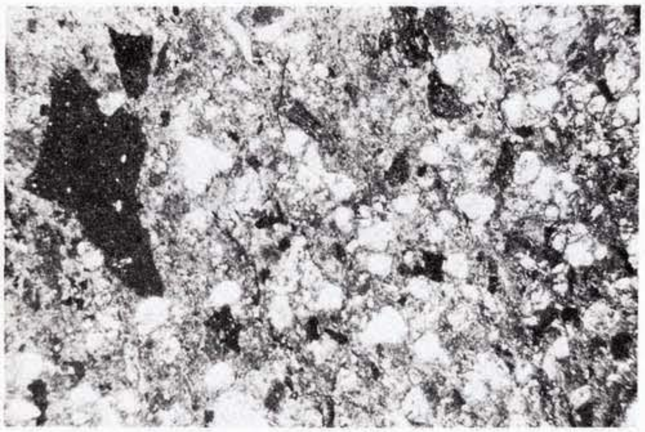

Figure 10.--Photomicrograph of bedded tuff northeast of Wausau. Note the angular volcanic fragments and rounded quartz grains set in a fine rhyolite matrix.

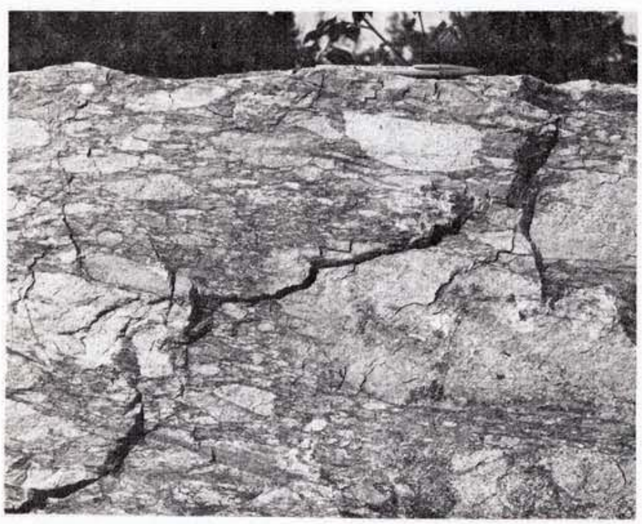

Figure 11.--Photograph of a rhyolite breccia 10 km east of Wausau. The coarse fragments suggest deposition near a vent. Note that the fragments have been flattened and elongated by deformation.

Flow-banded rhyolite (fig. 12), lahars (fig. 13), and welded tuffs (fig. 14) are well preserved in Wausau and along the Rib River east of Athens. Relict spherulites (fig. 15), perlitic cracks (fig. 16) and intensely welded vitric fragments suggest that some of the rhyolites may originally have been obsidian. Volcanic conglomerate, sandstone and siltstone are interbedded with welded tuffs and lava flows between Wausau and Brokaw. The conglomerates consist mainly of boulders up to 20 cm in diameter of volcanic rocks in a matrix of finer volcanic fragments.

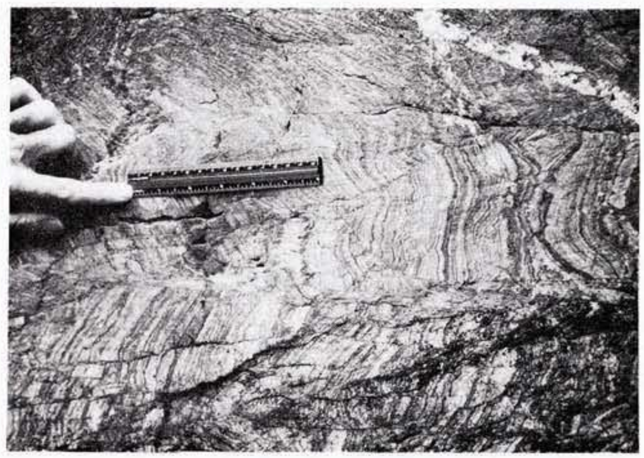

Figure 12.--Photograph of a flow-banded rhyolite along the Rib River east of Athens.

Conglomeratic (laharic?) rhyolites are complexly interbedded with welded rhyolitic tuffs along the west side of the Wisconsin River between Wausau and Brokaw (SW¼ sec. 10, T. 29 N., R. 7 E.). The conglomerates range up to several meters in thickness and contain boulders up to 25 cm in diameter. The conglomerate units are interbedded with massive welded tuff units at least 10 m thick. Most of the boulders in the conglomeratic units are volcanic; however, pebbles, cobbles and boulders up to 20 cm in diameter of purple quartzite and granite are present in some layers. The conglomeratic units have limited lateral extent. The presence of quartzite and granite boulders precludes a simple explanation for these units, and suggests denudation of an older metasedimentary-plutonic terrane during deposition. The volcanic sandstones consist of round sand-size volcanic fragments, quartz grains, and scattered quartzite pebbles. These units range in thickness from a few meters to several tens of meters and have a very restricted distribution between the lava flows or ash flows.

Except for local development of sericite in deformed areas, the felsic

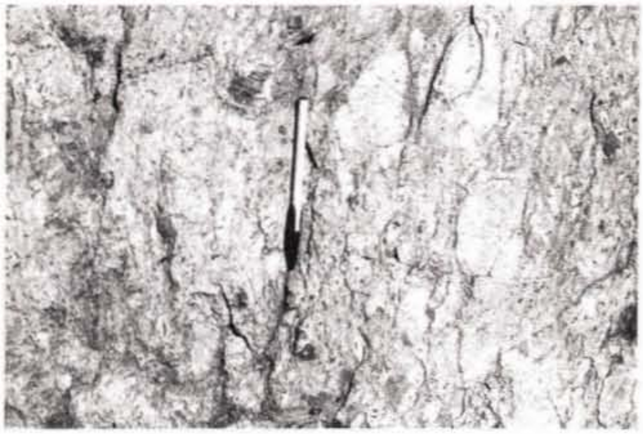

Figure 13.--Photograph of volcanic mudflow (lahar) deposits at Highland Grove School in Wausau. Note the mixture of clasts in a fine tuffaceous matrix.

Figure 14.--Photomicrograph of welded rhyolitic tuff from Wausau showing flattened and welded shard fragments with phenocrysts of quartz (white) and plagioclase (mottled areas in the lower part of the photograph).

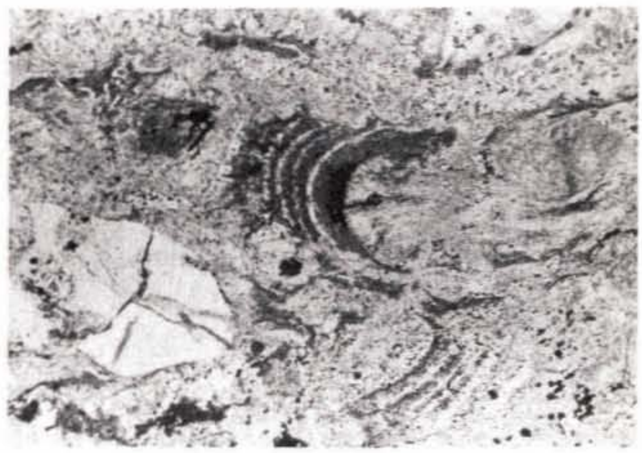

Figure 15.--Photomicrograph of relict spherulitic texture in rhyolite from Wausau showing the concentric banding and radial growth of crystals.

Figure 16.--Photomicrograph of relict perlitic cracks in rhyolite from Wausau, indicating that the rock was originally glassy and that it has undergone little subsequent recrystallization.

volcanic rocks show little evidence of metamorphism. The rocks have been locally deformed and converted to sericite schists, or the volcanic fragments may be extensively deformed. The extremely fine grain size and preservation of primary features such as hard structures also indicates a general lack of recrystallization.

The felsic volcanic rocks are interpreted to be mainly aquagene tuffs with interbedded sediments. Their subaqueous origin is similar to that of the mafic and intermediate rocks. However, the welded tuffs, flow banded rhyolites and lahars at Wausau and near Athens are probably of subaerial origin. The volcanic sandstones and conglomerates north of Wausau are believed to be alluvial facies of the volcanic rocks. Their restricted lateral extent and interlayered welded tuffs may indicate that they are valley-fill deposits on the flanks of a volcano. Therefore, the subaerial felsic volcanic rocks may represent volcanic islands in a basin of unknown dimensions.

Chemistry of the Metavolcanic Rocks

Seven new chemical analyses of volcanic rocks from Marathon County are presented in appendix 1. The analyses were obtained as an aid to classifying the volcanic rocks, and are not presented as a comprehensive study of the petrochemistry of the rocks. The volcanic rocks range from 53 percent SiO_2 to 74.5 percent SiO_2 and belong to the calcalkaline series of rocks as shown on the AFM plot in figure 17. The felsic volcanic rocks range from dacite to rhyolite and most are deficient in K_2O, although one sample from Wausau (We-27-1) contains abnormally high K_2O (7.41 percent).

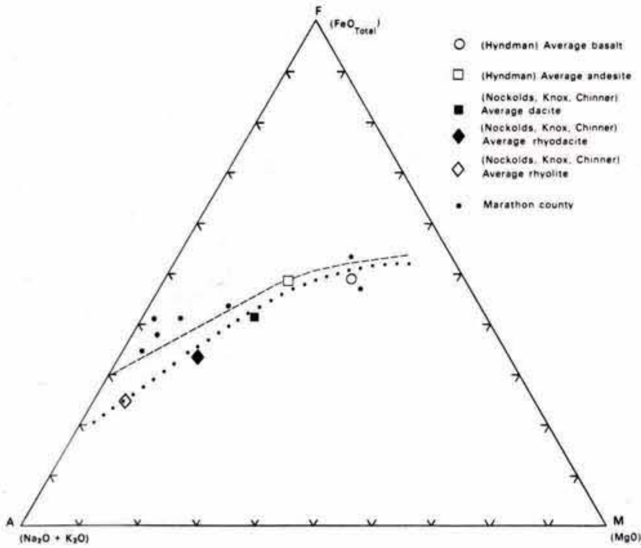

Figure 17.--AFM plot of volcanic rocks from Marathon County showing a calc-alkalic trend.

Metasedimentary Rocks

Graywacke and slate associated with volcanic rocks in north central Marathon County were named the Hamburg Slates by Weidman (1907) who believed that they covered most of the area between Athens and Merrill. Our mapping indicates a much smaller distribution and complex interbedding with metavolcanic rocks. Most of these metasedimentary rocks are not sufficiently well exposed to allow delineation of discrete units. The coarser metasedimentary rocks are graywackes, consisting of quartz, plagioclase, and volcanic rock fragments. The finer grained metasedimentary rocks contain chlorite- and sericite-bearing slates or phyllites. Figure 18 is a photograph of sedimentary material interbedded with tuffs north of Wausau. Figure 19 shows relict shard fragments in some of the volcanic ash layers. Weidman (1907) interpreted the graywackes (his Wausau Graywacke) to be part of the basement upon which the volcanics were deposited, and the con-

Figure 18.--Photograph of slump structure in graywacke along Highway W north of Wausau. The folding is typical of the finer grained layers. Layers above and below are not folded.

Figure 19.--Photomicrograph of argillite from a fine-grained layer in the graywacke of figure 18. Note the abundance of angular, curved shard fragments showing it is actually a bedded tuff.

glomerate (his Marshall Hill conglomerate) to be younger and deposited on an eroded surface of the volcanics. As discussed below, the argillites, graywackes and conglomerates appear to be part of a volcanic succession and are so interpreted in this report.

In the Wausau area, argillite and graywacke are interbedded with clearly volcanic materials. The argillite (a unit within unit fv) exposed along the south side of Jim Moore Creek (sec. 17, T. 29 N., R. 8 E.) contains numerous lens-shaped carbonate concretions 2- to 8-cm in diameter. Graywacke associated with the argillite is a very hard, sandy textured rock with layers 3-10 cm thick. Pyrite is common in some samples. Most of the graywacke appears to contain considerable tuffaceous material, and in places, it grades vertically into massive lapilli tuff.

Well bedded argillite and graywacke (unit vs) with interbedded tuff is exposed along County Highway W north of Wausau (sec. 12, T. 29 N., R. 7 E.). The rock is medium to fine grained, with layers ranging in thickness from less than one cm to at least 30 cm and showing excellent samples of graded bedding and soft sediment deformation (slump structures) (fig. 19). Several layers of lapilli tuff are interbedded with the graywacke argillite, and some of the finer (argillite) units consist mainly of volcanic fragments. Conglomeratic units within and at the top of this sequence (along the Wisconsin River at the west end of the bridge at Brokaw) may be volcanic conglomerates or agglomerates. Welded tuffs, flow breccias and lahars exposed along the west side of the Wisconsin River (secs. 2, 3 and 11, T. 28 N., R. 7 E.) and in the 3M Company quarry (NW¼ sec. 11, T. 28 N., R. 7 E.) overlie the argillites and graywackes to the east.

An isolated area of metagraywacke and conglomerate (unit vs) with an associated prominant magnetic high of 1,000 nannoteslas (pl. 2) is located north of Stratford in secs. 34, 35, and 36, T. 28 N., R. 3 E., and sec. 31,

T. 28 N., R. 4 E. The occurrence appears to be completely enclosed by felsic and intermediate volcanics. The metagraywacke is fine to medium grained and medium to massively bedded. At the north end of the exposure on Hamman Creek, it appears to grade into andesitic and rhyolitic tuff. The associated conglomerate contains boulders up to 30 cm in diameter of quartzite, iron formation, felsic and mafic volcanic rocks and some plutonic rocks. The magnetic anomaly is evidently produced by concentrations of magnetite in the matrix of the conglomerate. The conglomerate exhibits spectacular deformation features (figs. 20 and 21). This conglomerate is important to an understanding of the stratigraphy and tectonics of Central Wisconsin and is discussed below (p. 57 of manuscript).

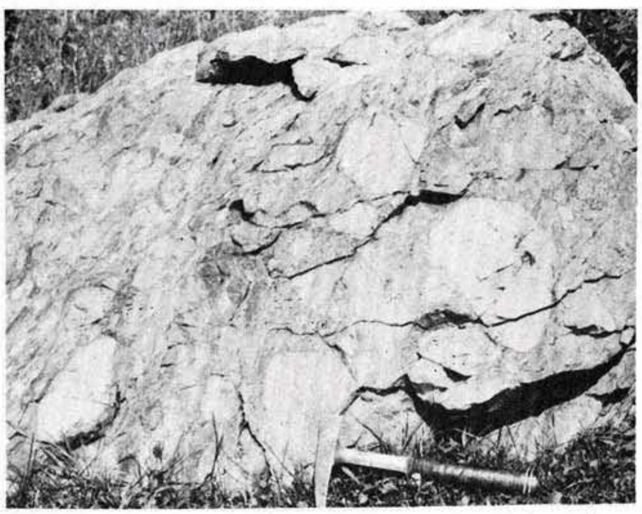

Figure 20.--Photograph of relatively undeformed conglomerate along Hamann Creek north of Stratford. Round quartzite boulders are readily recognizable.

Ferruginous cherty material exposed in test pits in a small area in the center of sec. 26, T. 29 N., R. 9 E. may be an iron formation. The unit is enclosed in metavolcanic rocks on the east side of the Eau Claire River, and

Figure 21.--Photograph of same conglomerate as figure 20 about 100 m north along Hamann Creek. Note the intense flattening of the boulders. Some boulders of volcanic rocks are only a centimeter wide and up to 10 cm long.

is located about 30 m north and 120 m east of an old exploration shaft reported by the present landowner to be 60 m deep. None of the material tested was magnetic, and the nature of the original iron minerals is unknown. However, the abundance of limonite suggests either a carbonate- or sulfide-chert iron formation. The shaft was dug about 1920 in an attempt to recover gold and was later filled with materials removed from the shaft. Material remaining on the waste pile includes abundant pyrite and some chalcopyrite in a chloritic schist with abundant vein quartz (see p. 73 of manuscript).

Intrusive Rocks

The volcanic rocks and gneisses in Marathon County have been intruded by numerous bodies that range in composition from ultramafic to granitic. The plutonic rocks occur as numerous distinct plutons, segmenting the volcanic sequence into a number of isolated blocks interpreted as roof pendants. Most of the plutons are very distinctive, and can be mapped as separate intrusions. Many are compositionally zoned and contain numerous pendants, screens and xenoliths of volcanic and older plutonic rocks in their margins.

Classification of the plutonic rocks is based largely on field identification, modified somewhat by petrographic studies. It is possible that future petrographic work may result in changing the classification, particularly of some of the compositionally zoned intrusions. The plutonic rocks are described in order from mafic/ultramafic to felsic, although we recognize that this is not necessarily the order in which they were intruded. Furthermore, the plutonic rocks are discussed according to their designation on the geologic map of Marathon County that accompanies this report. The classification used here includes quartz diorite, granodiorite, quartz monzonite, and granite.

Considering the large number of granitic plutons, and the variability within them, detailed petrography was not practicable for purposes of this report. Granites and quartz monzonites (plagioclase-poor and plagioclase-rich granites) are present as separate mappable plutons, with plagioclase-poor granites almost invariably forming the central parts of zoned plutons, or forming later intrusive phases into the plagioclase-rich (quartz monzonite) phases. To lump both these rock types together as granite is to obscure age relations established in the field. We prefer the classification used herein because it is more usable in the field.

Quartz diorites consist of 30 to 50 percent plagioclase (generally andesine to oligoclase), 10 to 30 percent quartz (as discrete grains or aggregates of finer grains), 10 to 30 percent hornblende, or biotite, or both, with or without minor microcline. Outcrops are generally gray in color. They are typically inhomogeneous and contain abundant xenoliths.

Quartz monzonites consist of 20 to 40 percent plagioclase (generally oligoclase), 20 to 40 percent microcline, 10 to 30 percent quartz and 5 to 20 percent hornblende, or biotite, or both. They typically are somewhat porphyritic. Both plagioclase and microcline are visible in hand specimens. They tend to contain hornblende, rather than biotite. Quartz monzonites are generally gray on fresh surfaces, but are buff to brick red on weathered surfaces. They tend to be more homogeneous than the quartz diorites.

Granites consist of 40 to 60 percent microcline, 10 to 20 percent plagioclase (albite to oligoclase), 10 to 35 percent quartz, and up to 10 percent biotite. Plagioclase may or may not be visible in hand specimens. They typically are pink to deep red on both fresh and weathered surfaces, although they may be gray in some plutons.

Intrusions ranging in composition from quartz monzonite to granite intrude the volcanic and dioritic rocks.

Typically, the margins are xenolith-rich, whereas the cores of individual bodies are relatively homogeneous. Some quartz monzonites appear to be gradational into quartz diorites, but dikes of quartz monzonite in the dioritic rocks suggest fracturing and intrusion of the peripheral dioritic rocks by later phases of the intrusion. The quartz monzonites generally have a pervasive cataclastic foliation which, in places, is truncated by non-foliated granites (fig. 22), suggesting that the granites are younger. However, granites are also cataclastically deformed in many areas.

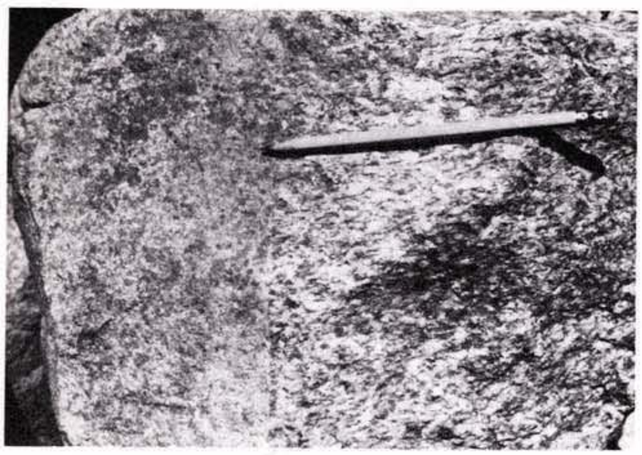

Figure 22.--Photograph showing typical intrusive relations in Marathon County. Foliated quartz monzonite on the right (with foliation parallel to the pencil) is cut by a massive granite on the left in sec. 16, T. 27 N., R. 8 E.

The granitic plutons range in size from about 5 to 130 km^2 with many showing concentric zoning from a granitic core to a quartz monzonite or quartz diorite border. Narrow but distinct contact metamorphic halos were observed around several intrusions where the felsic volcanic rocks were recrystallized to a massive saccharoidal rock and mafic volcanic rocks were recrystallized to hornblende hornfelses. Excellent examples of intrusion breccias are exposed on the margins of some intrusions.

The granitic rocks exhibit a wide variety of textures and mineralogy. Quartz monzonites are commonly porphyritic with plagioclase and microcline phenocrysts up to 1 cm long. Subhedral embayed quartz phenocrysts are present in some samples. In some, the matrix is dominantly granophyric; in others, the matrix is a fine-grained hypidiomorphic granular, or allotriomorphic granular mixture of quartz, feldspars and mafic minerals. Other plutons have a uniform hypidiomorphic granular or allotriomorphic granular texture. Mafic mineral content ranges from virtually zero to 25 percent. Biotite is most common, but hornblende is present in several quartz monzonite plutons. In some plutons the microcline is highly perthitic; in others, it appears to be almost pure microcline. The granitic rocks also differ in color--quartz monzonites are typically gray and weather to a buff color; granites are pink to deep brick red in color due to fine hematite inclusions in the feldspars. A cataclastic foliation may be superimposed on any of the original igneous textures. Individual plutons were mapped on the basis of their distinctive mineralogy and texture.

Ultramafic Rocks

Several small, poorly exposed ultramafic bodies (unit um) composed mainly of talc and serpentine occur along major cataclastic zones in Marathon County. The ultramafic bodies may be elongated parallel to the strike of the zones.

An ultramafic body 80 to 100 m wide and bound on the east and west by foliated granite is exposed southeast of Wausau near the NW¼ cor. sec. 10, T. 27 N., R. 8 E. It consists of talc, serpentine, and actinolite(?) and contains talc-serpentine pseudomorphs after orthopyroxene(?). The strike and extent of the body were not determined; however, foliation in the surrounding granite strikes about N. 35° E. This may be an altered pyroxenite. Talc-serpentine float in rockpiles derived from fields near the W¼ cor. sec. 9, T. 26 N., R. 7 E. along the same N. 35° E. cataclastic zone suggest another ultramafic body in that area.

An ultramafic rock is exposed over a width of about 30 m between pillowed metabasalts and strongly foliated and recrystallized quartz diorite south of Rozellville (NW¼NW¼SW¼ sec. 22, T. 26 N., R. 4 E.). A similar ultramafic body is exposed along the Little Eau Pleine River (NE¼SE¼ sec. 24, T. 26 N., R. 3 E.) between a mass of amphibolite and a foliated, recrystallized quartz diorite. These bodies consist of massive serpentine with varigated colors and abundant pseudomorphs after olivine as well as talc-rich zones in which the foliated talc is complexly folded. Talc-serpentine float in rock piles derived from the SE¼SW¼ sec. 14, T. 26 N., R. 4 E. suggest a similar ultramafic body in that area as well. The ultramafic bodies are all associated with strongly foliated rocks, and although they are in contact with amphibolite-facies rocks, the preservation of primary(?) olivine textures suggests that the ultramafic rocks themselves have not been highly metamorphosed. They probably were emplaced along the major fault zones during or after deformation.

Mafic Rocks

Several small gabbroic intrusions (unit mg) of diverse texture, and presumably several ages, are present in Marathon County. Most intrusions are metamorphosed and deformed.

A metagabbro pluton exposed along the Eau Claire River north of Callon (sec. 14, T. 28 N., R. 8 E.), is poorly exposed, underlies approximately 20 km^2 and is highly variable in texture and mineralogy. Parts of it are coarse ophitic gabbro with subhedral plagioclase crystals of 5 to 8 mm in size and enclosed in pyroxene that is variably altered to blue-green hornblende or biotite or both. The biotite-bearing rocks generally contain quartz. Other parts have a finer ophitic texture (2 to 3 mm); still other parts have compositional layering 0.5 to 1.0 cm thick. In places, the pyroxenes are partially altered to coarse-grained (2 cm), radiating hornblende crystals with strongly serrated crystals and abundant hornblende needles within the plagioclase. In other places the pyroxenes are partially altered along cleavages, or to fine randomly oriented hornblende (uralite). No pattern of these textural types was found during the mapping. The pluton cuts a prominent cataclastic zone along the Eau Claire River, and contains inclusions of metabasalt, metarhyolite (some of which is foliated), and foliated granitic rocks. The paucity of cataclastic features in the gabbro suggests that it is post-kinematic. Since the gabbro post-dates the deformation but has been metamorphosed, the implication is that metamorphism occurred after the deformation in this area.

Two small (1 to 2 km^2) isolated

masses of metagabbro are present northeast of this pluton in secs. 2, 10 and 11, T. 28 N., R. 9 E. and sec. 25, T. 29 N., R. 9 E. The intrusion in sec. 25, T. 29 N., R. 9 E. is unusual in that it contains poikilitic pyroxene crystals (largely pseudomorphed by hornblende) up to at least 10 cm long and 5 cm wide enclosing round, 1 cm plagioclase crystals. The other intrusion is a medium to coarse grained rock similar to the intrusion near Callon.

A number of small mafic bodies with a variable texture and composition (from hornblendite to quartz diorite) occur as inclusions in a leucocratic granite intrusion along the boundary between Tps. R. 27 and 28 N., in Rs. 8 and 9 E. They range in size from blocks several hundred meters to 4 km long and up to 1 km wide. Composition and texture vary within some of the blocks. Some consist of 60 to 70 percent brown hornblende crystals up to 2 cm long enclosing plagioclase and pyroxene in which the pyroxene does not appear altered to hornblende; others have a typical ophitic texture, but are composed of hornblende and plagioclase without pyroxene; others are typical salt-and-pepper diorite; still others are quartz-bearing diorites in which the hornblende has been largely converted to biotite. In general, the mafic blocks are altered and digested by the surrounding granite.

The diversity of these mafic rocks in eastern Marathon County have the appearance of a large layered mafic intrusion that has been extensively segmented by younger intrusions. Blocks of pyroxenite, anorthosite, gabbro and diorite now occur as isolated inclusions in several different granitic intrusions. The body near Callon may be one of the larger segments.

Gabbroic anorthosite (unit an) is present in abundant float boulders and scattered outcrops on the eastern edge of Marathon County in sec. 3, T. 29 N., R. 10 E. and in sec. 1, T. 28 N., R. 10 E. These represent the westernmost exposures of the Tigerton anorthosite, which is extensively exposed in Shawano County (Weis, 1965). The rock, which consists of labradiorite, hornblende, pyroxene and biotite, ranges from anorthosite to gabbroic anorthosite. Plagioclase crystals up to 25 cm long are present locally. The anorthosite occurs as blocks of various sizes included in the Wolf River batholith (described below, p. 34). Magnetite in the anorthosite produces a prominent aeromagnetic anomaly in Langlade, Shawano and the eastern edge of Marathon County (Zietz and others, 1978). Conceivably all of these occurrences are part of a single large mafic intrusion that has been segmented by later intrusions.

Several gabbroic masses are present in southwestern Marathon County. A relatively unmetamorphosed mass of coarse grained ophitic anorthositic gabbro produces a prominent oval aeromagnetic anomaly of 1,400 nannoteslas north of Marshfield (pl. 2).

A prominent circular aeromagnetic high of 1,200 nannoteslas in southeastern Marathon County (pl. 2) probably reflects a gabbroic intrusion; however, no exposures or boulders to confirm this were found since the area is underlain by Paleozoic rocks and a thick cover of glacial deposits.

Metadiabase Dikes

Dikes of metadiabase (not shown separately) up to 100 m wide are present in places along some of the major fault zones in Marathon County. The metadiabases consist mainly of hornblende and plagioclase with a variable amount of quartz. Some are foliated throughout; others have massive centers and foliated margins. A metadiabase dike occurs east of the Eau Claire River in secs. 13, 18 and 24, T. 29 N., R. 9 E. and strikes parallel with the foliation in the fault zone. Other metadiabases are exposed in the SE¼SE¼ sec. 2, and in the S½ of sec. 1, T. 29 N., R. 3 E. and in the NE¼NE¼SE¼ sec. 27, T. 30 N., R. 4 E. along the major fault zone that goes through Athens.

Quartz Diorites

Plutonic rocks ranging in composition from quartz diorite to granite are the most abundant rock type in Marathon County. They occur as compositionally zoned stock-like plutons and contain numerous pendants, screens and xenoliths of volcanic and older plutonic or metamorphic rock. Quartz diorite intrusions in Marathon County are typically small, heterogeneous and generally highly contaminated with xenoliths. Many of the quartz diorites appear to be the contaminated border phases of more granitic plutons. Intrusions of this type are present northeast and southwest of Mosinee (with excellent exposures in the Wisconsin River Valley at Mosinee) (unit di) in T. 26 N., Rs. 6 and 7 E., north and east of Marathon City (unit di), at Rib Falls (unit di), in smaller masses in secs. 12 and 13, T. 29 N., R. 8 E. and secs. 6 and 7, T. 29 N., R. 9 E. (unit qd), and an elongate mass along the Little Eau Pleine River (secs. 14, 15, 16, and 17, T. 26 N., R. 3 E.) (unit qd).

The quartz diorite is typically medium- to coarsely-crystalline with white plagioclase and partly chloritized greenish gray hornblende, which is probably pseudomorphic after pyroxene. Quartz, if present, is fine-grained and interstitial. Mafic inclusions of pyroxenite, metagabbro, greenstone, and granite(?) are elongated parallel to the northeasterly trend of the wall of the pluton. The rocks locally display a pronounced flow lineation, as at the roadcuts on U.S. 51 in the SE¼ sec. 21, T. 29 N., R. 7 E. Compositional variation between diorite, quartz diorite, and quartz monzonite was produced by differences in lithology of contaminants from the roof. Abundance of xenoliths in these plutons suggests that they were emplaced at the lower epizonal level.

The quartz diorite (unit qd) consists of 40 to 60 percent plagioclase with oscillatory zoning (fig. 23) which averages about An_{35}, 20 to 30 percent

Figure 23.--Photomicrograph of quartz diorite showing oscillatory zoning in plagioclase. Patches of granular quartz are present in the upper part of the photomicrograph.

quartz, 10 to 30 percent hornblende or biotite or both, and locally minor microcline. These plutons are actually intrusion breccias that range from small veinlets of intrusive material in the volcanic rocks to dominantly intrusive material with variously digested xenoliths of country rock (fig. 24).

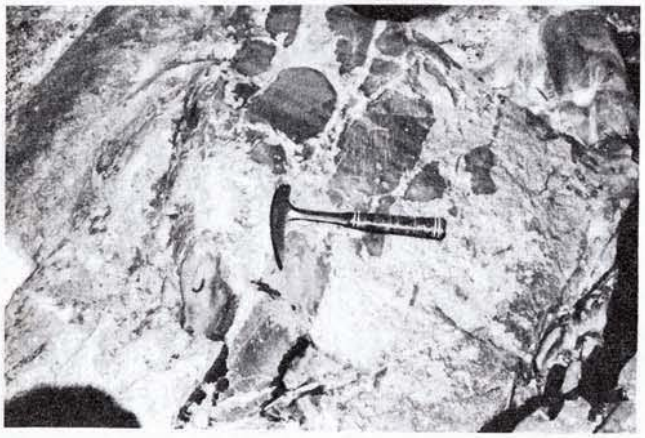

Figure 24.--Photograph of intrusion breccia north of Highway N along Randall Creek in western Marathon County. Blocks are mafic volcanic rocks included in a quartz monzonite.

Rims of quartz diorite a hundred meters or more wide may represent development along the steep walls of an intrusion, whereas broad areas of intrusion breccia may represent the roof zone of a pluton. Because they are commonly intruded by more granitic rocks, the quartz diorites appear to be the first of a succession of intrusions into the volcanic rocks. The dioritic rocks are far more common along contacts with intermediate and mafic volcanic rocks than they are along contacts with felsic rocks. The dioritic composition may be due in part to the composition of the parent magma, but it may also be due to contamination by digestion of intermediate to mafic volcanic rocks into which the magma intruded. Thus the original magma may have been more felsic than diorite.

A large mass of highly contaminated quartz diorite (unit di) and subordinate diorite intrusion breccia is exposed in the area north and east of Marathon. Similar rocks crop out northeast of Big Eau Pleine Reservoir in sec. 1, T. 26 N., R. 6 E. Most exposures of this quartz diorite contain various recrystallized and assimilated, lensoidal greenstone xenoliths with vertical-north-easterly elongation. The symmetrical occurrence of diorite-quartz diorite and associated granitic plutonics on northwest and southeast sides of the granite of Ninemile pluton (T. 27 N., R. 6 E.) suggest that these units were shouldered aside during emplacement of the syenites and related granite plutons. This quartz diorite is probably related to, but older than, quartz monzonite south of the syenite body near Stettin, because the quartz monzonite contains nearly assimilated diorite(?) xenoliths. However, the quartz monzonite-diorite contact to the west is gradational. This relationship is best seen in a road cut on Highway 29 in the southern part of sec. 33, T. 29 N., R. 6 E. The diorites are locally sheared and converted to phyllonites in the area east and south of Marathon in sec. 8, T. 28 N., R. 6 E.

A quartz diorite-quartz monzonite complex near Moon comprises highly contaminated plutonic rocks of widely variant mineralogy and structure. This unit was extremely difficult to map because of lithologic heterogeneity and poor exposure. Contacts between some of the units are shear zones trending east-northeasterly. An intrusion breccia of quartz is exposed near the paper plant in Mosinee (Myers, 1973, p. 79-

89). A similar breccia crops out about 2 km northeast of Mosinee and probably continues southwest beneath alluvium to the area east of Moon. Hornblende diorite (unit di) crops out along Silver Creek (sec. 19, T. 30 N., R. 7 E.). Although the size and shape of this body are conjectural because of poor exposure along its west edge, its faulted southeastern contact against quartz monzonite is nearly exposed in outcrop. As this rock is not sheared, it may be younger than the granite, aplite and quartz monzonite.

Quartz Monzonite near Kalinke

The quartz monzonite near Kalinke (unit kqm) underlies about 110 km^2 in Tps. 29 and 30 N., Rs. 9 and 10 E., in northeastern Marathon County with good exposures near the locality of Kalinke (sec. 34, T. 30 N., R. 9 E.). The pluton is variable in texture and composition, but is mainly a medium-grained porphyritic quartz monzonite. Sericitized subhedral microcline phenocrysts range from 0.5 to 1.5 cm. Subhedral oligoclase (An_{28}) phenocrysts are typically about half as large as the microcline. Much of the pluton has a fine granophyric matrix (fig. 25), but parts of it have a hypidiomorphic granular matrix. Visual estimates of ten thin sections indicate a composition of 30 to 40 percent plagioclase, 30 to 40 percent microcline, 20 to 30 percent quartz and 5 to 10 percent biotite. Both green and brown biotite occur in patches of mosaic crystals in the granophyric variety, and in larger crystals in the hypidiomorphic granular variety. Most of the quartz is strained, but in several samples subhedral 8 mm quartz phenocrysts are present containing embayments similar to those in volcanic rocks.

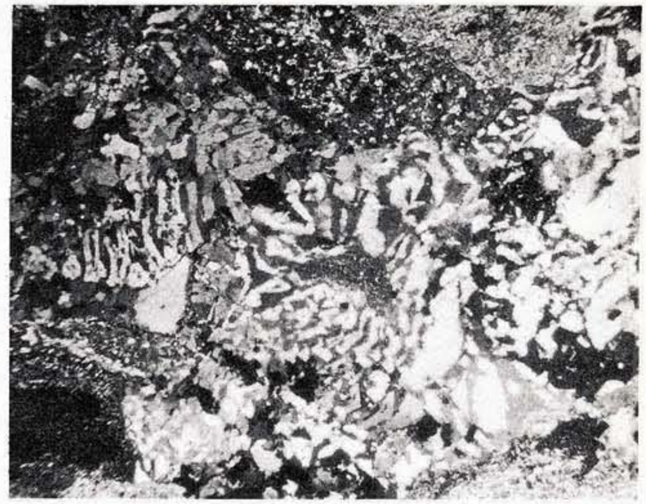

Figure 25.--Photomicrograph of quartz monzonite near Kalinke showing extensive development of granophyric texture.

The pluton is isotropic along its western margin with a distinct chilled zone and contact metamorphic halo in the surrounding felsic and intermediate rocks. Xenoliths of felsic and intermediate volcanic rocks are present in the pluton. The eastern margin of the pluton is a cataclastic zone more than a kilometer wide. In the cataclastic zone the plagioclase phenocrysts are altered to a greenish color and are bent and broken into lensoidal porphyroclasts in a fine-grained matrix that has been variably recrystallized to a granoblastic texture. The mafic minerals (biotite and epidote) are recrystallized into lens-shaped mosaics along the foliation, imparting a streaky character to the rock.

Quartz Monzonite Southeast of Wausau

A similar porphyritic quartz monzonite (unit qm) with a granophyric matrix is exposed in the roadcut along Highway 51 at Mosinee (SW¼SE¼ sec. 26, T. 27 N., R. 7 E.).

The plutons are composed of 30 to 50 percent microcline, 30 to 50 percent plagioclase, 10 to 30 percent quartz and 10 to 20 percent biotite, or hornblende, or both. In most samples the microcline is non-perthitic, and in some the K-feldspar is untwinned. Plagioclase may also be prominently twinned to untwinned. Quartz diorite is present along the western margin of the quartz monzonite pluton near Mosinee. Numerous small dikes and veins of quartz monzonite intrude the quartz diorite and xenoliths of quartz diorite are common near the margin of the quartz monzonite, showing clearly that the quartz monzonite is younger.

At least three northeast-trending cataclastic zones up to 1 km wide cut the plutons east of Mosinee. Within the zones the quartz monzonite has a distinct foliation produced by elongation of the quartz and recrystallization of the biotite in streaks along the foliation. The larger crystals (porphyroclasts?) are either rounded or lenticular, and numerous examples of broken crystals are present. Texturally, the rock consists of alternating coarse- and fine-grained layers about 1 cm wide. Both layers have an allotriomorphic texture, presumably due to recrystallization of the finer zones. The zones are interpreted as recrystallized cataclastic zones since they cut a rock with an isotropic fabric. Had they been produced by regional metamorphism, the entire body would be foliated, not just the zones.

Quartz Monzonite East of Unity

A coarse grained biotite-rich pink to red granitic pluton (unit cgr) underlies at least 99 km^2 in Tps. 27 and 28 N., R. 2 E., east of Unity on the western edge of Marathon County with good exposures in and just south of Cherokee County Park (sec. 14, T. 28 N., R. 2 E.). The pluton ranges in composition from granite to quartz monzonite, and consists of 35 to 60 percent microcline, 25 to 40 percent plagioclase (An_{28}), 20 to 30 percent quartz, 5 to 10 percent hornblende or biotite or both. Grain size ranges up to 2 cm for the microcline and plagioclase phenocrysts; the matrix is 1 to 2 mm in size. The texture varies from hypidiomorphic granular to allotriomorphic granular. A faint but pervasive cataclastic foliation with a strike of N. 50° E. to north-south and a dip from 75° NW to vertical indicating post-emplacement deformation. This pluton has yielded a U/Pb age from zircons of 1,840 Ma (see p. 14). An excellent example of an intrusion breccia between this granite and intermediate volcanic rocks to the north is exposed north of Highway N along Randall Creek (sec. 18, T. 28 N., R. 3 E.). A number of grus quarries are developed in the southeastern part of the pluton (secs. 1, 2 and 3, T. 27 N., R. 2 E.; secs. 35 and 36, T. 28 N., R. 2 E.) (see also p. 75 of manuscript).

Quartz Monzonite Aplites

Several unusual granitic plutons (unit grap) are present in Marathon County. One is a fine-grained quartz monzonite aplite exposed in several places west of the Wisconsin River; the other is a coarse-grained leucocratic granite exposed east of Rothschild. Whereas most aplites are dikes, these are sizable plutons and are therefore unusual. Fine-grained, sparsely porphyritic quartz monzonite aplite underlies about 42 km^2 in T. 28 N., Rs. 5 and 6 E. (southwest of Marathon City).

A poorly exposed smaller mass, north of the town of Moon (sec. 34, T. 27 N., R. 6 E.), appears to interfinger with contaminated quartz diorite to the south. A nearly identical aplite forms a 1.5 km border phase along the southwest side of the Granite Heights (T. 30 N., Rs. 6 and 7 E.). The aplite is a fine-grained (1-2 mm), hypidiomorphic granular, pale orange-pink rock with 40 to 50 percent plagioclase (An_{10}), 20 to 25 percent microcline and 20 to 30 percent quartz. Accessory mafic minerals include biotite and hornblende.

Leucogranite East of Rothschild

A leucocratic potassic granite pluton (unit lg) underlies at least 57 km^2 in Tps. 27 and 28 N., Rs. 7, 8 and 9 E. east of Rothschild. It consists of 60 to 70 percent non-perthitic microcline and 30 to 35 percent quartz with accessory biotite present only locally. It is highly variable with medium- to fine-grained (aplitic) granite with numerous small areas of pegmatite and graphic granite (fig. 26). It contains up to 8.10 percent K_2O. The leucocratic granite is a late stage pluton because it truncates cataclastic foliation in surrounding rocks (fig. 22), has intruded and metamorphosed mylonitic rocks in sec. 33, T. 28 N., R. 8 E., and contains numerous large xenoliths of mafic rocks. The pluton is mainly undeformed, although cataclastic zones are present locally in the rock.

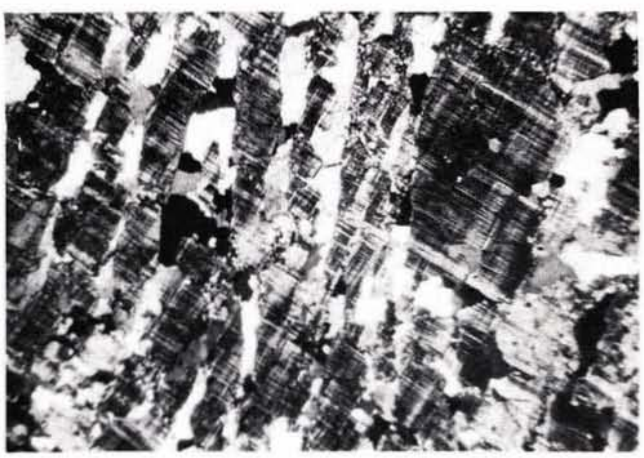

Figure 26.--Photomicrograph of coarse graphic intergrowth of quartz and microcline typical of the leucocratic body southeast of Wausau.

Red Granite of Granite Heights

The principal quarry stone near Wausau is the red granite of Granite Heights (unit ghg) with good exposures in abandoned quarries at Granite Heights (NE¼ sec. 26, T. 30 N., R. 7 E.). It is a homogeneous, leucocratic, dark red granite with a grain size of 0.5 to 1.0 cm and few mafic minerals. Visual estimates of six thin sections from various quarries in the pluton show that it is composed of about 45 to 60 percent perthitic microcline, 25 to 35 percent quartz in discrete grains, 15 to 20 percent plagioclase (An_{5-10}), and less than 5 percent green biotite. The texture is allotriomorphic granular with subhedral to anhedral grains and prominent sutured grains. The granite is quarried at several locations in the county and marketed as Wisconsin Ruby Red Granite. Those parts of the intrusion with a cataclastic foliation are not amenable to quarrying.

The granite pluton consists of two lobes connected by a narrow neck. One lobe is east of the Wisconsin River; the other lobe is west. The eastern lobe intrudes felsic metavolcanic rocks along its southern boundary and has a red color, a chilled zone and a contact metamorphic halo in the volcanic rocks. It is intrusive into intermediate to mafic metavolcanic rocks along its northern edge, where the pluton is gray and heterogeneous with numerous mafic inclusions, as shown along the west edge of the NW¼ sec. 27, T. 30 N., R. 8 E. The western lobe intrudes felsic metavolcanics on the south and intermediate to mafic metavolcanics on the north. A partial rim of quartz monzonite 1 to 2 km wide forms a border zone along the southwestern edge of the pluton. The quartz-monzonite phase is exposed in roadcuts along Highway 51 near the center of sec. 34, T. 29 N., R. 6 E.

Within the quarries the granite is massive, however, considerable parts of the pluton have a prominent cataclastic foliation. Several poorly exposed cataclastic zones containing mylonite cross the pluton. The eastern boundary of the eastern lobe contains abundant cataclastic rock, including mylonite.

Red Granite West of Edgar

A red granite (unit wgr) virtually indistinguishable from the red granite of Granite Heights underlies at least 46 km^2 west of Edgar and underlies much of the political township of Wein. Some of the best natural exposures of the body are near Wein (NE cor. sec. 21, T. 28 N., R. 4 E.).

Red Granite East of Stratford

Smaller areas of similar dark red granite (unit rgr) are exposed east of Stratford where Highway M crosses the Eau Pleine River (sec. 26, T. 27 N., R. 4 E.) and near Poniatowski (sec. 15, T. 29 N., R. 4 E.).

Granite South of Little Rose

A pink, mafic-poor, medium-grained granite (unit lrg) underlies much of the high ground between the Eau Pleine and Little Eau Pleine Rivers in Tps. 26 and 27 N., R. 3 E., southwest of Stratford. The pluton underlies at least 109 km^2, with the best exposures in the NE¼ sec. 8, T. 26 N., R. 3 E. about 5 km south of Little Rose. Petrographically it consists of 50 to 60 percent microcline, 20 to 30 percent quartz, 10 to 15 percent plagioclase (An_{10}) and minor biotite (fig. 27). This pluton truncates a broad zone of cataclastic rocks, including mylonites and phyllonites along its eastern margin. The general paucity of cataclasis within the pluton suggests that it was intruded late in the tectonic history of the area.

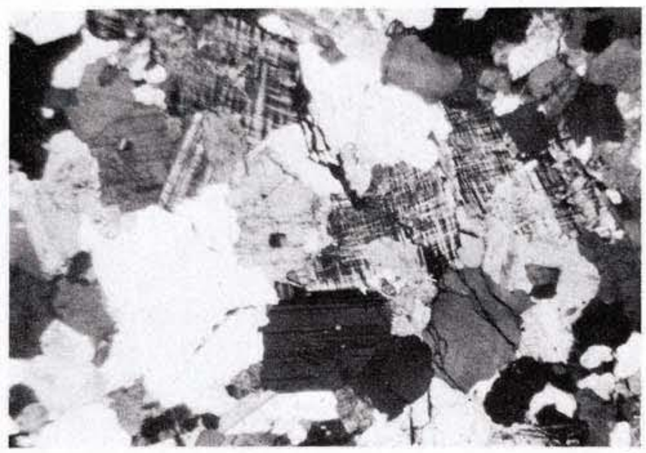

Figure 27.--Photomicrograph of granite with an allotriomorphic granular texture of interlocking grains from near Little Rose.

Granite East of Abbotsford

A similar mafic-poor pink granite (unit gr) is present east of Abbotsford in T. 28 N., R. 3 E. Poor exposure in the area prevents determining the size of the pluton. This granite occurs along the major boundary fault between the gneissic rocks and the lower grade rocks within Marathon County, and shows extensive cataclastic deformation. It is not known whether this pluton intrudes the volcanic rocks in the area.

Granite East of Lake Dubay

A gneissic granite (unit ggr) underlies approximately 20 km^2 immediately east of Lake Dubay in southern Marathon County (T. 26 N., Rs. 7 and 8 E.). The pluton is a medium-grained pink leucocratic granite with a prominent cataclastic foliation. It is intrusive into volcanic rocks and quartz diorite intrusion breccia along its northern contact and is bounded on the south by amphibolites and gneisses.

Granite Near Eau Pleine Reservoir

A pink to red, medium- to fine-grained granite pluton (unit epg) that is elongated northwesterly underlies most of the high ground between the Eau Pleine and Little Eau Pleine Rivers in T. 26 N., Rs. 5 and 6 E. with exposures along the Eau Pleine Reservoir (NE¼ sec. 27, T. 26 N., R. 7 E.). The granite has a markedly inequigranular allotriomorphic granular texture (fig. 28) and consists of 40 to 50 percent non-perthitic microcline, some of which is granophyric, 20 to 25 percent plagioclase (An_5), 20 to 30 percent quartz and 5 to 10 percent biotite containing numerous pleochroic halos from small zircons. A coarse-grained (5 to 8 mm) and a fine-grained (2 to 4 mm) phase were distinguished in the mapping. A prominent northwest trending cataclastic foliation is developed on both the north and south edges of the pluton; the central part is not foliated. The Eau Pleine and Little Eau Pleine River valleys occupy much of the foliated zones.

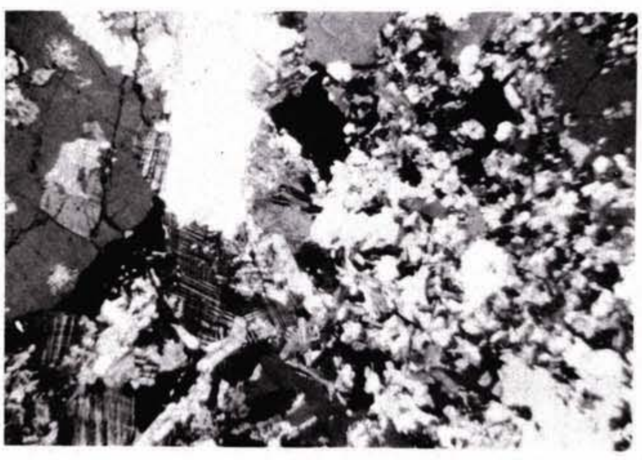

Figure 28.--Photomicrograph of granite with markedly inequigranular texture from Eau Pleine Reservoir.

Chemistry of the Granitic Rocks

Samples from several granitic intrusions were chemically analysed to provide a check on the field identification of the rocks (app. 1). The analyses are also used to help interpret the origin of the rocks. In a vast majority of cases, the analyses have confirmed the field identification of the rocks; however, in a few cases the analyses show that the field classification should be modified. The AFM plot (fig. 29) shows a scatter of compositions compared with the average compositions of granites as given by Hyndman (1972). The samples from Marathon County show considerable variation in composition. This variation may be the result of several different factors: (1) the rocks may represent several different igneous intrusions, each with a slightly different chemical composition; (2) contamination of the intrusions by incorporation and digestion of chemically different rocks; or (3) different degrees of alteration.

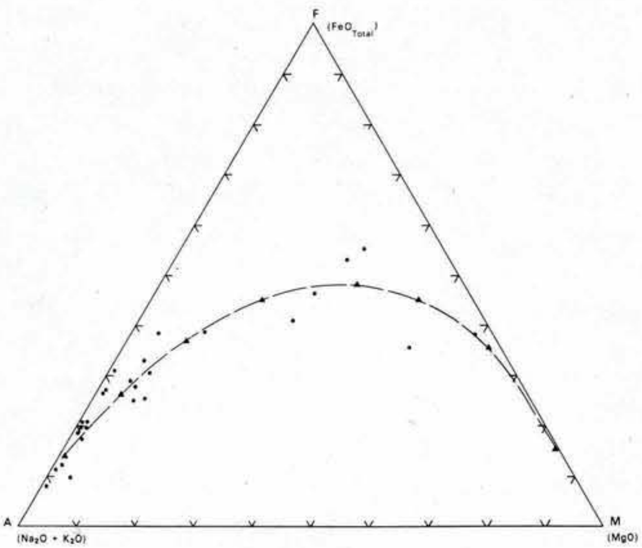

Figure 29.--AFM plot of Lower Proterozoic granitic rocks from Marathon County.

MIDDLE PROTERZOIC

The Middle Proterozoic in Marathon County is represented by widely distributed igneous rocks, including quartz monzonites, granites, syenites, and several types of diabase dikes. The quartz monzonites and granites are part of a large batholith whereas the syenites are small, circular bodies.

Wolf River Batholith

The Wolf River batholith is a major Middle Proterozoic batholith underlying at least 3,500 km^2 in northeastern Wisconsin (Van Schmus and others, 1975a), and underlies at least 860 km^2 in eastern Marathon County. The western margin of the batholith, including several intrusive phases and the contact relations with older rocks, was mapped during this survey. The batholith intrudes the greenschist-facies volcanic-plutonic rocks along most of its western boundary, but intrudes amphibolite-facies rocks in the southern edge of the county and in Portage County to the south. U/Pb ages from zircons in the batholith indicate that the batholith is 1,500 Ma old (Van Schmus and others, 1975a).

The major rock type of the Wolf River batholith exposed in Marathon County is a coarse-grained porphyritic quartz monzonite (unit wrg) which extends from the northeastern corner of the county southward approximately two-thirds of the way across the county. It consists of euhedral and subhedral perthitic feldspar phenocrysts, 3 to 4 cm long, set in a quartz-microcline-plagioclase-hornblende matrix with an average grain size of 5 mm. Hornblende or biotite or both constitute up to 25 percent by volume of the rock. Medaris and others (1973) refer to this intrusion as the Wolf River granite. The Wolf River granite is remarkably uniform in appearance, is mainly free of inclusions, and is coarse grained to within a few tens of meters of the margin of the intrusion.

A few outcrops of anorthosite (unit an) are present along the eastern edge of the county (sec. 36, T. 29 N., R. 10 E. and sec. 1, T. 28 N., R. 10 E.). They consist of gray anorthosite and gabbroic anorthosite consisting of labradorite (An_{50-55}) crystals from 1 to 5 cm long with hornblende, pyroxene and biotite. The anorthosite occurs as large, extensively intruded xenoliths in the Wolf River granite (Weis, 1965).

South of a line from Galloway to sec. 32, T. 27 N., R. 9 E. the exposed rock (unit rrp) is significantly finer grained than the Wolf River granite. The rock is a porphyritic quartz monzonite with euhedral microcline crystals about 1 cm long, some of which are mantled by oligoclase and set in a 2 mm quartz - microcline - plagioclase -

hornblende/biotite matrix. This phase of the Wolf River batholith extends southwest as far as Stevens Point, and is called the Red River porphyritic quartz monzonite by Medaris and others (1973). Whereas the Wolf River granite intruded the greenschist facies volcanic-plutonic rock, the Red River porphyritic quartz monzonite intruded mainly amphibolite facies rocks in southern Marathon County and adjacent Portage County.

The western margin of the Wolf River batholith is controlled in large part by a major fault zone along the Eau Claire River. At Eau Claire Dells and to the northeast near Hogarty, rocks of the Wolf River batholith have metamorphosed the deformed volcanic and plutonic rocks (discussed later) to hornblende and pyroxene hornfelses. The contact effect of the batholith can be seen in and immediately east of Eau Claire Dells County Park (sec. 7, T. 29 N., R. 10 E.) and along Sportsman Road immediately south of the Park. At this locality the intrusion post-dates the deformation of unit kqm. However, along the Little Eau Claire River south of Highway 29 (secs. 7, 18, 19 and 30, T. 27 N., R. 9 E.) a zone of cataclastic foliation more than 1.5 km wide cuts rocks of the Wolf River batholith (fig. 30). The strike and dip of the foliation is consistent with that in older rocks and suggests recurrence of the cataclastic deformation after emplacement of the Wolf River batholith.

The Wolf River batholith is interpreted to be an anorogenic intrusion (Medaris and others, 1973), and chemically related to alkalic plutons (Anderson, 1975; Anderson and Cullers, 1978). Thus it is significantly different than the Lower Proterozoic calc-alkaline intrusions discussed above. Additional information on the Wolf River batholith is available in the publications cited, and will not be presented here.

Syenite Plutons

Two concentrically zoned syenitic plutons west of Wausau (pl. 1) intruded Lower Proterozoic metavolcanic and plutonic rocks about 1,520 Ma (Van Schmus, 1980). The more alkalic Stettin syenite pluton to the northwest and the two crescentic segments of the larger Wausau pluton consist of three zones: (1) an alkali-rich wall zone, (2) a contaminated intermediate zone and (3) a core zone. The Wausau pluton is cored by granite and quartz monzonite of the Ninemile pluton (fig. 31).

Weidman (1907) mapped the geology of north-central Wisconsin and paid special attention to the mineralogy of the syenites near Wausau; Dickey (1936) evaluated the nepheline potential; Emmons and Snyder (1944) hypothesized formation of the Stettin syenite body by metasomatism of feldspathic rocks along shear zones with alkali-rich solutions derived from a subjacent granite batholith; Turner (1948) studied the heavy accessory minerals and radioactivity of the Stettin pluton; Geisse (1951) described the petrography of this pluton; and petrographic and geochemical investigation of the mafic minerals and nepheline of the Stettin pluton were studied by Koellner (1974), Myers (1976), and Sood and others (1980). The plutons were mapped in detail by Myers for this report.

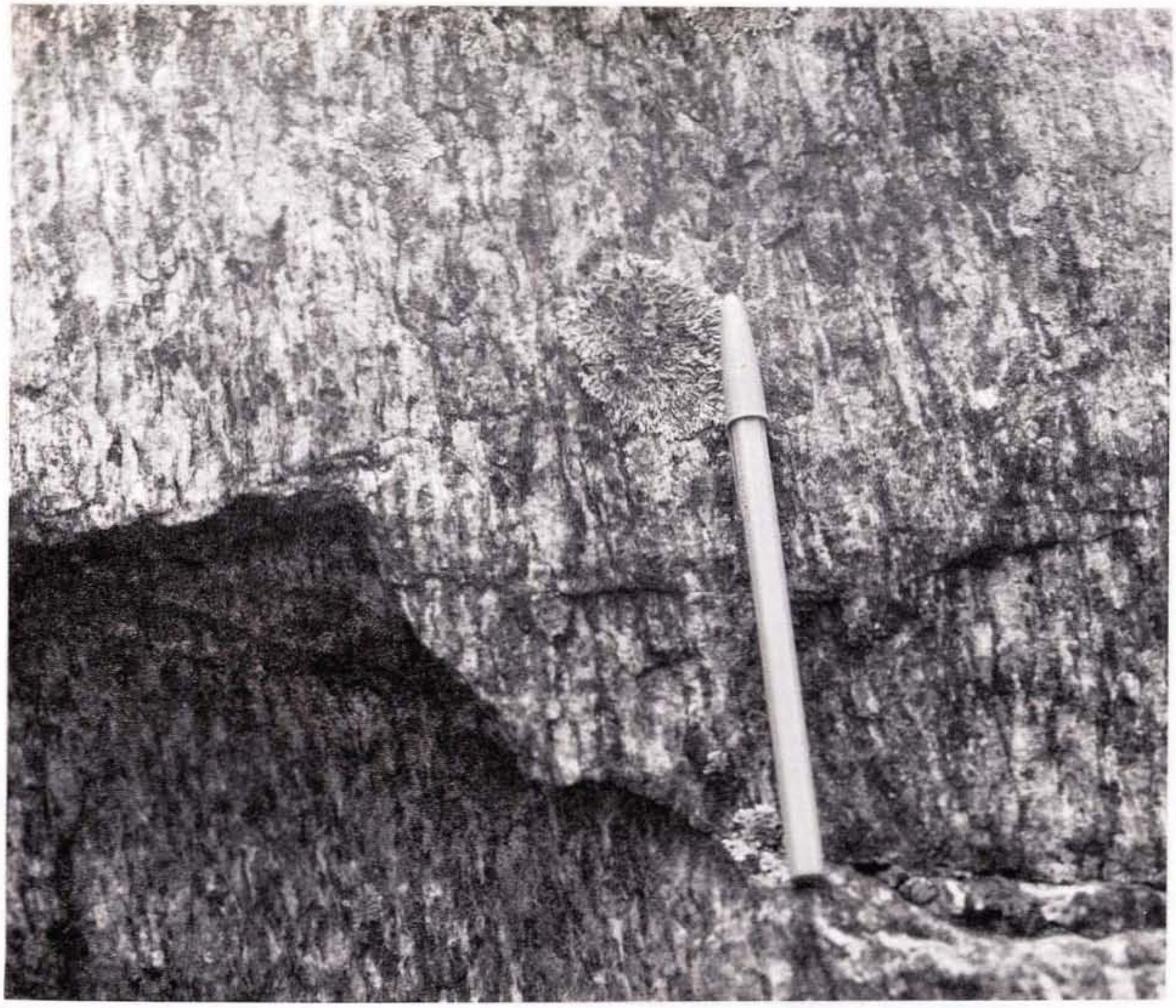

Figure 30.--Photograph of flaser gneiss developed in the Wolf River granite south of Ringle.

Stettin Pluton

The concentrically zoned Stettin pluton is oval in plan, elongated northeasterly, with a length of 8.8 km and a width of 6.4 km. Older volcanic rocks enclosing the pluton have been extensively syenitized. The eastern and southern margin of the pluton is a complexly laminated series of altered volcanic screens and pendants and various, contaminated intrusive phases of the syenite including nepheline syenite. The wall zone comprises a discontinuous outer rim of gneissic nepheline syenite, and an inner layer of tabular syenite. The intermediate zone is composed of amphibole and pyroxene syenite showing considerable variation in composition and texture. The amphibole syenite is commonly quartz-bearing. The core zone is 2 km in diameter and is located asymmetrically near the north end of the pluton. The core zone comprises a well-defined, cylindrical rim of indistinctly banded nepheline syenite surrounding a core of pyroxene syenite. Field relations indicate the following intrusion sequence: (1) py-

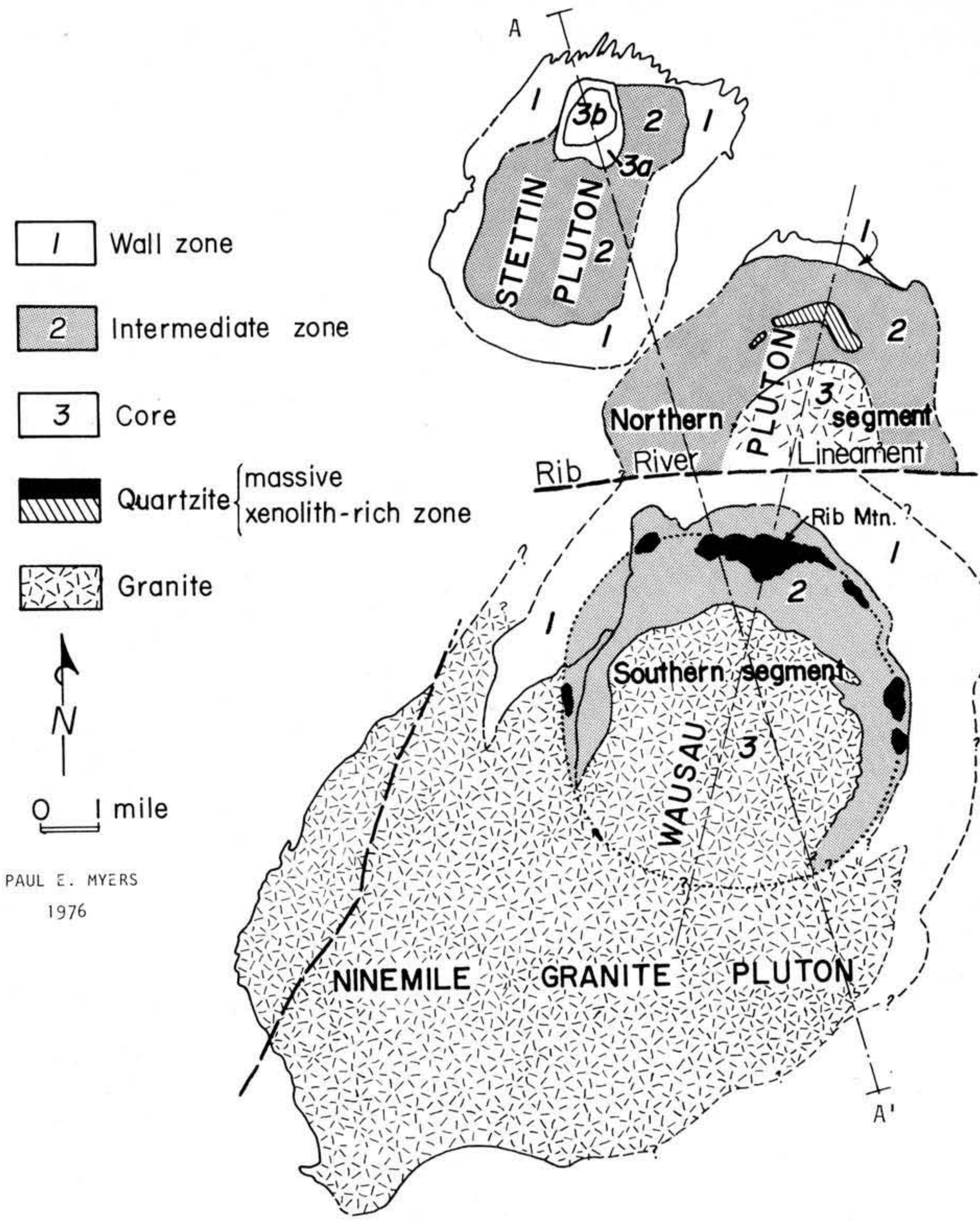

Figure 31.--Generalized geologic map of the Stettin and Wausau syenite bodies and the Ninemile granite pluton which intrudes the Wausau pluton. Section A-A' is shown in figure 47.

roxene syenite, (2) nepheline syenite, (3) tabular syenite, and (4) amphibole syenite. Numbers 3 and 4 could be reversed. This evidence is based wholly on field relations. It should also be emphasized that the intrusion sequence may not be the same as the crystallization sequence.

A summary tabulation of paragenetic relations of minerals in each zone of the Stettin syenite pluton is presented with modification from Koellner (1974) in figure 32.

Wall zone: The outermost rim of the Stettin pluton is gneissic nepheline syenite composed mainly of alkali feldspar, perthite, nepheline, aegirine, sodic amphibole and biotite. It is in sharp contact with, and veined by, tabular syenite composed of coarse, well-oriented laths of perthite, sodic amphibole, pyroxene and lensoidal mafic inclusions composed essentially of the same minerals but in different proportions and of finer grain size. The mafic inclusions are well-oriented parallel to the tabular fabric of the enclosing syenite and to the wall of the pluton. They contain large perthite porphyroblasts of similar composition and size as those in the enclosing syenite. The tabular syenite (unit tsy) forms the outermost layer on the north and west sides of the Stettin pluton where the nepheline syenite (nsy) is absent. The abundance of mafic inclusions increases outward in the tabular syenite, suggesting considerable contamination by the basaltic wallrock. A unit mapped as lensoidal syenite (lsy) and a closely associated syenite aplite (syap) are found locally where the nepheline syenite is absent. The lensoidal syenite is an aplitic, gneissose rock consisting of mafic inclusions rich in biotite enclosed in an aplitic syenite. The syenite aplite is similar in texture and mineral composition but relatively free of mafic inclusions.

The wall zone is rimmed by a discontinuous layer of syenitized metavolcanic rocks (unit syv) and syenite aplite (syap). Clots and veinlets of biotite syenite aplite spread out irregularly into the metavolcanic envelope of the pluton. On the northeast side of the pluton, these veinlets take on the appearance of dike swarms. Rocks mapped as syenite aplite are intergradational with syenitized metavolcanic rocks, and were probably formed by thorough metasomatic replacement of them by the addition of K_2O + Al_2O_3 and a loss of CaO + MgO. The first wave of replacement formed tiny anastomosing veinlets and irregular masses of interstitial, very fine-grained K-feldspar and subordinate biotite. The biotite formed at least in part at the expense of chlorite. Subsequent waves of replacement produced a syenite aplite composed almost totally of K-feldspar and biotite. Coarse K-feldspar porphyroblasts are common in these rocks, and are concentrated along vein-like structures. Primary textures in the metavolcanic rocks are obliterated at an early stage of syenitization. Iron oxides, mainly as hematite, probably represent residual iron which could not be accommodated in the metasomatic biotite.

The tabular syenite (tsy) (figs. 32 and 33, table 3) is composed dominantly of coarse laths of microperthite. Vein and patch type perthites predominate. Poikilitic amphibole (hastingsite) rims pyroxene (intermediate between acmite and hedenbergite according to Koellner,

ZONE	ROCK TYPE	PARAGENETIC RELATIONS
WALL ZONE	Tabular Syenite (Myers, 1973)	——zircon—┤ ├——— pyroxene—┤ ├—alkali feldspar—┤ ├— opaques—┤ ├——— green amphibole—┤ ├—biotite—┤
WALL ZONE / CORE ZONE	Nepheline Syenite (Koellner, 1974, p. 12)	——nepheline——┤ ├—alkali feldspar—┤ ├—olivine—┤ ├—pyroxene—┤ ├—opaques—┤ ├—green amphibole—┤ ├—biotite—┤
CORE ZONE / INTERMEDIATE ZONE	Pyroxene Syenite	├—alkali feldspar—┤ ├apatite┤ ├—opaques—┤ ├—olivine— ├—pyroxene—┤ ├—green amphibole—┤ ├—biotite—┤ ├carbonate┤ ├blue amphibole-
INTERMEDIATE ZONE	Amphibole Syenite (Koellner, 1974, p.33)	├—alkali feldspar—┤ ├apatite┤ ├—opaques—┤ ├—pyroxene—┤ ├—green amphibole—┤ ├—biotite—┤ ├blue amphibole-

Figure 32.--Diagram showing paragenetic sequence for various units in the Stettin pluton (modified from Sood and others, 1980).

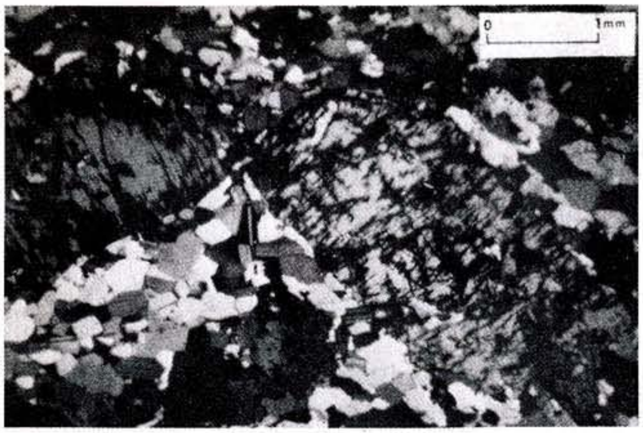

Figure 33.--Photomicrograph of tabular syenite (unit tsy) showing parallel alignment of feldspar crystals.

1974, p. 65). The tabular fabric (fig. 34) is characterized by a random orientation of perthitic feldspar tablets in a plane parallel to the outer wall of the pluton and the long dimensions of the mafic inclusions. Perthitic feldspar tablets within mafic inclusions and across their contacts are identical to those in the tabular syenite. This textural relationship strongly suggests a metasomatic origin for the perthitic feldspar. Veins of tabular syenite locally cut gneissic nepheline syenite in the zircon minesite in the SE¼ sec. 22, T. 29 N., R. 6 E. The tabular syenite contains between 5 and 80 percent mafic inclusions, which have been strongly biotitized. With increasing mafic content, the mafic minerals, mainly sodic amphibole, become poikilitic. Although mafic inclusions in the tabular syenite contain a much higher percentage of pyroxene and olivine, they are of about the same chemical composition. The abundance of mafic inclusions increases conspicuously outward in the tabular syenite, which forms the outermost layer of the Stettin pluton on the north and west sides where nepheline syenite is absent.

Gneissic nepheline syenite (nsy) of the wall zone (figs. 32 and 35 and table 3) is a gray, banded rock composed mainly of perthitic feldspar, nepheline, olivine, pyroxene, magnetite, amphiboles, and biotite. The nepheline occurs as blocky, pinkish grains, which weather much more rapidly than the associated minerals, giving the rock its characteristic pitted surface. The nepheline is partially altered to cancrinite and iron oxides. Banding and mafic content of the nepheline syenite increase outward toward its contact with syenitized volcanic rocks, a relationship best exposed on private land on the northwest corner of the intersection of Highway O and Stettin Road (SE¼SE¼ sec. 22, T. 29 N., R. 6 E.). In addition to the essential minerals listed above, the nepheline syenite commonly contains significant amounts of brown zircon and sphene of unusually large size (to 14 mm) apatite, fluorite, allanite, sodalite, pyrochlore, and thorogummite(?). Re-

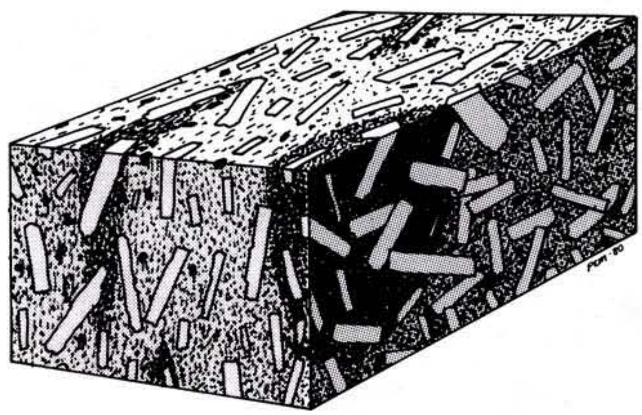

Figure 34.--Diagram showing typical fabric of tabular syenite (unit tsy) with coarse tablets of microperthite in random orientation parallel to the wall of the pluton. Microperthite laths in the lensoidal mafic inclusions tend to have a preferred orientation parallel to those in the enclosing syenite.

TABLE 3.--Modal mineralogy in volume percent of selected rocks of the Stettin pluton

	Zone of the pluton								
	Intermediate zone Amphibole syenite				Core zone Pyroxene syenite	Wall zone Tabular syenite	Wall zone Nepheline syenite		
Sample No.:	10	77	503	108	6 and 504	65	46	2	92
Mineral									
Quartz	7.1	6.6	2.9	1.4	--	--	--	--	--
Nepheline	--	--	--	--	--	--	26.4	17.6	6.6
Perthite	80.7	83.5	90.3	83.0	87.4	80.2	63.6	75.7	61.4
Albite	0.5	--	0.2	--	--	--	--	--	--
Amphibole	11.2	8.6	5.1	13.6	5.5	19.1	8.4	4.6	29.5
Pyroxene	--	--	--	0.6	4.1	--	--	--	--
Biotite	0.2	--	--	--	0.5	0.2	0.6	0.4	0.4
Altered biotite	--	0.6	0.3	0.5	--	--	--	--	--
Zircon	--	0.2	0.2	0.1	0.7	--	--	--	--
Apatite	--	--	--	--	0.1	--	--	--	--
Fluorite	0.2	--	0.5	--	--	--	--	--	--
Calcite	--	--	--	0.3	0.1	--	--	--	--
Sphene	--	--	--	--	--	--	--	--	1.1
Opaque Minerals	0.1	0.1	0.3	0.2	1.3	0.1	1.0	--	0.5
Alteration	--	0.4	0.2	0.3	0.3	0.4	--	--	0.5

Table modified from Sood and others (1980, p. 28); leaders (-), not observed.

cent analyses of these zircons by Van Schmus (oral communication) yielded a Pb/U age of 1,520 ± 10 Ma; it appears that the Stettin pluton is about 20 m.y. older than the Wolf River batholith. Zircon from the section 22 locality is deep red-brown, doubly terminated euhedral prisms up to 14 mm in length. Some crystals display geniculate twinning similar to rutile. Chemical analyses of three zircons from a nearby site (NW¼ sec. 22) by F.B. Hall (Weidman, 1907, p. 313) show an Al_2O_3 content of between 4.28 and 7.80 percent and an Fe_2O_3 content between 1.21 and 4.47 percent. Ca, Ti, Th, and REE were also detected. Brown pyrochlore octahedra up to 2 mm in diameter were found at the section 22 location by Weidman (1907, p. 308-309). Allanite is confined mainly to the pegmatitic phases of the nepheline syenite. Apatite and unusually large sphene crystals show affinity for clusters of mafic minerals in the nepheline syenite. Large sphene crystals up to 7 mm in length can be collected from nepheline syenite lenses and masses near its contact with tabular syenite. The conspicuous, characteristic gneissosity and isoclinal folded nepheline syenite along the south side of the Stettin pluton suggest considerable deformation of the rocks during emplacement. It is likely that the nepheline syenite, like the syenitized metavolcanic rocks next to them, represent extensive metasomatic replacement of wallrocks. The abundance of zircon and hastingsite amphibole, biotite, and carbonate indicates a miaskitic trend for the nepheline and pyroxene syenites. Compositions of the nepheline and pyroxene syenites are very similar. In contrast, the amphibole syenite, according to Koellner (1974, p. 144) is agpaitic, and could contain carbonatite.

Intermediate zone: The intermediate zone, comprising mainly massive and flow-lineated gray to pinkish orange amphibole and pyroxene syenite, is poorly exposed, and its boundaries are gradational. Syenites in the intermediate zone are composed dominantly of alkali feldspar and up to 35 percent of poikilitic arfvedsonite which encloses pyroxene nuclei. Textural variants include lineated and massive pegmatitic and aplitic phases. Inclusions are relatively rare in the intermediate zone, and become more abundant outward. Swirled flow lineation in the amphibole syenite (unit asy along the Wisconsin River in Wausau, sec. 35, T. 29 N., R. 7 E.), indicates viscous flow of a crystal mush and a relatively dry melt. In the pyroxene syenite (unit psy) of this zone, the dominant mafic mineral is still amphibole, and the pyroxene occurs as discreet grains not rimmed by amphibole. At a stone quarry 0.3 km north of Stettin Road (SE¼ sec. 14, T. 29 N., R. 6 E.) the pyroxene syenite contains very coarse feldspars showing schiller structure (moonstone). Small

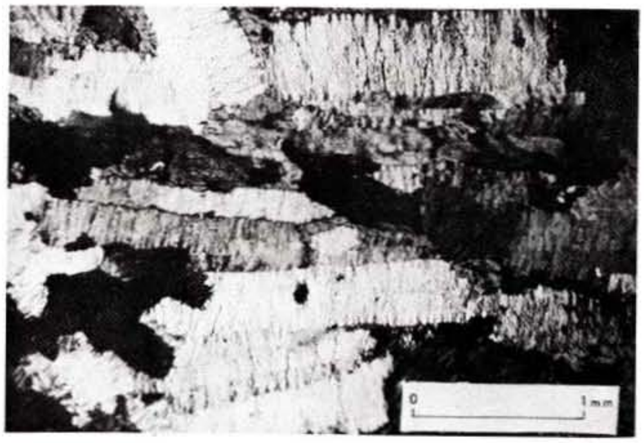

Figure 35.--Photomicrograph of nepheline syenite (unit nsy) showing euhedral nepheline grains surrounded by a matrix of discrete albite crystals and amphibole.

sill-like masses of tabular syenite occur in these rocks in the southwestern corner of the intermediate zone. In contrast to the prevailing orange-pink colors of the amphibole syenite, the pyroxene syenite is typically a somber brownish gray with islands of coarse mafic minerals enclosed in coarse tablets of randomly oriented feldspar. The amphibole syenite, which contains abundant dike-like and irregular masses of zoned pegmatite and aplite, shows a much stronger lamination with or without lineation than does the pyroxene syenite. The lineation in the amphibole syenite (fig. 36) is produced by alignment of feldspar tablets and lensoidal clots of amphibole and subordinate pyroxene. Pegmatitic phases of the amphibole syenite contain up to 12 percent quartz as coarse segregations, commonly rimmed by blue (riebeckitic) amphibole. The major mineral in the amphibole syenite is micro- to megaperthitic feldspar surrounding mafic minerals which are probably later. The principal mafic mineral is bluish-green arfvedsonite-riebeckite (table 3) which locally mantles Fe-rich augite. Pyroxene is nearly absent in the outer parts

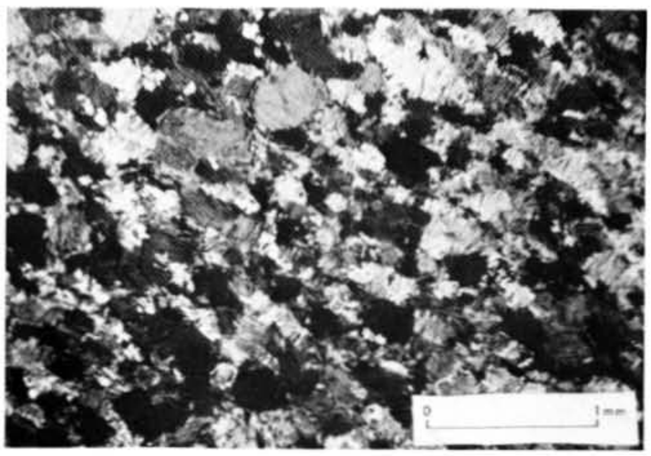

Figure 36.--Photomicrograph of aplitic syenite (unit asy) showing a fine-grained mass of anhedral perthitic feldspar.

of the intermediate zone. Amphiboles are altered to red-brown biotite. Some of the amphibole grains poikilitically enclosed euhedral feldspar (fig. 37). Accessory minerals include zircon, which is commonly zoned, quartz (up to 12 percent), fluorite, calcite, Fe-Ti oxides, apatite and allanite.

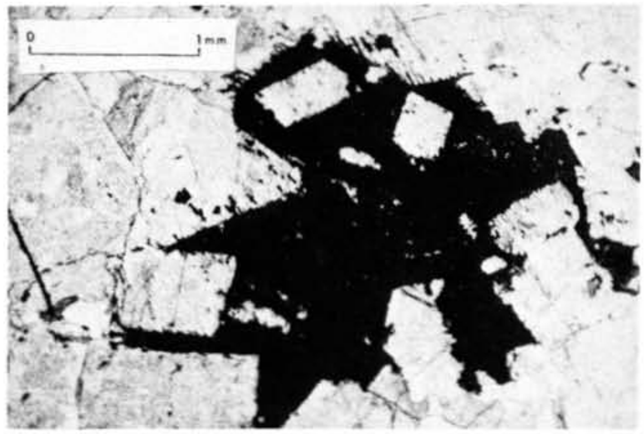

Figure 37.--Photomicrograph of amphibole syenite (unit asy) showing poikilitic texture. Note the euhedral outlines of the feldspar crystals enclosed in the amphibole grain.

Core zone: The core of the Stettin syenite pluton comprises two distinct, concentric parts: (1) a cylindrical, outer core margin of indistinctly banded or lineated, medium-grained nepheline syenite (nsy), and (2) an inner core of coarse, equigranular, homogeneous pyroxene syenite (psy) essentially identical to that in the intermediate zone. Bending, crushing, and alignment of feldspar grains during intrusion produced a crude lamination that dips inward at between 60 and 70 degrees. Abundant, locally coarse magnetite octahedra in the nepheline syenite produces a strong donut-shaped magnetic anomaly about 1.7 km in diameter. Drilling by Bear Creek Mining Company in the southeast corner of the inner core retrieved about 80 m of core classified by company geologists as larvikite. No carbonatite was found, although the agpaitic trend found by Koellner (1974, p. 144) suggests that it may exist at depth. The nepheline syenite of the core margin is pale yellowish gray with pitting due to differential weathering of the nepheline. The fresh nepheline is pale olive brown and occurs as well-oriented, subhedral to euhedral grains enclosed by tablets of feldspar up to 2 cm long.

The dominant mineral is tabular microperthite (60 percent orthoclase with 40 percent oligoclase ribbons). An additional 25 percent of the rock is subhedral to euhedral nepheline, which is partially altered to cancrinite. Mg-rich pyroxene and pleochroic, olive brown amphibole are of about equal abundance and make up about 20 to 30 percent of the rock. Accessory (2 to 5 percent) Mg-rich olivine and dark brown biotite accompany the other mafic minerals in lenticular clusters and islands occurring interstitially in the nepheline syenite. The biotite partially rims the amphibole and was probably formed at a late stage of crystallization. Biotite occurs sparsely in two distinct varieties: (1) reddish brown to dark brown, and (2) light brown to dark green. Both are strongly pleochroic. Accessory zircon, confined mainly to mafic clusters, sphene, fluorapatite, fluorite, calcite, and Fe-Ti oxides are the dominant accessory minerals.

Wausau Pluton

The northern and southern parts of the Wausau syenite pluton on opposite sides of the Rib River lack a concentric symmetry. Their similar rock types and zonal structure suggest that they are cogenetic and approximately coeval. Each part of the pluton consists of a poorly defined wall zone composed mainly of contaminated amphibole syenite, and intermediate zone of xenolith-rich quartz syenite with a conspicuous, steeply dipping annular structure, and a core zone of biotite-amphibole granite, quartz monzonite, and subordinate amphibole syenite. The granite and quartz monzonite belong to the Ninemile pluton which stoped and assimilated the southern half of the southern section of the Wausau pluton and a large volume of older metavolcanic and metasedimentary rocks to the southwest. Xenolith trains, which extend into the Ninemile pluton from the intermediate zone of the southern part of the Wausau pluton, indicate foundering of the roof of the Ninemile pluton. Wedges of Ninemile-type granite also occur in the core and intermediate zones of the northern part of the Wausau pluton.

The elongate, crescentic northern part of the Wausau pluton is rimmed in part by amphibole-pyroxene-biotite-bearing syenite. The intermediate zone, containing abundant metavolanic and subordinate quartzite xenoliths, has the composition of an amphibole quartz syenite. Biotite and quartz are less abundant in quartz syenites north of the Rib River, where more mafic xenoliths predominate.

The nearly circular southern part of the Wausau pluton has a diameter of 12.8 km. Its wall zone, which is exposed only along both sides of the Wisconsin River south of Rothschild, is composed dominantly of pyroxene-bearing amphibole syenite similar to that in the intermediate zone of the Stettin pluton. The intermediate zone of the southern part of the Wausau pluton consists of xenolith swarms in a flow-lineated matrix of amphibole-pyroxene quartz syenite. The xenoliths are mainly feldspathized quartzite, biotite schist, metadiabase, metadiorite, and porphyritic metavolcanic rocks, whose maximum dimensions lie in a nearly vertical plane parallel to the cylindrical wall of the intermediate zone. Maximum dimensions of the xenoliths range from a few centimeters to 3.4 kilometers for the quartzite on Rib Mountain. Xenolith shape is at least partly a function of lithology: schist xenoliths have much higher length-to-width ratios than quartzite xenoliths. Metavolcanic and metadiabase xenoliths tend to be more angular and have intermediate length-to-width ratios. A ring of very large quartzite xenoliths in the intermediate zone has a diameter of 8 km and is partly engulfed by the Ninemile pluton.

<u>Wall zone</u>: The wall zone of the Wausau pluton, because of poor exposure, voluminous lithic contamination, and gradational contacts, is not readily defined nor mapped. The dominant rock type in this zone is gray or pink amphibole syenite (asy and psy) with varying amounts of pyroxene, olivine, biotite, and quartz, probably depending on quantity and types of xenoliths. Biotitized metavolcanic rocks adjacent to the contact are ribboned and veined by zones of pegmatite-aplite syenite dikes and sills (fig. 38). Excellent exposures of metavolcanic rocks cut by syenite veinlets can be seen along the Wisconsin River bluffs in the north part of Wausau (NE¼ sec. 26, T. 29 N., R. 7 E.). The metavolcanic rocks, which become schistose in the vicinity of their contact with syenite, display a foliation and lamination dipping

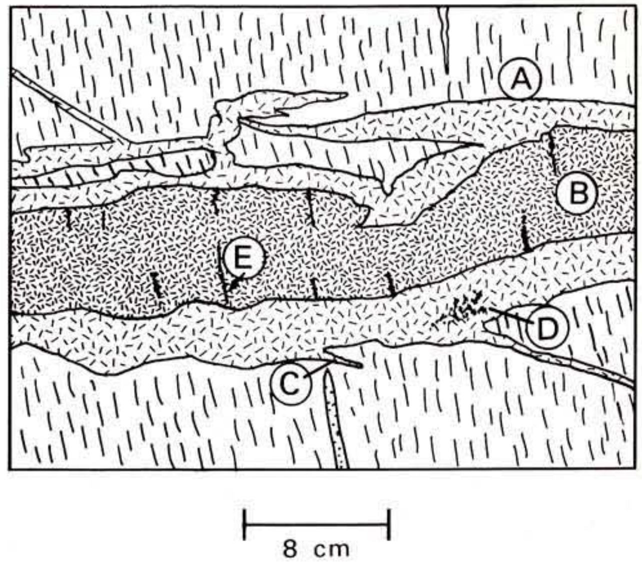

Figure 38.--Sketch showing laminated, schistose metavolcanic rock cut by subhorizontal dikes of syenite pegmatite (A) with grains 2 to 4 mm diameter and an aplitic core (B) with grains of less than 2 mm diameter. Note pinched aplite veinlet along schistosity at (C) and unassimilated mafic xenolith in pegmatitic portion of dike at (D). Thin seams of powdery magnetite occur inside the dike parallel to schistosity in enclosing metavolcanics (E). The right-hand edge of this cross section is north-northwest. Location, west side of Wisconsin River, NE¼ sec. 26, T. 29 N., R. 7 E.

steeply north-northwest, and are cut at nearly right angles by nearly horizontal dikes of amphibole-biotite syenite aplite and pegmatite. The dikes show no effects of chilling, and are cut by thin seams of magnetite. Biotite and K-feldspar increase at the expense of epidote plagioclase, and chlorite in metavolcanic rocks near the dikes. It is significant that the eastern contact of the Wausau syenite pluton with metavolcanic rocks shows little evidence of shearing during or after syenite emplacement, whereas the cataclastic matrix of lensoidal quartz syenite in the intermediate zone indicates considerable shearing and vertical displacement during intrusion.

The transition from coarse-grained syenites of wall zone into xenolith-rich quartz syenites of the intermediate zone is best seen by traversing southward along Highway 51 in secs. 15, 22 and 27, T. 29 N., R. 7 E. Both the wall and intermediate zones pinch out southward against enclosing metavolcanic wallrock, thus resulting in the pronounced north-south elongation of the pluton.

<u>Intermediate zone</u>: The vertical, cylindrical inner shell of the intermediate zone is a biotite quartz syenite (lqsy) crowded with xenoliths of differentially granitized quartzite, biotite schist and metadiabase xenoliths in a foliated, cataclastic matrix. The width of this inner shell varies from a maximum of 2.3 km on the north to 1.6 km on the east to zero, where it pinches out between masses of Ninemile granite on the west side. This zone was stoped and mostly assimilated in the roof zone of the Ninemile pluton. The lensoidal quartz syenite (lqsy) is best exposed in a crescentic area from Hardwood Hill on the west to Rib Mountain on the north to Mosinee Hill on the east. At the south end of Mosinee Hill (NE¼NE¼ sec. 27, T. 28 N., R. 7 E.) relationships of quartzite and biotite schist xenoliths to the enclosing quartz syenite are well-exposed in an abandoned 3-M quarry. Mosinee Hill, like other prominent ridges in this zone, is the erosional remnant of a large keel-shaped quartzite xenolith (fig. 39). The lensoidal shape of these larger xenoliths is inferred from shapes of associated quartzite xenoliths nearby. The quartzite in these

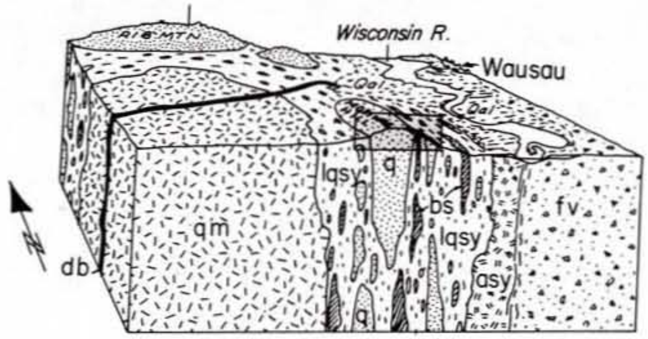

Figure 39.--Block diagram of the northeastern corner of the southern segment of the Wausau syenite pluton at Mosinee Hill showing abundant well-oriented quartzite (q) and biotite schist (bs) xenoliths in a flow-laminated, lensoidal quartz syenite (lqsy). The Ninemile quartz monzonite pluton (qm) intruded the quartz syenite with only a local discordance. The lensoidal syenite is bounded on the east by a thin wall of amphibole syenite (asy) which is itself in fault contact eastward with felsic volcanic rocks. These rocks are cut with sharp discordance by a prominent diabase (db) dike which is characterized by a strong reverse magnetic polarity. The Qal is Wisconsin River alluvium.

xenoliths is exceptionally coarse-grained and commonly devoid of such primary structures as bedding. They consist of more than 90 percent polygonized quartz grains. Accessory minerals are mainly muscovite and iron oxides. The quartzite, near its contact with quartz syenites, is impregnated with interstitial pink microcline, which selectively replaced more permeable parts of the quartzite so as to accentuate such subtle primary features as bedding. Where the percentage of K-feldspar reaches approximately 25 percent, the quartzite takes on the appearance of a leucogranite. However, the subspherical shape of residual quartz grains and the interstitial distribution of the K-feldspar distinguish it microscopically from igneous granite. This type of granitization, however, requires a considerable metasomatic addition of K_2O and Al_2O_3.

The lensoidal quartz syenite of this zone is a distinctive rock composed of quartzite and mafic xenoliths of considerable size range in a foliated matrix composed dominantly of microcline perthite, biotite, and quartz. Lensoidal shape of the xenocrysts in the matrix and the interlensing foliation indicate cataclasis during emplacement. Quartzite xenoliths are partially granitized and display relict bedding. Biotite schist xenoliths are pancake-shaped with pronounced elongation parallel to cataclastic foliation and length/width ratios from 5:1 to 15:1. In contrast, associated quartzite xenoliths are more angular, less commonly oriented with respect to any primary structure, and have much lower length/width ratios (usually less than 5:1). With only minor textural variations, this rock characterizes the entire inner shell of the intermediate zone.

The Rib Mountain quartzite xenolith, with surface dimensions of 3.3 x 0.8 km, is the largest of the xenoliths in the intermediate zone. Bedding within the xenolith dips steeply north and south, and ripple marks indicate tops face southward toward the core of the pluton. It may be significant that a swarm of quartzite xenoliths with about the same overall dimensions as the Rib Mountain quartzite occur in the same relative position of the northern segment of the Wausau syenite on the hillside north of Employers Insurance Company offices (secs. 21, 22 and 27, T. 29 N., R. 7 E.). However, in this location, none of the xenoliths appears to be of mappable dimensions.

Another quartzite outcrop of considerable significance is 1.5 km north of the Stettin Road bridge over the Little Rib River (NE¼ sec. 29, T. 29 N., R. 7 E.). A lensoidal xenolith of phyllitic quartz-sillimanite-muscovite schist composed of 88 percent polygonized, unstrained quartz, 8 percent sillimanite and 3 percent muscovite is separated by only a few meters from another quartzite composed of over 95 percent very coarse quartz grains with strongly sutured grains and conspicuous strain lamellae. The sillimanite-bearing quartzite probably came from a high-grade metamorphic basement; the coarse quartzite with no sillimanite and sutured, strained quartz grains shows evidence only of deformation without significant recrystallization. Camera lucida drawings of these two quartzites are included for comparison (figs. 40 and 41).

Structures and cross-cutting relations of quartz syenites exposed at the

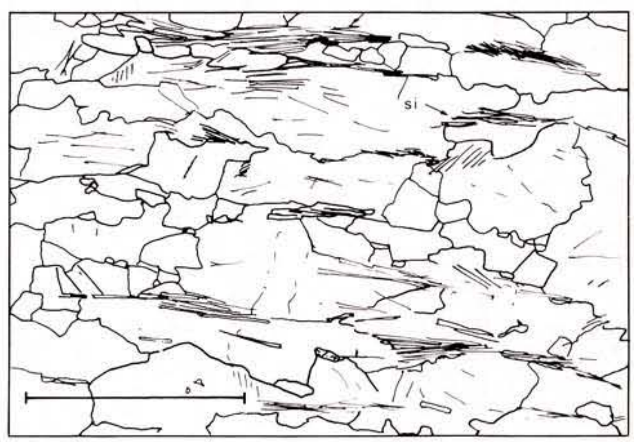

Figure 40.--Drawing of a quartzite inclusion in the Wausau syenite showing lenticular quartz grains with concordant sheaves of sillimanite (si). Bar is 1 mm long. Compare with figure 41.

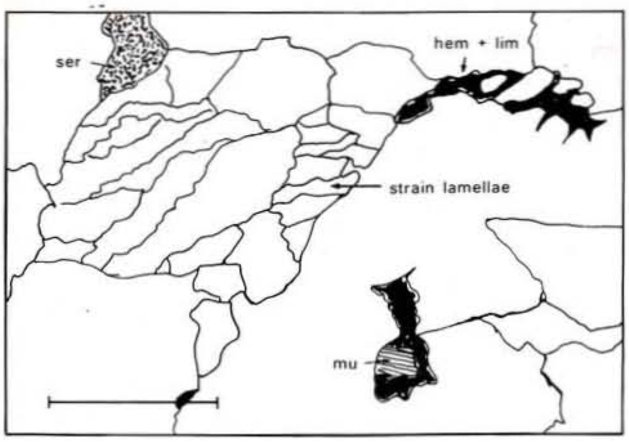

Figure 41.--Drawing of a quartzite inclusion in the Wausau syenite showing strained quartz with sericite (ser) blebs with interstitial clots of hematite and limonite (hem + lim). Bar is 1 mm long. Compare with figure 40.

Old Technical Institute in Wausau (NE¼NE¼ sec. 35, T. 29 N., R. 7 E.) typify those seen throughout the northern crescent of the Wausau pluton. An early, medium-grained pyroxene-amphibole quartz syenite containing northwest-oriented quartzite, schist and volcanic xenoliths is cut by coarser-grained, flow-lineated quartz syenite of similar composition. Average xenolith orientation here is structurally continuous with the concentric lamination of the Wausau syenite pluton. Thin screens of biotite schist and quartzite were rafted up or dropped down and brecciated in the viscous syenite magma. These features are listed and described below in order of decreasing age. The rocks were first described by Weidman (1907, p. 203-208).

1. The oldest rocks are xenoliths in the quartz syenite. They include thoroughly recrystallized, schistose, amphibolitic metavolcanic rocks, quartzite, and virtually unaltered porphyritic felsic tuff.

2. An early, fine-grained, flow-laminated, lensoidal quartz syenite may represent a chilled phase. This rock is composed of orthoclase microperthite, clinopyroxene, biotite and quartz.

3. Coarse-grained, flow-lineated pyroxene-amphibole quartz syenite are composed of orthoclase and microcline microperthite, barkevikite, hedenbergite, fayalite, quartz, and accessory magnetite, fluorite, zircon, apatite, allanite and sphene. Irregular, lensoidal and tabular inclusions amphibolite, quartzite, and schist which show little assimilation occur in this unit. The inclusions show a strong northwesterly elongation, while the enclosing quartz syenite possesses a strongly discordant, swirled flow lineation suggesting viscous flow of a crystal mush. A thin sheet-like xenolith of mafic biotite schist (metadiabase?) shows plastic deformation and pull-outs on its western end (fig. 42), whereas its more brittle eastern end is segmented into many angular fragments (fig. 43).

4. Late-stage, lenticular granite pegmatite veins with quartz cores, probably representing residual liquid segregations in silica-oversaturated portions of the syenite magma, crystallized along incipient contraction fractures in the cooling quartz syenite (fig. 40).

5. Crystallization of sodic amphi-

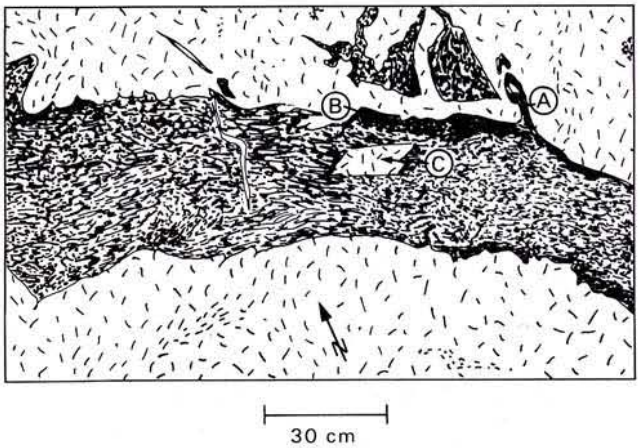

Figure 42.--Plan view of part of a sheet-like biotite schist xenolith showing "pull-outs" (A), a mafic selvage (B), and a pseudo-inclusion (C). Note discordance of flow lineation across long dimension of the xenolith.

bole along joint surfaces (fig. 44).

The features at the Old Technical Institute are very similar to those seen at the Employers Mutual Insurance Company offices near the intersection of Highways 51 and 29 (NW¼SE¼ sec. 27, T. 29 N., R. 7 E.). Both outcrops probably represent rocks which lie near the contact between the wall and intermediate zones. In contrast to the flow-lineated syenitic matrix between xenoliths in the rocks of the wall zone, those of the intermediate zone display a conspicuous cataclastic matrix suggesting considerable mechanical displacement of wallrock fragments during intrusion.

Rocks at the Employers Insurance Company offices were studied by Sood and others (1980, p. 19-21) and previously by Myers (1974). The quartz syenite at this location is composed of coarse perthite (80%), quartz (10%), and sodic pyroxene partly replaced by mixtures of dark green amphibole, carbonate, and magnetite (10%). Quartz is interstitial. Rich segregations of magnetite occur in this outcrop and probably account for the significant magnetic anomaly associated with this unit (Henderson and others, 1963). Pink and brownish gray quartz syenite at this location contains up to 60 percent volcanic xenoliths and are best seen on horizontal surfaces. The xenoliths (fig. 45) show a pronounced flow orientation and are accompanied by mafic schlieren and clots of irregular form and orientation; their more gradational boundaries indicate more thorough assimilation.

A series of samples taken west to east and south to north across the outcrop at this location yielded the chemical compositions shown in table 4. Compared to Nockold's (1954) average syenite composition, these quartz syenites are richer in SiO_2, total iron, and poor in alkalies, lime, Rb, and Sr. These differences are due at least in part to the assimilation of large amounts of rhyolitic or quartz latitic volcanic xenoliths or both.

Ninemile pluton: The Ninemile pluton is elliptical in plan with a northeasterly elongation, dimensions of 15 x 19 km and an area of 218 km^2. Rocks similar to those of the Ninemile pluton crop out on opposite sides of the Rib River (sec. 6, T. 28 N., R. 7 E. and NW¼ sec. 33, T. 29 N. R. 7 E.) near the north end of the Wausau pluton (secs. 16 and 17, T. 29 N., R. 7 E.). The eastern contact of the Ninemile pluton is buried beneath Wisconsin River alluvium. This pluton is one of the youngest in the area with a U/Pb age of 1,500 Ma (Van Schmus, verbal communication). It contains xenoliths of highly sheared rocks. Similarity in age and

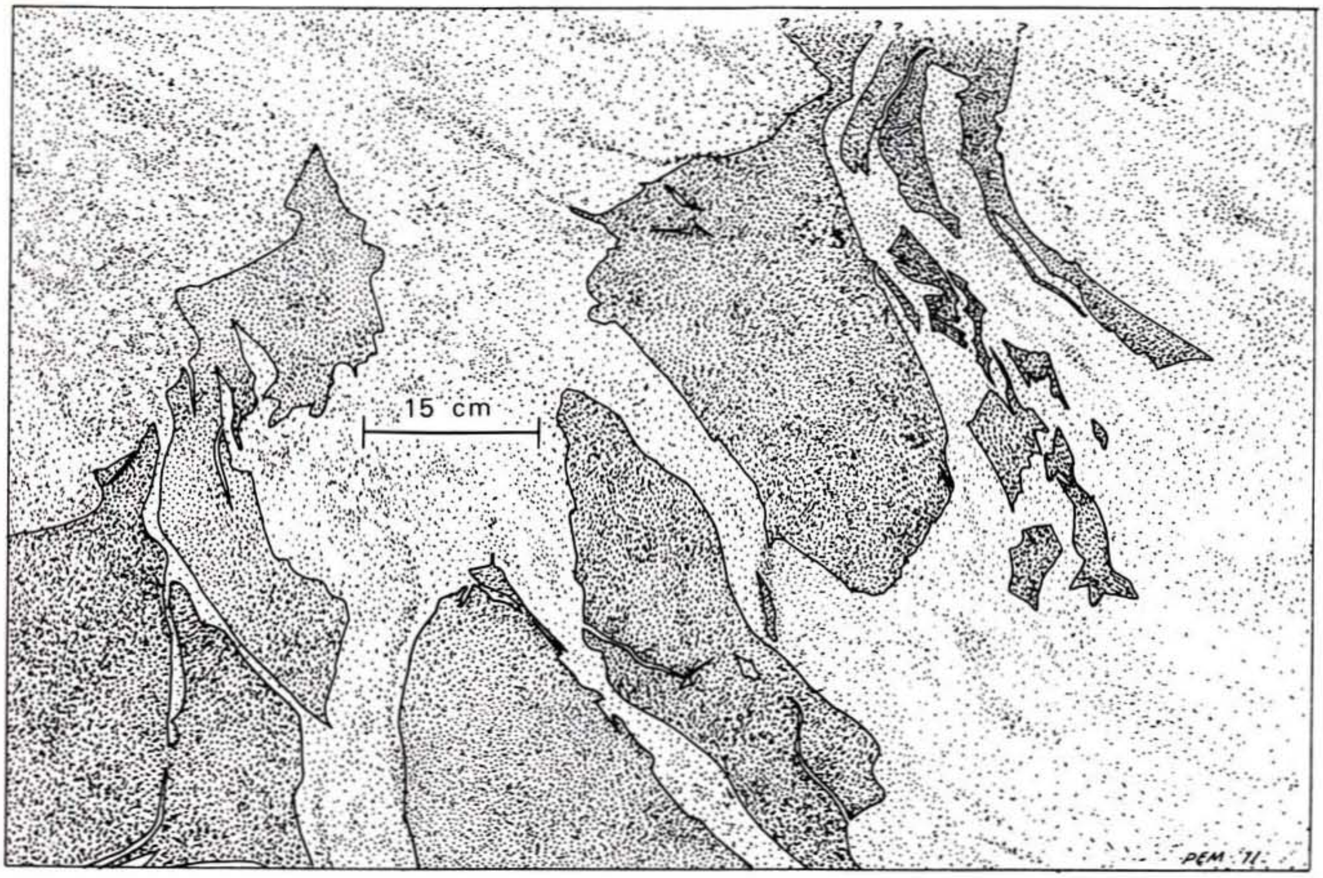

Figure 43.--Sketch of a segmented biotite schist (metadiabase?) xenolith in flow-lineated amphibole-pyroxene-biotite quartz syenite. This is an oblique view of an outcrop which slopes 20 degrees towards the bottom of the picture.

appearance link it genetically with the Wolf River batholith to the east. The Ninemile pluton intruded, stoped, and partially assimilated syenites and quartz syenites of the Wausau pluton and metavolcanic rocks and granitic plutonic rocks in the region south of the Wausau pluton (figs. 31 and 39).

The uniform, moderate pinkish orange color of the weathered granites of the Ninemile pluton gives a false impression of homogeneity. Sample traverses across the pluton disclose its compositional and textural heterogeneity (table 4). The dominant rock type is a quartz monzonite composed essentially of microcline microperthite, quartz, plagioclase, dark green amphibole, and dark brown biotite. Ribbon perthite predominates over patch- and bleb-type perthite. The perthite commonly contains cleavage-oriented biotite inclusions, a fact that indicates a relatively early age for the perthite. The origin of the quartz is a problem of major significance in a consideration of the emplacement dynamics of the Ninemile pluton. Evidence that the quartz is xenocrystic quartzite is: (1) quartz grains are polygranular (rock) aggregates; (2) the quartz shows wavy extinction, strain lamellae (fig. 46), even where the other minerals in the rock do not; (3) the quartz grains are subequant with sharp angular edges-

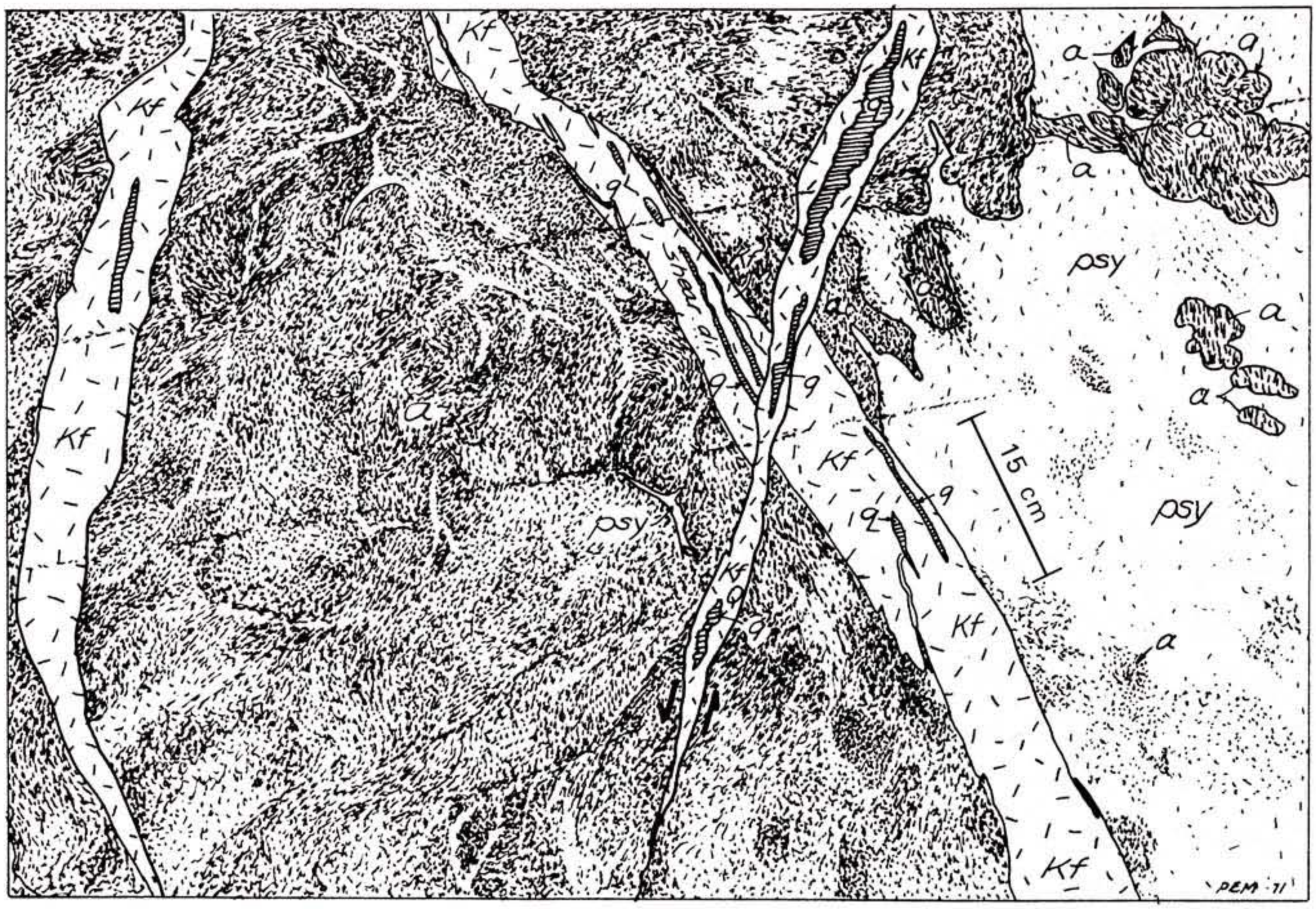

Figure 44.--Detailed outcrop map showing amphibolite (a) xenolith with swirled lineation and thin seams of quartz syenite cut by coarse pyroxene-bearing quartz syenite (psy). Lenticular veins with walls of K-feldspar (Kf) and cores of quartz (q) show mutually crosscutting relations with an intervening offset along a small fault. Joint coatings are of coarse, sodic amphibole.

indentation of grains is rare; and (4) Ninemile granites are compositionally and texturally int erg radational with quartz syenites. The Ninemile quartz monzonites are all otr iomorphic- and less commonly hyp idiomorphic-granular. Perthite grains are typically blocky, rectangular with sutured contacts and Carlsbad twinning. Some plagioclase grains contain pellet-like sericite blebs. The perthite locally contains cleavage-oriented biotite flakes and encloses subhedral grains of coarse, green amphibole. The dark green and dark brown colors of amphibole and biotite respectively indicate their high iron content. The high iron content of these rocks is further indicated by the abundance of hematite, which accounts for the red color of the Ninemile granites throughout the area. The hematite, commonly euhedral hexagonal prisms, occurs as interstitial fibers and as large masses with quartz, apparently as a replacement of some other mineral. Zoned zircon, subhedral apatite, purple fluorite, muscovite, allanite, and monazite(?) are accessory minerals. Vugs in the granite commonly contain well-formed clusters of smokey

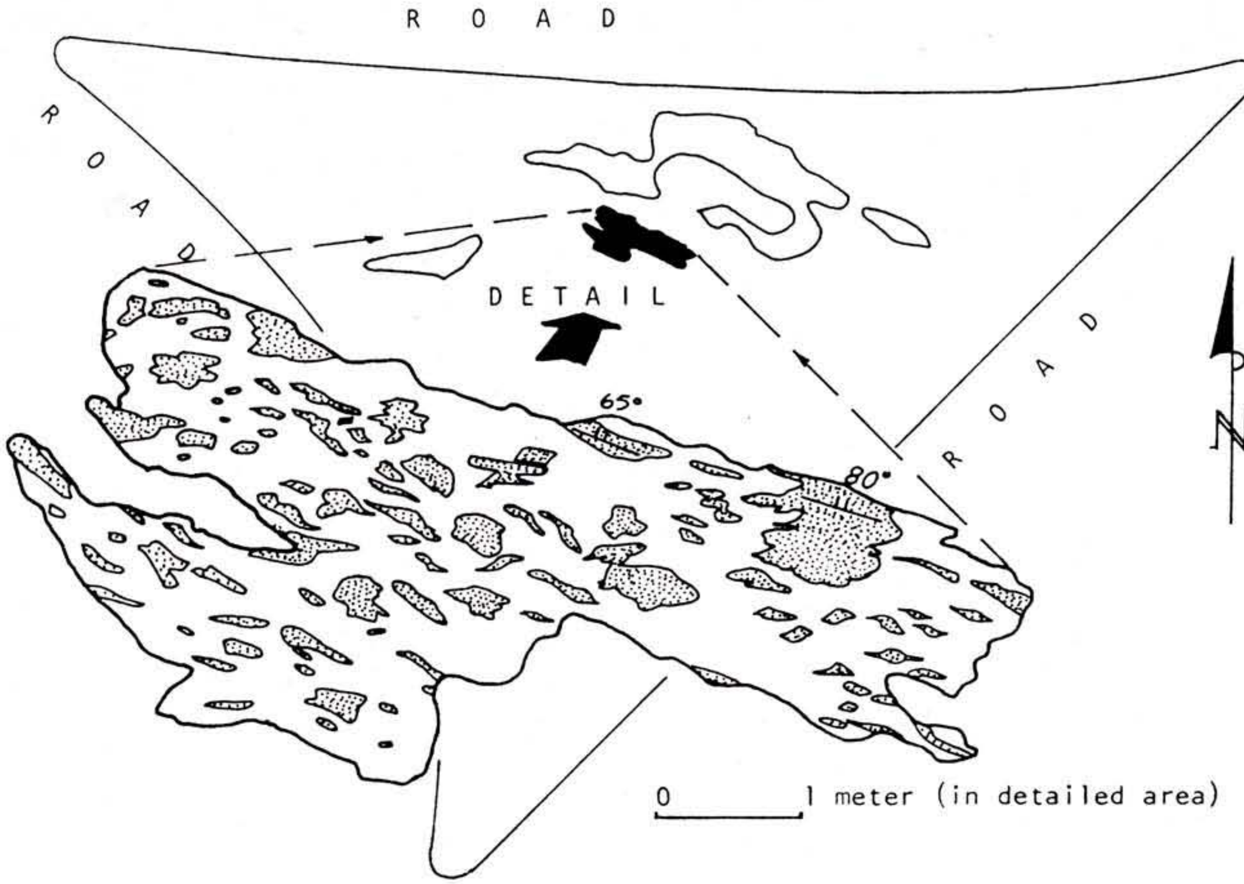

Figure 45.--Detailed outcrop map showing volcanic xenoliths (dotted) in flow-lineated pyroxene-amphibole quartz syenite (white). Outcrops are located in the grassed area between three roads behind Employers Mutual Insurance Company.

quartz, which are commonly associated with such pegmatoid minerals as phenacite and tourmaline. Quartz-lined miarolitic cavities are also common, especially in the western and northern parts of the Ninemile pluton.

Pendants and xenoliths of quartzite, quartz syenite, syenite, syenogabbro, and foliated quartz-plagioclase aplite are most common in a circular area which is the trace of the partially assimilated intermediate zone of the Wausau pluton. The syenogabbro is composed of perthite-rimmed plagioclase, dark olive brown to green amphibole, dark orange-brown biotite, clinopyroxene, and accessory apatite, quartz, allanite, epidote, and olivine(?).

Textural and compositional heterogeneity of the Ninemile granites and the existence of miarolitic cavities indicate shallow intrusion. It is suggested the Ninemile pluton was intruded beneath a collapsed syenitic caldera complex shortly after its formation.

Comparison of the Stettin and Wausau Plutons

Despite obvious differences in size, shape, xenolith types, zoning sequences, and silica saturation, the Stettin and Wausau plutons share two significant similarities: (1) the py-

TABLE 4.--Modal mineralogy in volume percent of selected rocks from the Ninemile pluton

Sample No.	Rock Type	Minerals K-feldspar	Perthite	Plagioclase	Quartz	Biotite	Amphibole
72395	Leucogranite	28	24	12	35	tr	--
72392A	Biotite granite	12	51	--	31	2	--
72392B	Quartz syenite with xenocrystic quartz	62	--	--	35	2	--
72391A	Biotite granite	6	62	--	29	3	--
72391B	Leucogranite	10	55	--	21	--	--
72393	Gneissic quartz syenite[1]	16	46?	--	35	2	1
72394A	Hematitic quartz monzonite	57	10	10	21	--	--
72394B	Quartz syenite[2]	47	23	9	19	--	--
72390A	Biotite quartz monzonite	32	3	30	27	0.6	2
72390B	Biotite granite	--	60	5	28	4	1
72390C	Biotite quartz monzonite	28	12	21	32	7	--
72390D	Altered biotite granite	30	14	8?	35	3	--
72389	Leucogranite	50?	30?	5	15	1	--
72388A	Hornblende-biotite granite	42?	16?	5	26	7	2
72388B	Biotite granite	54	5	--	35	3	1
72387A	--- do. ---	41	23	--	26	9	tr
72387B	Granite protomylonite	25	42	5	25	2	--
72386	Leucogranite	70	5	--	22	--	--
72385	Biotite-hornblende quartz monzonite	29	--	37	16	9	8
72379	--- do. ---	--	35	10	40	5	10
72251	Leuco-quartz monzonite	37	--	34	28	tr	--
72400	Granite protomylonite	--	65	--	31	2	--
72401A	Biotite granite	--	76	4	15	2	--
72401B	Amphibole-biotite syenite[3]	--	40	5	2	25	21
72401C	Mafic syenogabbro[3]	--	--	34	2	26	28
72402A	Biotite syenite[3]	26	--	46	--	8	16
72402B	Schistose quartz-plagioclase aplite[3]	--	--	15	60	5	--
7294	Quartz monzonite flaser gneiss	10	64	25	--	1	--
72403	Quartz monzonite	--	60	15	23	1	1

Upper grouping represents a north to south traverse; bottom, west to east traverse. For many samples it was impossible to determine the proportions of potassium feldspar and perthite; however, the total should be reliable; leaders (-), not observed; tr, trace.

[1] or granite aplite.
[2] or monzonite with quartz veins.
[3] xenolith.

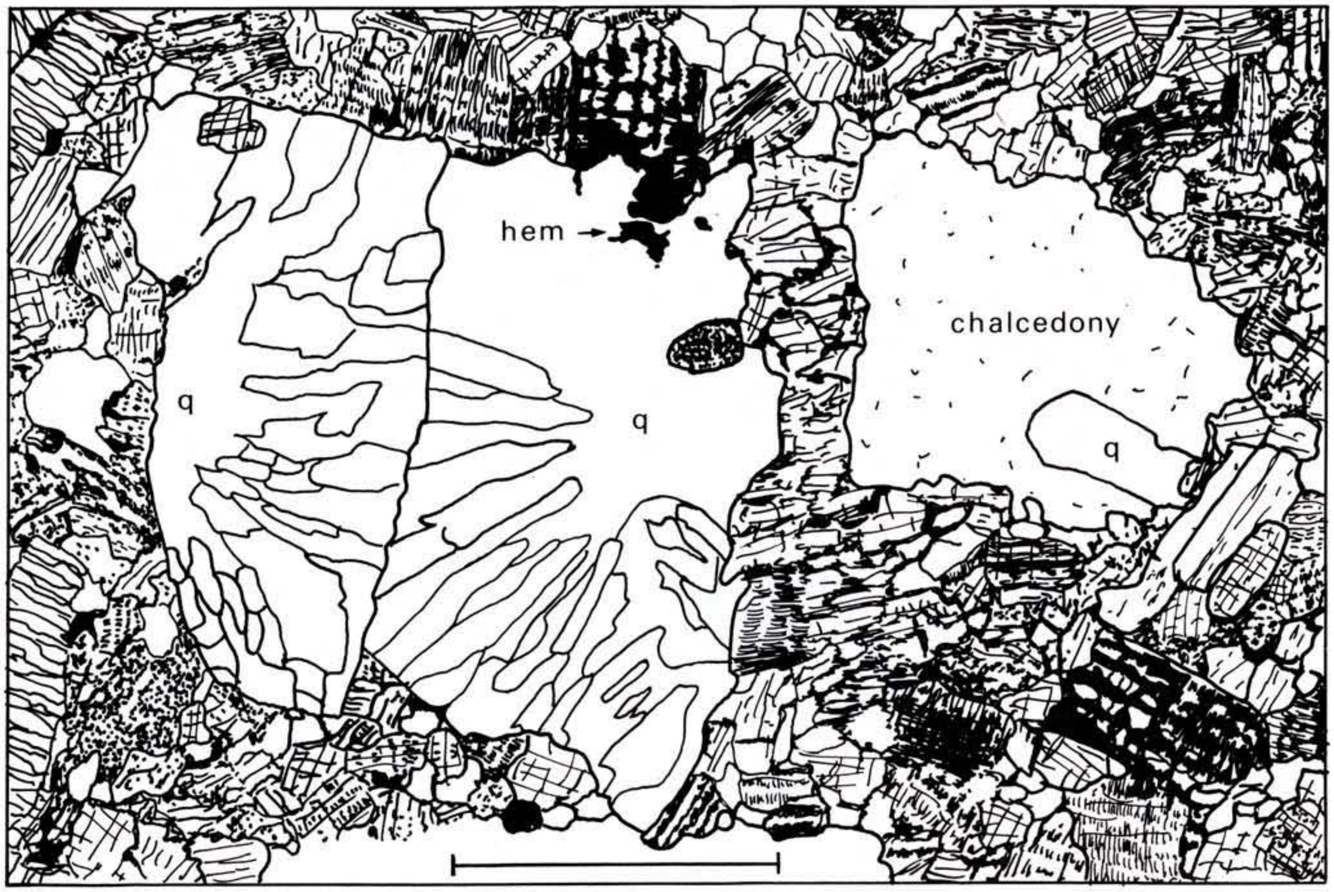

Figure 46.--Micrograph diagram of quartz syenite xenolith in Ninemile granite consisting of hematite-impregnated microcline perthite with blocky quartz (q) xenocrysts and a cavity with a euhedral quartz crystal (right) in chalcedony. Location SW¼SW¼ sec. 35, T. 28 N., R. 6 E. Bar is 1 mm long.

roxene and amphibole syenites of the intermediate zone of the Stettin pluton are compositionally equivalent to the outer wall zone of the Wausau pluton, and (2) their concentric, cylindrical structure and close proximity suggest a common ancestry and perhaps structural control in the subjacent basement. The Ninemile pluton probably represents a marginally contaminated late-stage differentiate of the same magma which produced the syenites and quartz syenites. Pegmatitic phases of the amphibole syenite of the Stettin pluton locally contain up to 15 percent quartz (Koellner, 1974, p. 31), thus making the two rocks similar in composition. The relatively low silica content of the Stettin pluton may be due in part to the low silica saturation of the volcanic rocks it intrudes. Quartz-filled miarolitic cavities in the Ninemile granite indicate shallow crystallization conditions. Concentric structures and rock units support the concept of collapsed calderas one of which is cored by a granite pluton in which it partially foundered. According to Van Schmus (oral communication) the Stettin pluton was intruded at 1,520 ± 10 Ma, and the Ninemile and Wolf River plutons were intruded at 1,500 ± 110 Ma. The ages are compatible with field evidence.

Shearing with chaotic vertical displacement and mixing of wallrock fragments was greatest in the inner part of the intermediate zone of the Wausau pluton and less important in the wall zone of the Stettin pluton. Semidetached wallrock slices, partly sheared away from the walls, are seen on the east and south sides of the Stettin pluton. In contrast, xenoliths in the contaminated intermediate zone of the Wausau pluton were completely detached and show no obvious relationship to contiguous wallrock. Thus, there appears to have been significantly greater xenolith transport in the Wausau pluton. The occurrence of sillimanite in a quartzite xenolith in the intermediate zone of the Wausau pluton suggests derivation of at least part of the xenoliths from a high-grade metamorphic basement. Its occurrence in close proximity with another type of quartzite rules out a metasomatic origin for the sillimanite at this site. The structure section (fig. 47) is a cross section of the Stettin and Wausau syenite terrane after crystallization of the Ninemile pluton about 1,450 Ma.

Diabase Dikes

Both pyroxene and olivine diabases are present in Marathon County. They range up to 30 m in width and are characteristically undeformed and unmetamorphosed. The dikes cut all other rock types and thus are the youngest Precambrian rocks in the area. The diabases typically range in grain size from 1 to 5 mm, and those examined petrographically have ophitic textures. They appear to vary in mineralogy. An olivine diabase exposed in NE¼SE¼NE¼ sec. 11, T. 29 N., R. 2 E. has pink-red titanaugite ophitically enclosing plagioclase (An_{55}) and olivine. Others exposed in the SW¼ sec. 31, T. 30 N., R. 4 E. at Athens contain colorless augite ophitically enclosing the plagioclase. Most of the dikes are poorly exposed, with only one exposure of a given dike. Those with exposed contacts trend east to east-northeast. Most of the dikes have no recognized magnetic signature; however, one prominent dike exposed in the grus quarries south of Rib Mountain has an associated aeromagnetic low that can be traced for more than 100 km from northern Shawano County westward across most of Marathon County. The magnetic low shows that this dike is reversely polarized. Where exposed it is a medium grained (2 to 3 mm) pyroxene diabase about 15 m wide with a chilled margin. Other diabase dikes are exposed in Big Sandy Park NW¼SW¼ sec. 19, T. 29 N., R. 9 E., SE cor. sec. 13, T. 29 N., R. 8 E.; NE¼ sec. 19, T. 27 N., R. 6 E.; SW¼ sec. 13, T. 27 N., R. 5 E.; NW¼NW¼ sec. 20, T. 29 N., R. 9 E.; and NE¼SE¼ sec. 28, T. 28 N., R. 9 E.

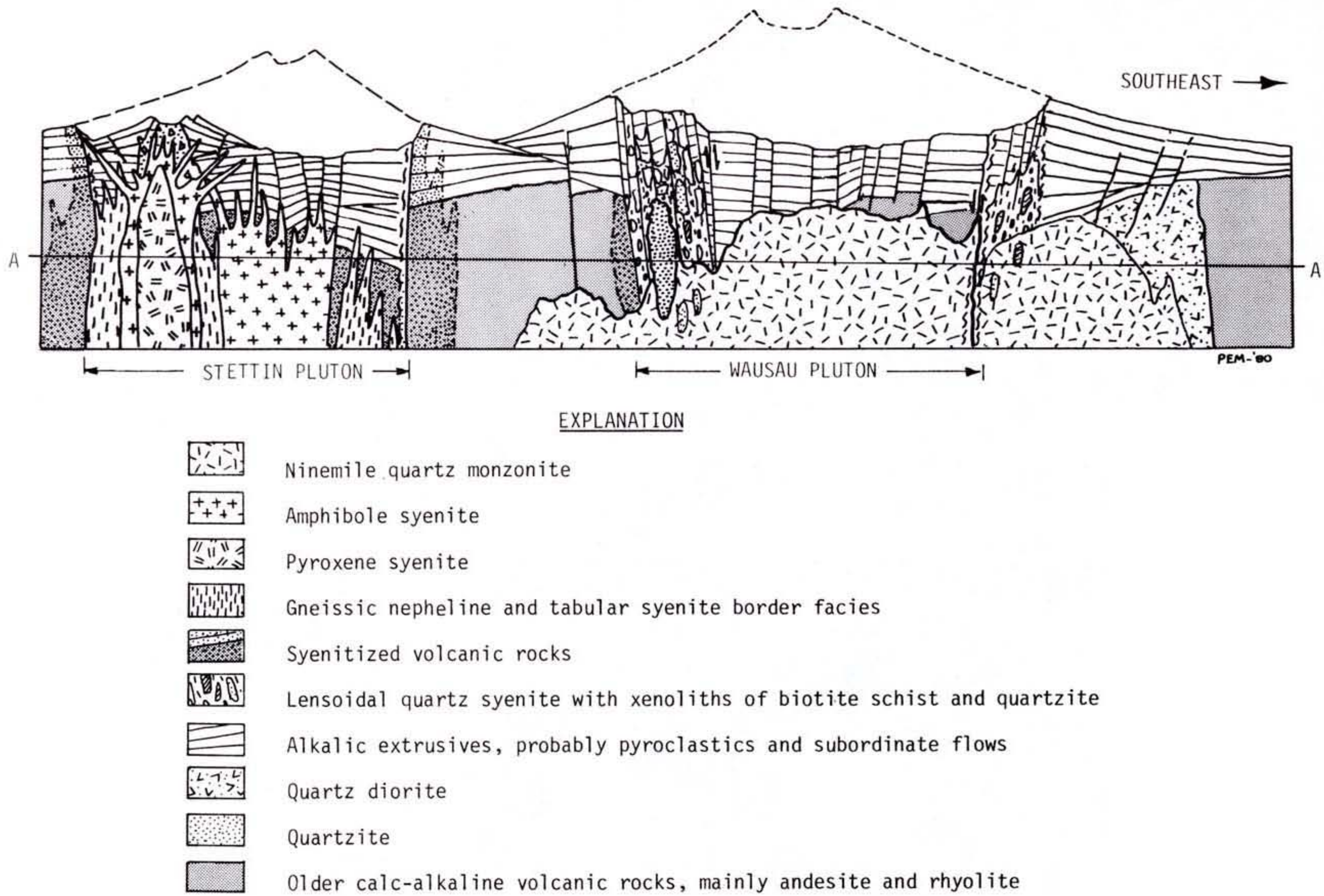

Figure 47.--Diagrammatic section oriented northwest to southeast across the Stettin and Wausau syenite plutons as they would have appeared about 1,450 Ma Line A-A' represents the present land surface. See figure 31 for location of section.

STRUCTURAL GEOLOGY

Regional Setting

Marathon County is on the southern margin of a large Early Proterozoic volcanic-sedimentary basin that extends across northern Wisconsin into Minnesota and Michigan (Sims, 1976). Although Precambrian rocks are widely distributed over the area, their detailed structural and stratigraphic relationships from one area to another is largely unknown. In central Wisconsin large areas of amphibolite facies rocks alternate with areas of greenschist facies rocks. The boundaries between several of these blocks are exposed in Marathon County allowing the relationship between them to be examined. The contact between the Middle Proterozoic Wolf River batholith and the Lower Proterozoic volcanic-plutonic terrane was also mapped in Marathon County. Thus the relationships between a variety of rock types have been examined and can be related to their geophysical signature. This allows extrapolation of these features into areas with thicker glacial cover.

Folding

Although the volcanic rocks have been extensively segmented by faulting and intrusion, it is possible to reconstruct several large-scale folds that underlie much of Marathon County. The trend of volcanic rocks is mainly N. 60° E. to east-west; however, the massive nature and broken surfaces of most outcrops prevents determination of the strike and dip. Top indicators are lacking in most volcanic rocks. Although pillow lavas are widely distributed, top determinations were possible at only three locations: (1) along Artus Creek (NE¼NW¼ sec. 29, T. 29 N., R. 6 E.); (2) along Highway A (SE cor. sec. 28, T. 30 N., R. 6 E.); and (3) south of Rozellville (SE¼SE¼NE¼ sec. 21, T. 26 N., R. 4 E.). At some places the pillows are so deformed that unambiguous top determinations are not possible (for example, NE¼NW¼ sec. 9, T. 30 N., R. 7 E.). Many pillow lava occurrences are frost-heaved blocks or boulders picked from fields by farmers. As such they show the distribution of pillow basalts, but provide no direct structural information.

The general distribution of volcanic rocks based on mafic and felsic rocks suggests a large northeast-trending synformal structure with its axis approximately through Wausau (fig. 48). Basalts are more abundant to the southeast near Ringle with an increase in rhyolites towards Wausau. North and northwest of Wausau basalts and andesites again predominate. West of Wausau, pillows in basalts exposed along Artus Creek (NE¼NW¼ sec. 29, T. 29 N., R. 6 E.) indicate tops to the southeast, suggesting that the basalts dip beneath the rhyolites in the Wausau area. Minor folds in the volcanic rocks that consistently plunge east to northeast at about 50° were observed in the volcanic rocks at widely scattered locations. The northeasterly plunge of minor fold axes suggests a similar northeasterly plunge for the fold axis. Therefore, the general distribution of volcanic rocks in roof pendants and minor structures can be interpreted as shown in figure 48.

The volcanic sequence appears to have been duplicated at least twice by faulting southeast of Wausau. One fault is parallel to and approximately 1.5 km west of the Eau Claire River (fig. 48), juxtaposing rhyolites and

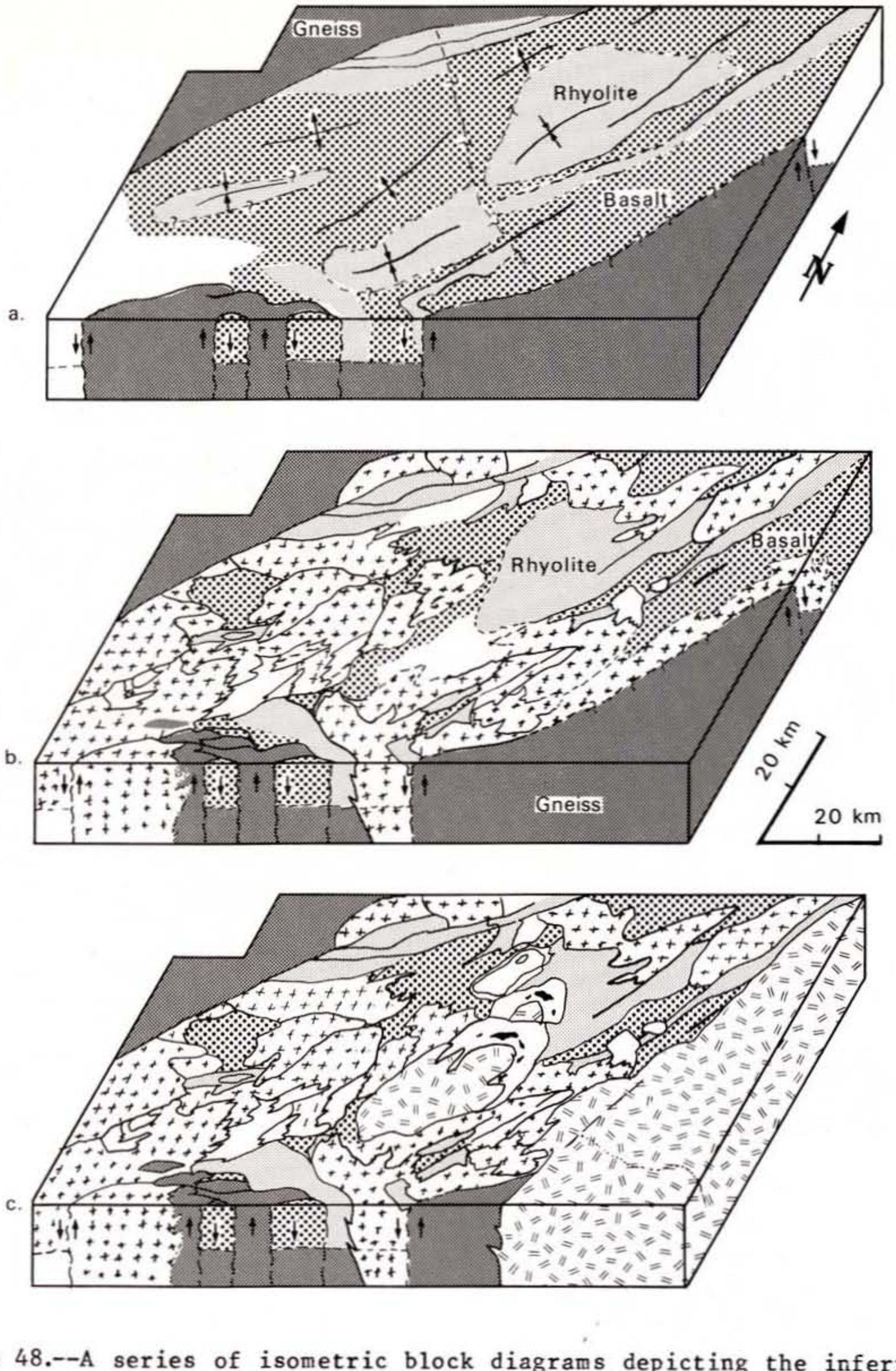

Figure 48.--A series of isometric block diagrams depicting the inferred structural history of Marathon County. (a) folding and faulting of the volcanic sequence; (b) intrusion of numerous granitic rocks with continued deformation to form the graben structure; and (c) intrusion of the Wolf River batholith and the syenite bodies. See also figure 3.

granites on the east with basalts on the west. The second fault extends northeasterly from Rothschild along Little Sandy Creek, again juxtaposing rhyolites on the east with basalts on the west. Foliation along these zones is near vertical suggesting a vertical dip. The presence of markedly foliated granitic rocks along these faults, (W½ sec. 5, T. 28 N., R. 9 E.; sec. 32, T. 29 N., R. 9 E.; SE¼SW¼ sec. 33, T. 29 N., R. 9 E., and along the eastern edge of the Kalinke quartz monzonite, secs. 1, 11 and 15, T. 29 N., R. 9 E. and secs. 17, 19 and 20, T. 30 N., R. 10 E.), suggests that intrusion predated or was synchronous with movement on the faults. The complex pattern of volcanic rocks west of the Wisconsin River suggests that the succession has been repeated by faulting or folding in that area as well. One proposed fault in this area extends northeast from Rib Falls to the NE cor. sec. 3, T. 30 N., R. 7 E. (fig. 48). The marked change in rock types northeast and southwest of the Rib River valley suggests a northwesterly trending fault, although no other evidence for such a fault was recognized.

In addition to what appears to be the large-scale folding and faulting, the volcanic rocks have been extensively segmented and disrupted by intrusions. This fact severely limits the documentation of older structures in the volcanic rocks; however, the general sequence of volcanic rocks in the larger roof pendants is consistent with the broad fold pattern outlined above. For example, the volcanic pendant south and east of Mosinee displays the same general northeast trend of volcanic units and has rhyolites to the west and basalts to the east. It also contains a possible repetition of the volcanic sequence with rhyolites juxtaposed against basalts along a fault with the inferred motion again being west side up. Granitic rocks along the continuation of this proposed fault have a prominent cataclastic foliation and several ultramafic bodies occur along the zone. Near Dancy, at the southern edge of the county, a possible fold nose of rhyolite is enclosed in granitic rocks. This suggests that the intrusions have engulfed the volcanic rocks without completely disrupting the older fold pattern. Several other possible synclines and anticlines are shown on the block diagrams in figure 49. Further discussion of possible folds is not warranted from the available data.

Faulting

Because recognition of cataclastic rocks is important to understanding the structural and tectonic history of central Wisconsin, a brief discussion of cataclastic rocks is presented below.

Cataclastic rocks have a superficial resemblance to regionally metamorphosed rocks, for which they are often mistaken. They differ, however, in the following ways: (1) they have a linear distribution and cut nondeformed rocks; (2) they grade across strike into rocks that are not cataclastically deformed, numerous examples of which are present in Marathon County; (3) they possess a weak to prominent foliation and lineation; (4) they are markedly inequigranular with shattered grains, with some rocks showing recrystallization of the fine matrix; and (5) they commonly have much associated vein quartz.

The cataclastic zones typically consist of a network of braided zones of intense cataclasis several millimeters to many meters wide bordering lens-shaped pods of relatively undeformed rock. Therefore, there is a wide disparity in the degree of cataclasis over short distances along and across the zones. The lensoidal pattern is present on all scales from thin section to map units. The cataclastic zones cross plutonic and volcanic rocks alike, with the result that an extremely wide variety of cataclastic rocks have been produced. A brief description of the major rock types mapped in Marathon County is presented here. In this report we have used our own classification of catacalstic rocks as defined below. Higgins' (1971) classification proved largely unusable in the field for two reasons: (1) it required thin sections to estimate the percentages of porphyroclasts and matrix, and (2) it is completely inadequate for working with deformed volcanic rocks. The discussion of deformed volcanic rocks is based on our observations and has no counterpart in Higgins (1971).

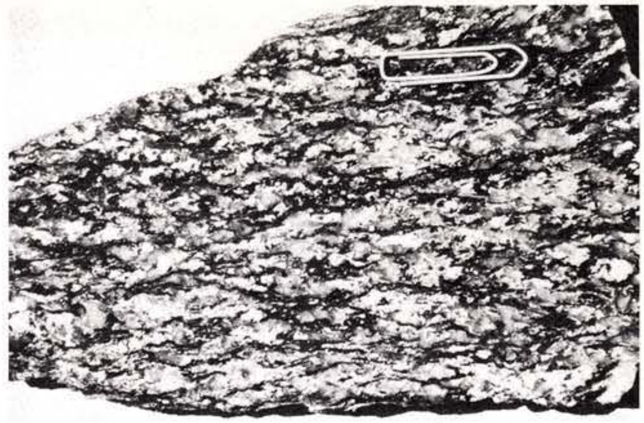

Figure 49.--Photograph of quartz monzonite flaser gneiss from Marathon City showing typical lensoidal structure. Paper clip is 3 cm long.

Figure 50.--Photomicrograph of a typical flaser gneiss showing the fractured porphyroclasts, matrix and lensoidal structure. Specimen is from along the Eau Pleine River east of Abbotsford.

Flaser gneiss is a streaky medium- to coarse-grained rock with foliation produced by the cataclastic degradation of plutonic rocks. It is characterized mesoscopically by a pervasive lensoidal structure produced by intersecting shear planes (fig. 49). Microscopically, the rock is markedly inequigranular with relatively undeformed porphyroclasts of feldspar and quartz in a fine-grained matrix of crushed material. Individual fragments tend to be crushed and boudinaged, with larger fragments typically assuming a lensoidal shape (fig. 50). Biotite, chlorite, epidote, and magnetite formed during cataclasis are concentrated along braided surfaces that intersect at angles of 10 to 30 degrees. This imparts a streaky appearance to the rocks. Lineation due to elongation of mineral grains is common in the plane of foliation. Flaser gneiss grades into undeformed plutonic rocks, and with continued cataclasis into mylonite or phyllonite. The flaser gneisses in this report are roughly comparable to Higgins' (1971) protomylonite; and mylonite as used here is approximately comparable to Higgins' (1971) mylonite.

Mylonite is typically a flinty, laminated rock (figs. 51 and 52) consisting mainly of finely crushed material (fig. 53), which may be compositionally banded. Like flaser gneiss, mylonite is very inequigranular, but has a greater percentage of crushed matrix. Foliation surfaces are closely spaced and typically intersect at less than 10 degrees. Streaky lineation in the direction of tectonic transport is produced by trains of fine-grained minerals in the plane of cataclastic foliation. Detached fold axes and intrafolial folds within mylonites in-

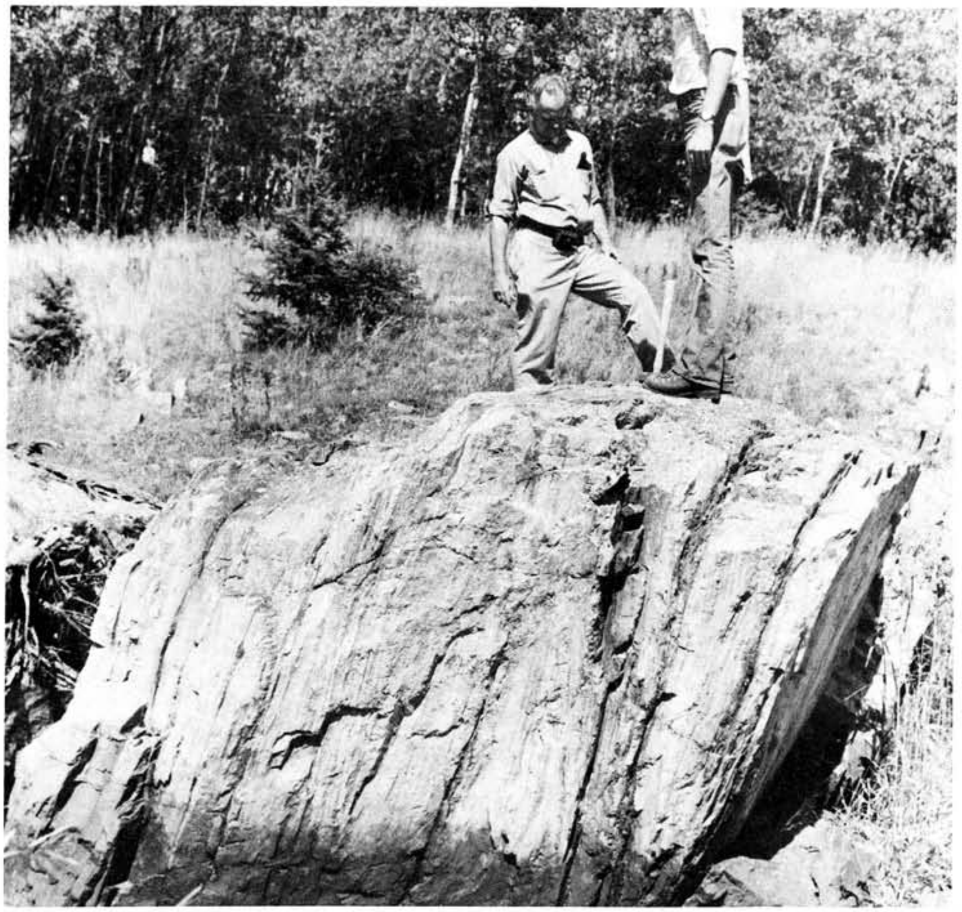

Figure 51.--Photograph showing outcrop of mylonite about 1.6 km southwest of Athens along the boundary between the gneisses and greenschist facies rocks.

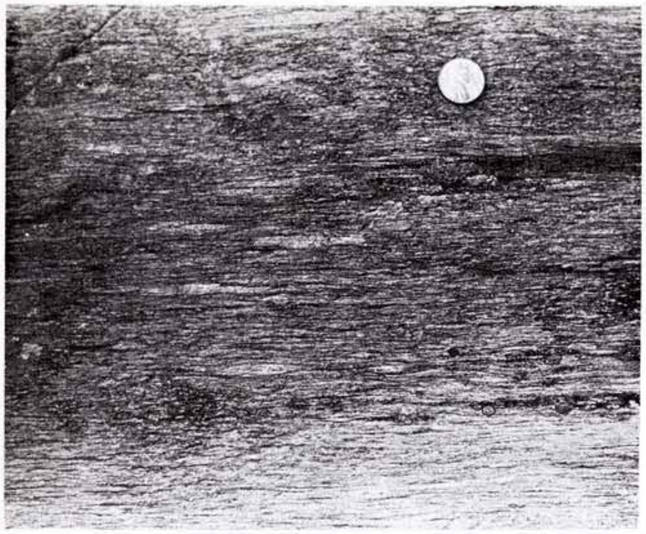

Figure 52.--Photograph of mylonite from Eau Claire Dells showing the typical streaky and lensoidal character of the rock.

Figure 53.--Photomicrograph of a typical mylonite from Marathon County showing the porphyroclasts and abundance of matrix. Specimen is from outcrop about 1.6 km west of Athens.

dicate local folding. Polygonization and increase in grain size of the fine matrix dictates local recrystallization of mylonites. While the parent rock for most flaser gneisses can be determined, the protolith for mylonites is much more difficult to ascertain (fig. 54). Mylonites in Marathon County have

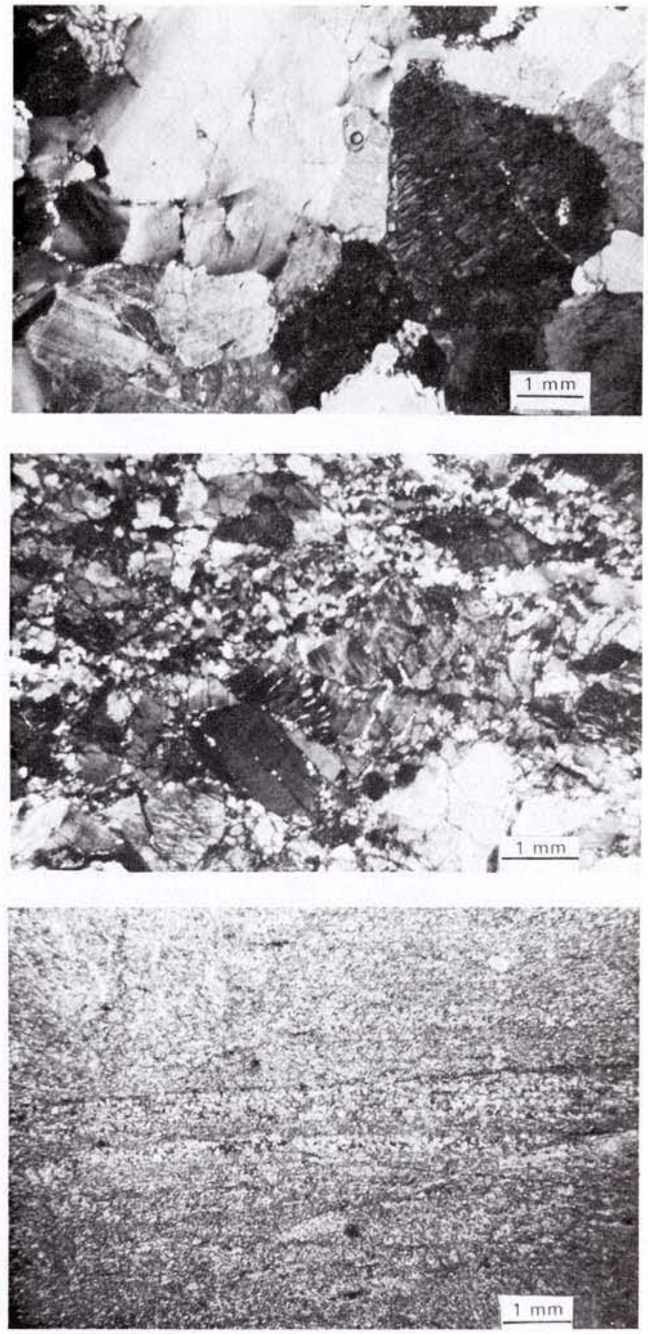

Figure 54.--Photomicrographs showing the progressive cataclastic degradation of the granite from Granite Heights northeast of Wausau. Top photomicrograph is undeformed granite, center is a mylonite, and the lower photomicrograph is an ultramylonite. Protolith for the mylonite can be established where transitional phases are present.

been derived from a wide variety of volcanic and plutonic rocks. Whereas felsic mylonite is commonly a hard, flinty rock owing to its high silica content, mylonite derived from intermediate and mafic rocks tends to be more chloritic and schistose. Felsic and intermediate to mafic mylonites are commonly intercalated on map or outcrop scale.

Volcanic rocks react differently to stress than do plutonic rocks. However, the literature on deformed volcanic rocks is extremely vague and meagre. The presence of a wide variety of volcanic rocks interspersed with cataclastically deformed plutonic rocks in Marathon County provides an excellent opportunity to compare features in deformed volcanic and plutonic rocks. Most of the deformed volcanic rocks are strongly foliated due to the extensive development of layer silicates; felsic volcanic rocks tend to be sericitic whereas intermediate and mafic rocks are chloritic. In some rhyolites, the phenocrysts are rotated into the plane of foliation and boudinaged (fig. 55). Deformation of rhyolitic tuffs results in flattening or elongation of the volcanic fragments or both (fig. 56). In some rhyolites the strain appears to have been taken up by recrystallization and flowage of the matrix, leaving relatively euhedral phenocrysts in a highly foliated sericitic matrix. Evidently the nature of the pre-existing volcanic rock (for example, a tuff _vs._ a lava flow, or a porphyritic _vs._ a non-porphyritic rock) affects the behavior of the rock during deformation. Deformation of fragmental andesites has produced spectacular examples of elongated fragments. In some areas the long dimension is 10 times the cross-sectional diameter of the lineated fragments. Boudinaged hornblende and plagioclase phenocrysts accompany the lineated fragments in several localities, suggesting dislocation rather than simple flattening.

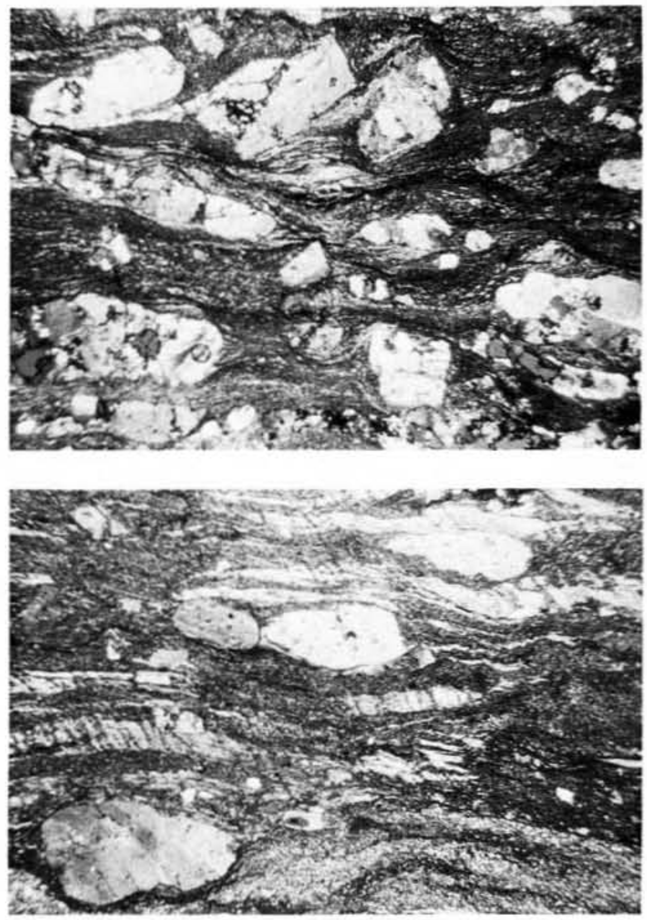

Figure 55.--Photomicrographs of deformed felsic volcanic rock showing a foliated sericitic matrix and boudinaged phenocrysts that have been rotated into the plane of the foliation. Note the crenulation folds in the matrix of the lower photograph.

Strike and dip of numerous cataclastic zones within the volcanic-plutonic terrane are similar to those of the major boundary faults. Cataclastic zones with a consistent trend cut volcanic and plutonic rocks alike. A pervasive cataclastic foliation with a consistent regional trend (east or

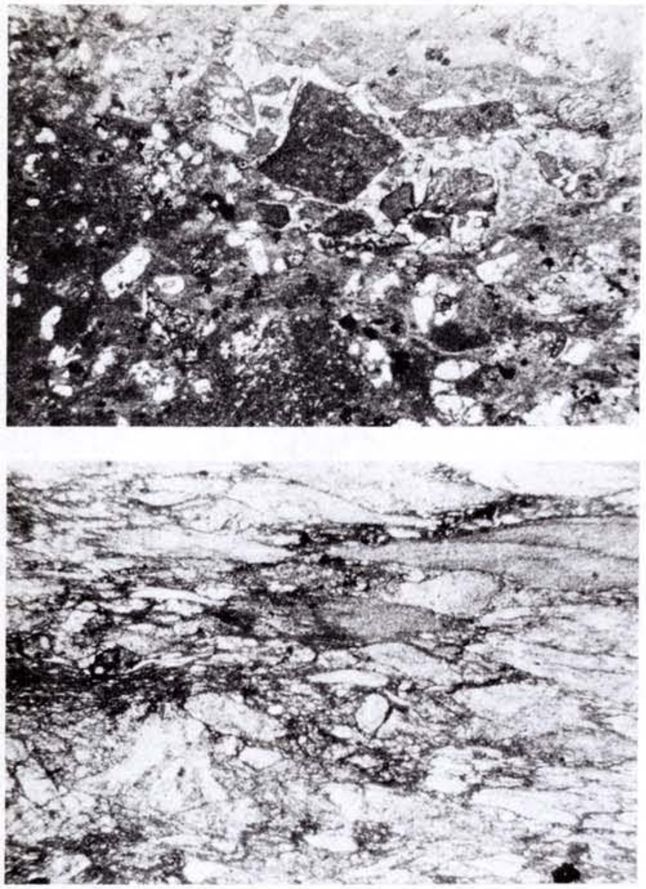

Figure 56.--Photomicrographs of felsic tuff showing the contrast between undeformed and deformed fragments. Upper photo from an undeformed tuff at Brokaw has roughly equant clasts, whereas the clasts are flattened and elongated in a deformed tuff from Highway J south of Big Sandy Park. Lower photograph is from same locality as figure 9.

northeast) is also present in most of the Lower Proterozoic plutons in Marathon County. The absence of pervasive cataclastic foliation in Middle Proterozoic plutons is a major distinction between them and Lower Proterozoic rocks.

Faulting is the dominant structure in and around Marathon County. The Lower Proterozoic greenschist facies volcanic-plutonic complex is bounded on all sides by major zones of cataclastic rocks. On the north, west and south the faults juxtapose greenschist facies rocks with amphibolite-facies gneisses, amphibolites and migmatites. On the east a major fault zone forms the western margin of the Wolf River batholith, which has locally metamorphosed the cataclastically deformed rocks.

For purposes of this report, the major cataclastic zone along the northern edge of the county will be referred to as the Athens fault zone, the cataclastic zone along the southern edge will be referred to as the Eau Pleine fault zone, and the cataclastic zone along the eastern edge of the county will be referred to as the Eau Claire River fault zone.

The Eau Claire River fault zone is a zone of rocks 1 to 5 km wide exhibiting varying degrees of cataclasis and extending from the northeast corner of the county southwest down the Eau Claire and Little Eau Claire River valleys about 61 km to Lake DuBay on the southern edge of the county, where it curves northwesterly and continues up the Eau Pleine River valley about 30 km to near Rozellville, where it curves southwesterly again passing north of Marshfield. A complex area of gneisses, amphibolites, migmatites and local low-grade metamorphic rocks lies south of the segment along the Eau Pleine River. At least five ultramafic bodies occur along this belt of cataclastic rocks. Several granitic plutons intrude the zone east of Wausau and a quartz monzonite pluton intrudes the zone just east of Marshfield.

The Athens fault zone is a similar broad zone of cataclastic rocks that extends in a southwesterly direction along the northern edge of the volcanic-plutonic terrane in Marathon County. It juxtaposes amphibolite-facies rocks on the north with greenschist facies rocks on the south. This fault zone has been traced from near Merrill southwest through Athens to Milan, where it curves in a more southerly direction. Cataclastic foliation in southwestern Marathon County strikes nearly north-south, suggesting that the two major bounding fault zones may merge near the southwest corner of the county; however, the combination of glacial and Paleozoic cover effectively masks the Precambrian in that area. Gneisses, some of them migmatitic, are exposed at Greenwood in Clark County, approximately 22 km west of the low-grade rocks at the western edge of Marathon County. This suggests that the greenschist facies rocks do not extend to the west. Several mafic to ultramafic bodies also occur along this fault zone, and several granitic plutons were intruded into the highly foliated, older rocks along the zone.

These major cataclastic zones coincide with both aeromagnetic and gravity lineaments. Magnetic lows and local highs parallel the structures (Zeitz and others, 1978). The Athens fault zone separates a prominent gravity low (over Marathon County) from significantly higher gravity values over the gneisses, indicating a marked contrast in the density of rocks on opposite sides of the fault. We interpret this to suggest that the structures involve considerable thicknesses of crust.

In addition to the major boundary fault zones, numerous cataclastic zones are present within the volcanic-plutonic terrane. Their trend and dip is parallel to the major boundary faults. These zones range up to several kilometers wide and consist of branching and recombining zones of intensely deformed rocks, including mylonites within a broader zone of less deformed rocks. Cataclastic zones also cut the gneissic rocks at Goodrich Dells on the Rib River in southeastern Taylor County (Elizabeth Palmer, oral communication, 1979) as well as along the major boundary fault zones. Thus a wide variety of rocks in Marathon County have undergone cataclastic deformation, producing a variety of different-appearing rocks.

The major cataclastic zones in Marathon County contain enclaves of rocks of diverse origin. For example, lensoids of amphibolite facies rocks up to a kilometer long are juxtaposed with greenschist facies rocks in the area between Marshfield and Rozellville, at March Rapids, at Athens, and at Eau Claire Dells. In addition, smaller lenses of amphibolite facies rocks are present along some of the cataclastic zones that cut quartz monzonite east of Mosinee. In the Eau Claire Dells area the amphibolite is at the eastern edge of the park and it has locally been contact metamorphosed to pyroxene-hornfels facies within a few meters of the contact with the Wolf River batholith. These enclaves have presumably been tectonically transported upward from an amphibolite facies basement by movement on the cataclastic zones.

Minor Structures

Linear structures of mesoscopic scale are widespread in Precambrian rocks in central Wisconsin, and their pattern is significant regarding the structure of the area. Reconnaissance mapping north, west and south of Marathon County in Lincoln, Taylor, Clark, Wood and Portage Counties and farther west in Chippewa and Eau Claire Counties (Myers, 1974, 1978; Myers and others, 1980) indicates a consistent pattern of minor structures in gneissic rocks in central Wisconsin. Axes of minor folds, mineral lineations and elongation of mafic xenoliths plunge to the west in most of the gneissic rocks. Second generation folds folded about an east-plunging axis are present at a number of places (Myers and others, 1980; Maass and Van Schmus, 1980) suggesting more than one period of deformation in the gneisses. In gneisses in and near Marathon County, fold axes and mineral lineations plunge west at 30° to 60° in the plane of foliation. Lineations in the gneisses steepen to near vertical along the major boundary faults between the gneisses and greenschist facies rocks in Marathon County.

Lineations are also present in the deformed phases of the greenschist facies volcanic-plutonic rocks. Elongated volcanic fragments, boudinaged phenocrysts and axes of minor folds plunge east at 50° or steeper in most of the volcanic pendants. Nearly vertical lineations, including streaking and elongation of minerals and xenoliths, are present in many of the plutonic rocks. Boundinaged quartz veins occur in both plutonic and volcanic rocks, and are especially abundant along larger cataclastic zones. Crenulation folds are present locally, indicating a complex history of deformation. Lineations in the volcanic rocks are nearly vertical in and near the major boundary fault zones. Westerly plunging lineations were not observed in the greenschist facies rocks, and no refolded folds were found. This suggests that only one period of deformation affected the greenschist facies rocks. The minor structures, therefore, suggest that the two terranes have undergone different structural histories.

Age of Deformation

The age of the deformation is difficult to establish from the available data. However, a general pattern of deformation and intrusion was recognized by LaBerge (1976), in which the oldest plutons (quartz diorites) typically are more intensely deformed than the quartz monzonites that intrude them. Granitic plutons are, in turn, generally less cataclastically deformed than quartz monzonites, and in places (fig. 24) truncate cataclastic foliation in quartz monzonites. In eastern Marathon County a cataclastic foliation in 1,900 Ma old (Van Schmus and others, 1975) rhyolite is truncated by the 1,850 Ma old (Van Schmus, 1976) Kalinke quartz monzonite. The western margin of the pluton is not foliated, but the eastern margin is extensively foliated along the Eau Claire River fault zone. Southeast of Wausau granitic plutons cut the cataclastic foliation in a similar foliated quartz monzonite. Similar relationships throughout the county suggest that deformation and accompanying igneous intrusions occurred over an extended period of time. The cataclastic rocks of the Eau Claire River zone were metamorphosed by the 1,500 Ma old Wolf River batholith, however, a 1.5 km wide zone of cataclasis within the batholith along the Little Eau Claire River suggests subsequent deformation of the batholith as well. Since the Eau Claire River zone is parallel to other cataclastic zones as much as 36 km west of the Wolf River batholith, it is unlikely that significant cataclastic deformation accom-

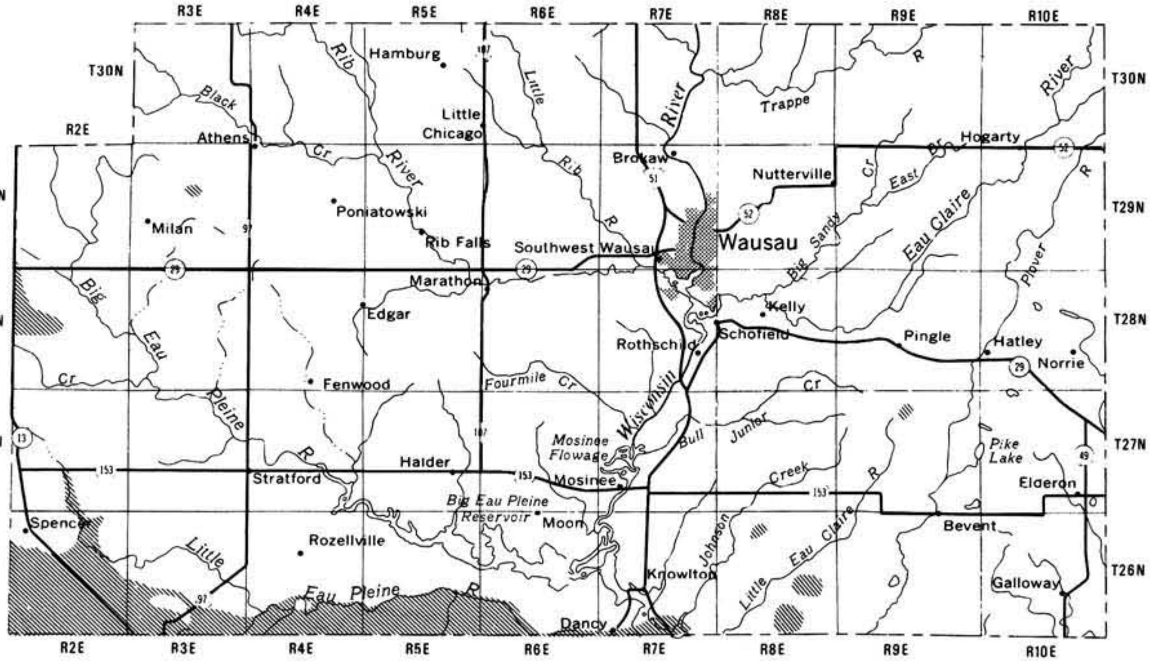

Figure 57.--Generalized map of Marathon County showing the distribution of Paleozoic rocks based on outcrop (this study) and water well records.

panied its emplacement. The chronological relationship of these events and the relative age of the gneisses and greenschist facies rocks is a major part of the geologic history of the area.

PHANEROZOIC

Paleozoic Rocks

Small outliers of sandstone of probable late Cambrian age are present in several areas in Marathon County, and although not exposed, water well records suggest a more continuous blanket of sandstone in the southeastern and southwestern corners of the county. Sandstone outliers crop out in the SW¼ sec. 5, T. 27 N., R. 9 E.; near the center of sec. 35, T. 27 N., R. 8 E.; a large mass in the S½ sec. 23, SW¼ sec. 24, W½ sec. 25, E½ sec. 26, T. 26 N., R. 8 E.; in the SE¼SE¼ sec. 27, E½ sec. 34, W½ sec. 35, T. 26 N., R. 8 E.; and in the SW¼ sec. 33, T. 26 N., R. 2 E. Local abnormally high concentrations of sandstone in the glacial material probably reflect additional outliers, but only those that crop out are plotted on the map. The sandstone is typically flat-lying, medium- to thick-bedded, cross-bedded, and ripple marked, with well cemented medium- to coarse-grained quartz sand and some conglomeratic layers. No fossils or fossil fragments were found. The lithology and unconformable position on the eroded Precambrian surface suggest that it represents the basal Mt. Simon or Galesville in this part of the state. The distribution of the sandstone outliers suggests recent removal of the Paleozoic rocks exposing the Precambrian basement over much of the county. Many of these outliers have been quarried on a small scale for building and flagstone. Figure 57 is a summary representation of the distribution of sandstone as determined from water-well data.

Pleistocene Sediments

Removal of the Paleozoic sediment has exposed the gently rolling Precambrian surface over much of Marathon County (fig. 58). It is probable that most of the major valleys were established during removal of the Paleozoic cover, although these valleys appear to have been significantly deepened and then largely filled with fluvial sediment during the Pleistocene.

Figure 58.--Photograph of gently rolling peneplaned Precambrian surface in western Marathon County. Rib Mountain is scarcely visible on the horizon near the left edge of the photograph.

The Pleistocene geology of Marathon County is particularly important and interesting. It is important because the major source of groundwater is the Pleistocene deposits and because the cobbles present on the abundant rock piles reflect the underlying rock in areas of poor outcrop over much of the county. It is interesting because deposits of at least three glacial advances into the county are recognized (LaBerge, 1971). Because the underlying rock is best reflected in only one of these units, its character and extent will be discussed first.

The oldest till sheet was informally named the Wausau drift for exposures in and around Wausau (LaBerge and Myers, 1972), and it has been formally included in the Wausau Member of the Marathon Formation by Mickelson and others (in press). It is exposed over the central and southern parts of Marathon County (fig. 59). This unit is generally less than 3 m thick, as shown by numerous water wells and exposures in road ditches. It contains rounded cobbles of various types, which are mostly less than 15 cm in diameter but some are larger. In addition, up to as much as 75 percent of the cobbles are angular fragments of the underlying rock. In some older geologic literature (Weidman, 1907; Hole, 1943), the area underlain by this till was described as driftless. However, the ubiquitous occurrence of cobbles, up to 25 cm in diameter, of Keweenawan rhyolite and basalt, coarse hematitic sandstone, and algal jasper from northern Wisconsin and Michigan, suggests glacial transport. These erratic cobbles occur on high ground as well as in valleys, and in general cannot be accounted for by stream transport. Thwaites (1943) recognized the glacial origin for these deposits and mapped the area as older till. Studies of depth of weathering and clay mineralogy led Mickelson and others (1974) to conclude that this is pre-Wisconsinan till. At least three distinctive local rock types form boulder trains that indicate movement of ice in an east southeasterly direction. White (Rib Mountain) quartzite boulders up to at least 1 m across are present east of Rothschild; nepheline syenite boulders in sec. 11, T. 29 N., R. 8 E. are 13 km east of the nearest exposures; and a purplish-brown tuff exposed along the Wisconsin River near Brokaw occurs in

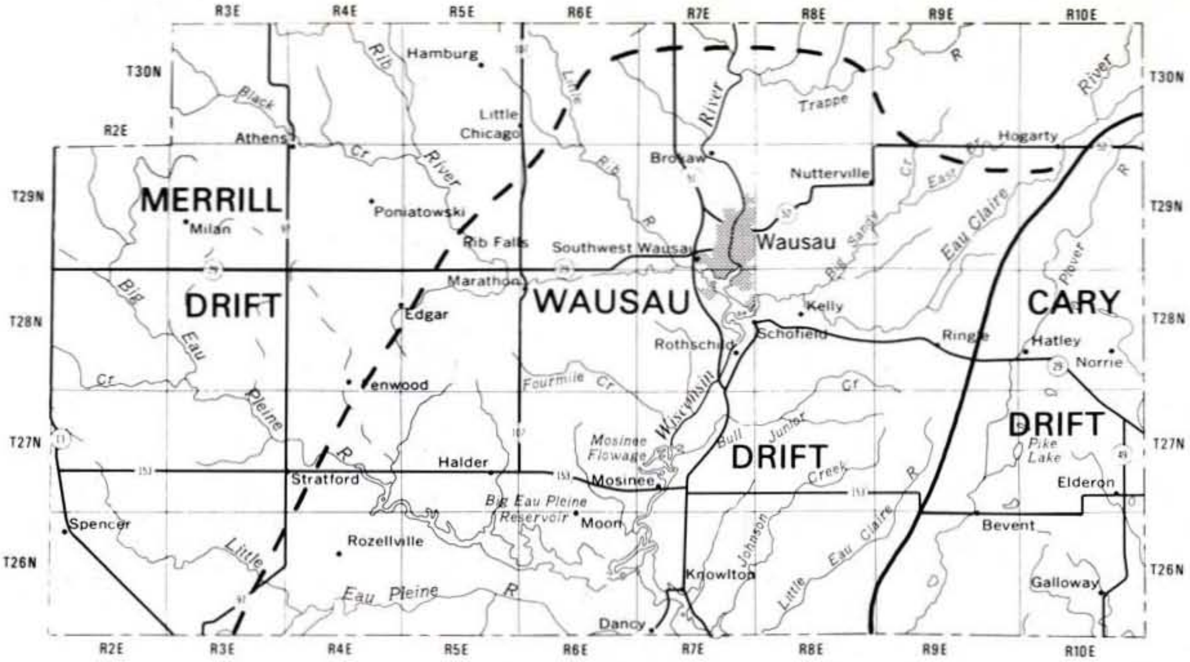

Figure 59.--Map showing the approximate distribution of different till sheets in Marathon County.

rock piles up to 11 km to the east. This inferred direction of ice movement is consistent with that reported by Weidman (1907) from his "first drift" in Portage and Wood Counties.

The second advance of the ice deposited the till of the Lincoln Formation (LaBerge, 1971; Mickelson and others, 1974; Mickelson and others, in press), which overlies the Wausau Member and is present along the northern edge and much of the western part of Marathon County (fig. 59). The southern edge of this till sheet corresponds with the boundary of older till on Weidman's (1907) map. Typically, the stones in the Lincoln Formation are of diverse rock types, generally well rounded and as much as 30 cm in diameter. There is little similarity between the rock types of rock piles and outcrops in the area. The presence of fewer outcrops in areas covered by the Lincoln Formation also indicates a thicker blanket of till. Drilling has established that the Lincoln Formation is at least 60 m thick in northern Marathon County, and till-fabric analysis by Stewart (1975) indicates movement of the ice to the southeast. Bogs developed on the Lincoln till yield pollen and radiocarbon ages of 36,000 to 40,000 years (Mickelson and others, 1974), making it middle Wisconsinan in age or older.

Late Wisconsinan ("Cary" of local usage) ice of the Green Bay Lobe moved into eastern Marathon County from the southeast (Thwaites, 1943). Prominent end moraines are present in this area. This is in marked contrast to the subdued topography of the older till sheets (with the exception of the Marshfield moraine, which appears to be composed of Merrill till). The late Wisconsinan drift has a distinctive boulder content consisting largely of Wolf River granite, Tigerton anorthosite, and numerous finer grained dolomite pebbles and cobbles. Unlike the older till, this till has a sandy ma-

Figure 60.--Photograph of Eau Claire Dells, located about 24 km east of Wausau. The Dells is probably the result of erosion of the Precambrian bedrock by glacial meltwater streams. The rectangular pattern of joints in the mylonite permitted the stream to cut the gorge through the otherwise hard bedrock.

trix and contains abundant large boulders up to at least 3 m in diameter. An outwash apron of gravel and sand occurs west of the terminal moraine. Major meltwater rivers included the Wisconsin, Eau Claire, Rib and Eau Pleine, which scoured their channels down to or into bedrock and later partially refilled them with sediment. Each of these rivers was in steep-walled valleys cut into the generally flat plain of Marathon County. Eau Claire Dells (fig. 60) was formed by glacial meltwater from the east and north cutting across the Precambrian fault zone described earlier.

A large area of fluvial sediment along the Wisconsin River from Mosinee to Wausau and thence up the Eau Claire River to the east and the Rib River to the west is probably outwash. Drilling for highway construction and footings for buildings indicates at least 30 m of sand and gravel locally in the major stream valleys. Fluvial sediment fills the Wisconsin River valley to an elevation of 366 m at Wausau. The surface of the deposit rises gently east and west of the Wisconsin River valley to about 375 m at Callon (13 km east of Wausau) and 378 m at Rib Falls (22 km west of Wausau). Prominences only 1 to 2 meters above the flat fluvial surface are generally Precambrian rock. The rock high at Mosinee appears to have been the southern limit for this fluvial fill. A second, lower fluvial plain is present in the Wisconsin River south of Mosinee and extends eastward up the Little Eau Claire River and westward up the Eau Pleine River valley. This sediment is an excellent source of groundwater in the county and has also been extensively exploited for sand and gravel aggregate.

The Wausau Member is important in that the underlying Precambrian rock is reflected in the lithology of the cobbles in the till. As noted above, the Wausau till is characterized by small, rounded cobbles of various rock types that have been transported up to as much as several hundred kilometers, yet it also contains abundant angular cobbles of indigenous rock that has been transported only a short distance. Furthermore, the thin veneer of till has almost no topographic expression and locally overlies nearly 260 km^2 of very friable rotten granite. Because the rotten granite is nearly undisturbed, it seems reasonable to assume that the ice did little eroding in those areas. The apparent lack of erosion may indicate that this area was near the margin of ice that deposited the Wausau till. In other words, the ice did not move far beyond this area. The thin till and small cobbles further suggest that the ice must have been rather clean. A puzzling part of the load of the Wausau ice is the lack of large boulders.

The mixing of the rounded, transported (glacial) cobbles and angular (indigenous) cobbles probably is not a glacial phenomenon. The mixing could readily be accomplished by two processes, neither of which is related to glacial activity. Frost heaving and uprooting of trees over the tens of thousands of years since the ice melted can and would mix local rock with the glacial cobbles. The mixing would occur only where the till is sufficiently thin that frost action and tree roots reach the underlying rock. Thus, areas where the till contains only rounded glacial cobbles probably indicate thicker till. Except for small areas (usually near outcrops), the Merrill and late Wisconsinan till are evidently too thick for mixing of local rock with the glacial cobbles in quantities sufficient to permit sub-till mapping of other than large lithologic units.

MINERAL RESOURCES

Although the principal focus of this report is the geology of the Precambrian units, incidental observations were made that relate to the mineral resource potential of Marathon County. No attempt was made to prepare a comprehensive mineral resource evaluation, this being left to a future study.

Sulfide Occurrences

According to current theories, volcanic rocks are favorable for a variety of sulfide ore deposits. As such, parts of Marathon County containing abundant metavolcanic rocks are considered to have some degree of metallic mineral potential. As tabulated below, sulfides, including pyrite, chalcopyrite, galena and sphalerite, have been identified, as have gossans. Discussions with farmers and others in the area disclose that there have been numerous attempts at mining a variety of metals in the area. For example, gold mining was attempted about 1920 in sec. 26, T. 29 N., R. 9 E. (see description below), and attempts at gold mining are also reported to have occurred near the northwest end of Rib Mountain. A shaft for iron mining occurs in the peculiar mafic rock near a postulated fault in sec. 7, T. 29 N., R. 8 E. Additional iron mines are reported to occur in sec. 36, T. 30 N., R. 7 E. between Highway W and the Wisconsin River.

Small amounts of galena were found in the dacite behind the Colonial Rest Home in Wausau in the SW cor. SE¼SE¼ sec. 24, T. 29 N., R. 8 E. Minor copper (malachite, chalcopyrite and pyrite) was found in the diorite in the roadcut along Highway N., near the SW cor. sec. 35, T. 29 N., R. 8 E. The rockpile in the woods at 10th and Winton St. in Wausau contains numerous pitted slabs, some of which contain what appears to be erythrite (cobalt bloom) on the surface. No sulfides other than pyrite were observed in hand specimen in the material removed from the basement excavation for St. Marys Hospital (NE¼SW¼ sec. 24, T. 29 N., R. 7 E.). Along the street at 8th and Brown St., (2 blocks west of the above locality) there is considerable disseminated pyrite, as well as veins more than 2 cm wide composed mainly of pyrite. These latter two locations may be related to a significant sulfide concentration.

A large mineralized shear zone passes through the NW¼NE¼ sec. 27, T. 29 N., R. 8 E. Rubble in the ditch and rockpiles in the fields on the farm in this area consist largely of sheared felsic rock, and vein quartz, much of which is iron-oxide stained. No sulfides were seen, but the abundance of iron oxides on some boulders indicate that considerable sulfide was present. Sheared dacite and non-oxide stained veinquartz is abundant in sec. 23, T. 29 N., R. 8 E.

An area of particular interest lies in the Town of Easton where there was an attempt at gold mining about 1920. The location of the shaft, reported to have been at least 30 m deep, is approximately 60 m west and 30 m south of the center post of sec. 26, T. 29 N., R. 9 E. The shaft has been filled in by dumping much of the former tailing and float boulders into the shaft by the farmer who owns the land. The rocks remaining at the surface consist of sheared metavolcanic rocks with relatively abundant quartz veins up to at least 5 cm across. Mineralization consists of pyrite, possibly some millerite, chalcopyrite, and malachite, which occurs as disseminations and lenses within the rock and in and along the quartz veins. Because there are no outcrops, there is no structural information available.

Approximately 30 m south and 10 m east of the center of sec. 26, T. 29 N., R. 9 E. are what seem to be test pits. The material around the pits is limonitic and has various sized blocks of sugary, recrystallized chert. This appears to be a highly oxidized sulfide or perhaps carbonate iron-formation. No magnetic material or jasper was seen, but the quartz does not appear to be vein quartz. How this iron-formation is related to the material described above is not known.

Approximately 1 km to the southeast, in the NE¼NE¼ sec. 35, T. 29 N., R. 9 E., are rock piles composed principally of two lithologies. The dominant rock type (approximately 75%) is a gossan or a boxwork of silica with much iron staining. The rocks are extremely pitted and porous with pockets and cavities several centimeters across and up to 5 cm deep. There appears to have been much sulfide (?) oxidized and leached out of this material. The remaining 25 percent of the boulders consist primarily of metabasalt, some of which contains abundant pyrite. There is no definite outcrop on the farm, but in the cut immediately north of the house near a machine shed there is rubble of highly-sheared, sulfide-rich metabasalt.

In the ditch along the north side of Partridge Road (south edge, sec. 26, T. 29 N., R. 9 E.) is rubble of a rather iron-stained metabasalt. This is also present in the excavation for the basement and septic system for the house just east of the Forestville School.

Another zone of sheared, mineralized granite in sec. 2, T. 28 N., R. 9 E., continues about N. 30° E. through the SE¼ sec. 35, to the NW¼ sec. 36, and the eastern part of sec. 25, T. 29 N., R. 9 E. This wedge of granite merges with the large area of granite lying east of the zone of greenstone.

An especially large quartz vein and some limonite boulders in the SW¼SE¼ sec. 19, T. 27 N., R. 9 E. may merit examination for possible economic mineral associations. Along the south side of sec. 11, T. 26 N., R. 3 E., there is abundant sheared vein quartz, some of which contains considerable pyrite. Many rockpiles in this area contain porous iron-stained siliceous boulders (gossan). No economic minerals were seen in the samples examined.

Relatively small amounts of sulfides, including chalcopyrite were observed at a number of places along the Eau Claire River mylonitic zone, and sulfide-bearing quartz vein material is present on the farm in the SE¼SE¼ sec. 31, T. 30 N., R. 10 E.

Rocks on a farm in the NW¼SW¼SW¼ sec. 9, T. 26 N., R. 7 E. are sheared amphibolitic greenstone with abundant vein quartz, somewhat gneissic quartz diorite--quartz monzonite, mylonite, aplite, and some granite. The area lies along the continuation of the N. 30° E. Eau Claire River shear zone and just west of a part of the Wolf River granite. According to the present land owner, the shaft was dug about the turn of the century as a gold prospect, but he did not know if any gold was recovered. Considerable pyrite and some chalcopyrite and malachite are present in quartz-vein bearing greenstone. No visible gold was observed.

In T. 29 N., R. 8 E. near the junction of Highways J and Z disseminated pyrite and chalcopyrite in much of the volcanics is found interlayered with intermediate and felsic volcanics with chert associated with some of the felsic volcanics. Chalcopyrite may be found in most of the darker zones exposed in the river at Big Sandy Park, and chert associated with sulfide-bearing felsic volcanics occurs in sec. 18, T. 29 N., R. 9 E.

The abundance of sulfide minerals in the northeastern part of Wausau and extending several kilometers to the northeast suggests that this area is particularly favorable for volcanic hosted massive sulfide deposits. For example, pyrite-rich rhyolite is exposed along the east side of the Wisconsin River in Gilbert Park and in the railroad cut to the south. Pyritic rhyolite is also abundant in the material removed for the basement of the Wausau North Hospital. Minor amounts of galena are present in rhyolite from places in northeastern Wausau, and chalcopyrite, sphalerite, and galena occur with pyrite, quartz, and calcite in a brecciated volcanic rock from an old exploration shaft near the center of sec. 7, T. 29 N., R. 7 E. This area appears to be the most promising locality for base metal exploration in the county.

Possible hydrothermal sulfide mineralization is present along the south side of sec. 11, T. 26 N., R. 3 E., where highly siliceous pyritic rocks are exposed for about 0.8 kilometers. Many rockpiles in this area contain porous iron-stained siliceous boulders. The occurrence is along a broad zone of sheared granites, volcanic rocks and, perhaps, sedimentary rocks. No economic minerals were observed, but clearly this area, as well as others, should be examined for possible base metal or precious metal content.

Molybdenite has been reported by M.G. Mudrey, Jr. from the roadcut in the parking lot of the Super 29 grocery store in Wausau (NE¼SE¼ sec. 27, T. 29 N., R. 7 E.). Mudrey reports that the molybdenite occurs in a thin vein in unit 1sy of the syenitic rocks.

Zircon and Rare Earths Occurrences

Although quantities of commercial significance of zircon have not been found, attempts were made to exploit the loose material from the Stettin pluton in the NW¼ sec. 22, T. 29 N., R. 6 E. in the 1920s. A small amount of zircon-bearing rock was mined from shallow open pits for benefication studies during the 1940s. In 1946, the U.S. Bureau of Mines conducted geophysical studies and did sampling by diamond drilling, trenching and soil sample. Some of the surficial material contained 25 percent zircon, but no zircon-bearing rocks of comparable grade were found in the sampling. No estimate of potential resources of zirconium and hafnium in the Wausau area can be made from the limited data. A petrographic discussion of these rocks may be found on p. 36 of manuscript.

Industrial Rocks and Minerals

Construction materials are produced from Precambrian and Phanerozoic rocks.

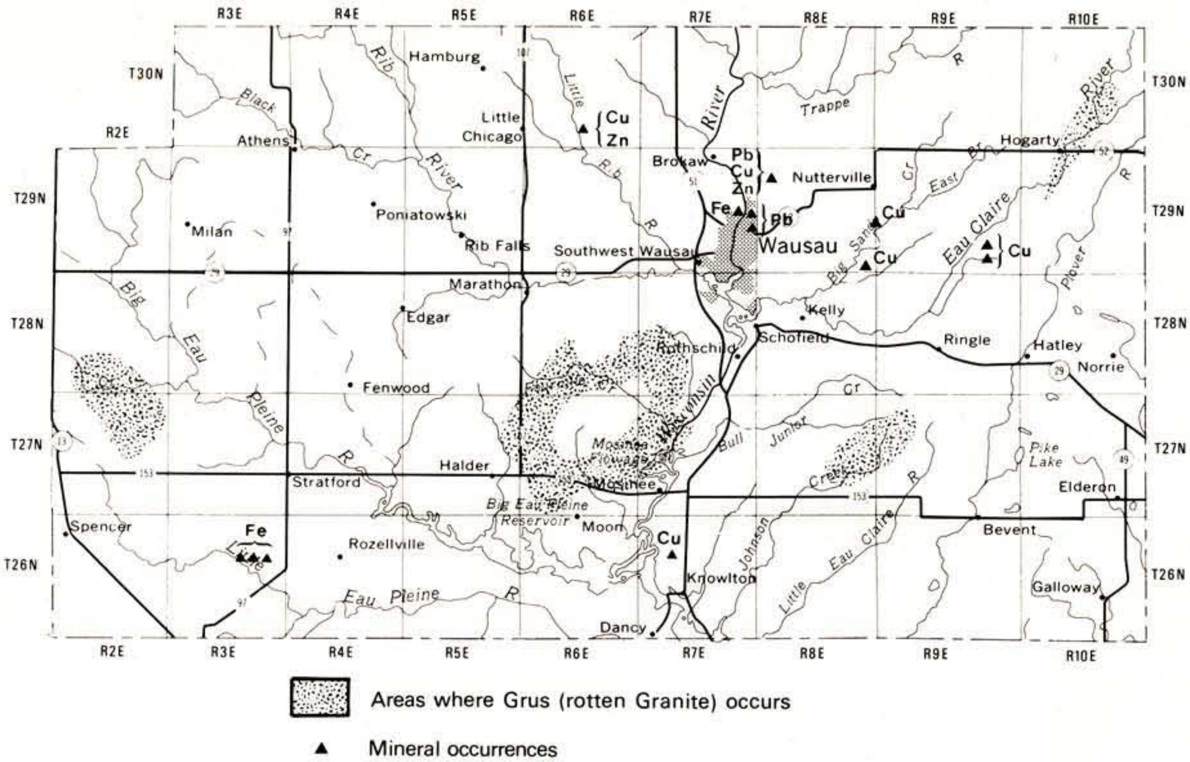

Figure 61.--Map showing areas of grus (shaded) and metallic mineral localities discussed in text.

Red granite from quarries north and northeast of Wausau has been a popular stone for buildings since the 19th century (Buckley, 1898). Although deformation has locally reduced the amount of granite amenable to quarrying, reserves are large. Similar red granite west of Edgar and Fenwood, and pink granite five miles north of Marshfield may be suitable for future use as dimension stone.

The grus (disintegrated or "rotten granite", as it is known locally) is extensively used throughout the county for road material. The widespread distribution of that material provides nearby sources in most areas. Several granite bodies in Marathon County contain extensive areas of partially disintegrated granite. Quartz and feldspar grains are largely disaggregated so that the material can be removed with power shovels without blasting or crushing. Although some of the deposits are at least 30 m thick, most are much thinner. Because of the decreasing availability of sand and gravel, these deposits constitute a major future source of aggregate. Areas with potential for grus occurrence are shown on figure 61.

The origin of the grus is not known, however, a number of observations made in the course of this survey may provide some clues. One group of observations concerns the rock fracturing patterns and grain characteristics. Figure 62 suggests that development of grus is controlled by joints intersecting in the granites. Some grus pits are located along shear zones, suggesting that fractures produced by shearing may have influenced the disintegration of the granite. The most extensively

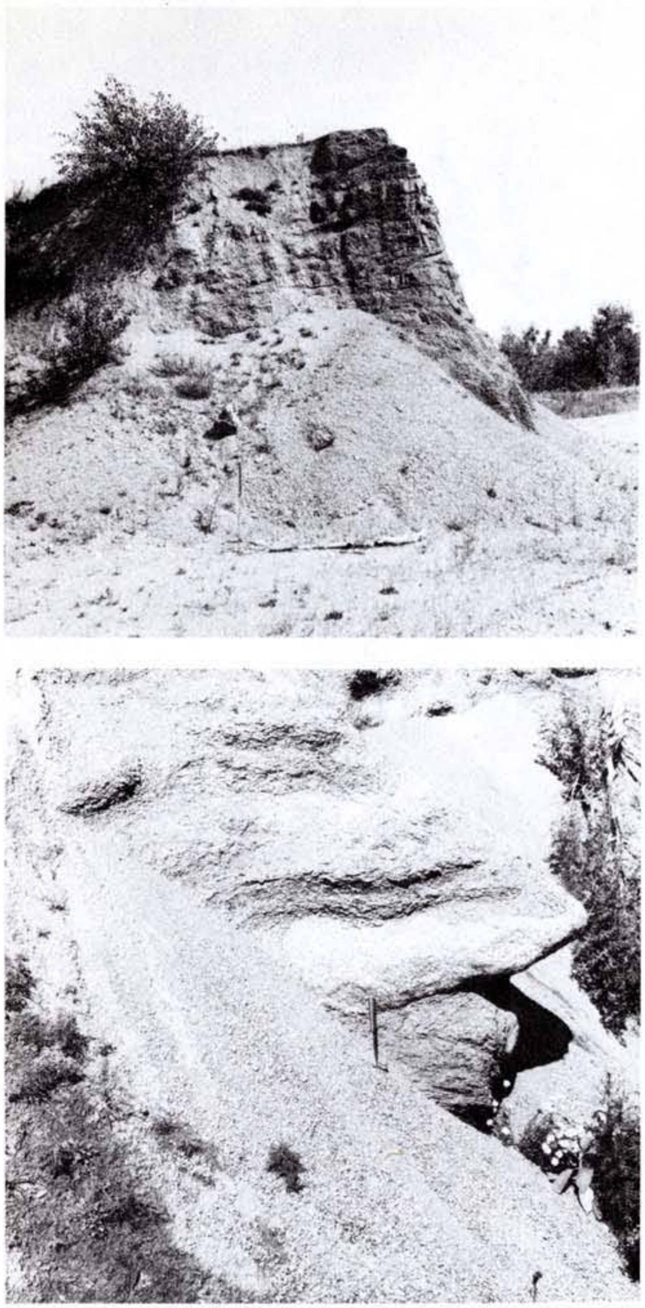

Figure 62.--(A) Grus quarry with near vertical and horizontal joints that control disintegration. (B) Spheroidal boulder in grus pit showing the exfoliation associated with the development of the grus.

developed grus occurs in the coarse-grained granites such as the Ninemile pluton south of Rib Mountain, the Wolf River granite near Hogarty, and the Cherokee granite east of Unity. Because the finer grained granites do not exhibit extensive grus development, it appears that grain size is a factor in disintegration. The propensity for grus to develop in mafic-rich granites suggests that alteration of the original hornblende or biotite or both may have resulted in a volume increase which forced the grains apart.

Some observations suggest that solutions may have contributed to grus development. Most grus pits are located within about 1.5 km of the edges of granite bodies. Perhaps solutions from the crystallizing magma might have altered the rocks near the margin, preparing them for the later conversion to grus. The lack of interlocking grains in the granites may also be a contributing factor, because only minor solution along grain boundaries would result in a disaggregation of the rock. Anderson (1975) reports that the Wolf River batholith has an abnormally high content of fluorite, which is also common in the syenite bodies (and presumably also in the Ninemile granite). Weathering of the fluorite may produce hydrofluoric acid which would dissolve (or etch) the grain boundaries and promote disaggregation of the granite.

Several outliers of Paleozoic sandstone have been quarried for dimension stone. The sandstone is attractively colored and splits readily along the bedding, yielding good quality stone, some of which is cut into blocks for building use. Three small outliers of sandstone were mapped. One in the SW¼ sec. 5, T. 27 N., R. 9 E., another near the center of sec. 35, T. 27 N., R. 8 E., and the third in the SW¼NE¼ sec. 1, T. 24 N., R. 7 E. These are nearly flat-lying, thin-bedded, well-cemented, ripple-marked, predominantly medium-grained sandstones with some coarser grained beds.

The 3M Company operates a large quarry in the rhyolite north of Wausau. The rhyolite is crushed and screened, and a selected size fraction is dyed and used to make granules for roofing shingles. The massive, fine-grained nature of the rhyolite is evidently ideal for this use.

Glacial deposits provide sand and gravel and are largely limited to the Wisconsin, Rib and Eau Claire River Valleys. The deposits are more than 30 m thick locally, but since they were deposited on a very uneven bedrock surface, their thickness varies greatly over short distances. The sand and gravel deposits are the major aquifer in the Wausau area, and this may be their most important use.

SUMMARIES

Geologic History

Gneissic rocks in northwestern and extreme southern Marathon County are probably the oldest rocks mapped although radiometric dates have not been published. They may be, at least in part, Archean (older than 2,500 Ma) or earlier early Proterozoic rocks that underwent deeper burial and at least one earlier deformation than the low-grade volcanic and plutonic rocks that underlie most of the county.

The high-grade metamorphic rocks of the Athens area apparently extend west at least into Chippewa and Eau Claire Counties where strongly deformed and metamorphosed volcanic rocks and calc-alkaline plutons were eroded and overlain by siliceous volcanogenic sediments. The younger rocks were subsequently folded and metamorphosed to greenschist facies. Blocks of the younger low-grade metavolcanic and metasedimentary rocks were then faulted down into the older sequence. The gneisses, therefore, were probably the basement on which the volcanic-sedimentary sequence in Marathon County was deposited.

The gneissic rocks are believed to be unconformably overlain by the early Proterozoic basalt to rhyolite sequence of dominantly subaqueous volcanic rocks and locally interbedded sediments. Abundant welded tuffs and flow banded rhyolites near Wausau and Athens suggest that these areas, at least, were above water, probably forming on islands in an early Proterozoic sea. These volcanic rocks may correlate with similar rocks farther north in Wisconsin, but may have been deposited in a separate basin. Felsic volcanic rocks, interpreted as fairly high in the volcanic pile, have been dated at 1,860 Ma by Van Schmus and others (1975). The volcanic rocks were folded into a large synclinal structure and plutons ranging in composition from quartz diorite to quartz monzonite intruded the volcanic pile. Cataclastic deformation occurred more or less continuously throughout this plutonic episode. The younger granites show less cataclastic deformation and were evidently emplaced after most of the deformation. The gneissic rocks north and south of Marathon County represent relatively uplifted blocks during Early Proterozoic time while the main part of the county was being relatively down-dropped in a graben-like basin. This occurred during the Penokean orogeny 1,850 Ma ago (Van Schmus, 1976).

A thermal event of unknown nature that reset the Rb/Sr ages to 1,630 Ma (Van Schmus, 1976) throughout Wisconsin produced no visible alteration of the volcanic and granitic rocks. The emplacement of the Wolf River batholith and syenite plutons near Wausau about 1,500 Ma ago was the major event in the Middle Proterozoic in central Wisconsin. Syenite intrusion was followed by emplacement of the Ninemile pluton and by quartz monzonite prophyry plugs. Unmetamorphosed diabase dikes of presumed Keweenawan age represent the youngest Precambrian rocks in Marathon County. No record of rock-forming events exists for the last 500 million years of Precambrian time. Presumably the area was undergoing erosion during most, or all, of this time reducing the area to a nearly flat surface with erosional remnants, such as Rib Mountain and Mosinee Hill standing above the nearly flat plane.

The late Cambrian seas advanced over this eroded deeply weathered surface, winnowing the quartz from the weathered granite and rhyolite, along with weathered quartzite, to produce a blanket of quartz sandstone and other sediments. Scattered remnants of Upper Cambrian sandstone indicate the continuity of the blanket. The area has evidently been exposed to erosion since mid- to late-Paleozoic time and an unknown thickness of Paleozoic sediments was deposited and subsequently eroded.

Pleistocene glaciers entered Marathon County at least three times. The earliest recognized advance was from the west and deposited the Wausau drift which is evidently of pre-Wisconsin age (Mickelson and others, 1974). The second glaciation was from the northwest and deposited that Merrill drift which overlies the Wausau drift and contains bogs that yield Wisconsinan (Woodfordian) pollen and radiocarbon dates of 36,000 to 40,000 years (Mickelson and others, 1974). The final glaciation advanced into eastern Marathon County moving west-northwest. This drift is 18,000 to 20,000 years old (late Woodfordian age).

Granitic Rocks

The Lower Proterozoic granitic rocks in Marathon County are believed to be related to a single igneous event. All are intruded into what may reasonably be interpreted as a single, but complex, volcanic-sedimentary sequence. The various plutons show similar, widespread cataclastic foliation, and many have gradational composition from quartz diorite to granite. The granitic rocks are believed to be high-level intrusions into the volcanic pile for the following reasons: 1) the volcanic rocks have undergone only greenschist facies metamorphism; 2) the plutons are markedly crosscutting with extensive development of intrusion breccias; 3) contact metamorphism is restricted to narrow zones; 4) pronounced zoning in plagioclase indicates rapidly changing crystallization conditions; and 5) textural variations in granitic rocks and the general lack of pegmatites. The plutonic rocks are probably upper mesozonal or epizonal. Cross-cutting relationships, where present, show an intrusion sequence from diorite to granite, suggesting differentiation of a single parent magma. The various granitic rocks may thus be co-extensive at depth as a large composite batholith as suggested by gravity and magnetic data. If this interpretation is correct, the various stock-like plutons may be cupolas on this large batholith.

Metamorphic Features

Although most or all of the Lower Proterozoic rocks in Marathon County have undergone at least greenschist facies regional metamorphism, there are significant local differences in type and abundance of metamorphic features. For example, the gneisses, amphibolites, quartzites and migmatites are mainly medium- to coarse-grained rocks with typical metamorphic (lepidoblastic or granoblastic) textures and amphibolite-facies minerals. They commonly are foliated or lineated or both, with compositional banding and little or no preservation of primary textures to indicate their protolith. These features suggest synkinematic recrystallization at amphibolite grade.

In contrast, the metavolcanic rocks contain abundant well preserved primary textures and structures. Large areas of mafic and intermediate metavolanic rocks consist of greenschist facies minerals that preserve the primary (igneous) textures and structures. The igneous minerals have simply been pseudomorphed by the metamorphic mineral assemblage. They are largely weakly-foliated rocks. In cataclastic zones, these rocks have well developed metamorphic textures, are compositionally banded, foliated, locally lineated, and retain few recognizable primary features. Thus, the development of typical metamorphic textures is related to zones of deformation.

The felsic metavolcanic rocks show excellent preservation of primary igneous textures in many areas, particularly in and around Wausau. They are dominantly non-foliated. These rocks consist primarily of quartz and feldspar, and thus do not indicate the grade of metamorphism to which they have been subjected. Along fault zones the felsic volcanic rocks are converted to sericite schists with deformed volcanic fragments and varying degrees of cataclastic deformation of the phenocrysts. In the fault zones these rocks have a more characteristic metamorphic fabric.

Plutonic rocks also contain zones of deformation (cataclasis) as described above. Within these cataclastic zones the plutonic rocks are foliated and commonly lineated, and may have alternating coarse- and fine-grained layers with granoblastic texture, whereas away from the zones of deformation the rocks contain typical igneous textures and mineralogy. The matrix in many of the foliated rocks has been recrystallized to a granoblastic mosaic with up to 1 mm crystals.

In summary, the greenschist facies metamorphism in the county produced typical metamorphic textures only along fault zones where the rocks were deformed. In most other areas the metamorphism is expressed only in mafic and intermediate metavolcanics where greenschist facies minerals pseudomorph the primary minerals.

Structural Summary

The general sequence of structural events in the county is believed to be as follows: (1) folding of the volcanic sequence and emplacement of some of the quartz diorites and quartz monzonites; (2) faulting which repeated the volcanic sequence and produced a cataclastic foliation in the older plutonic rocks; and (3) continued intrusion of granitic plutons which engulfed much of the volcanic pile accompanied by recur-

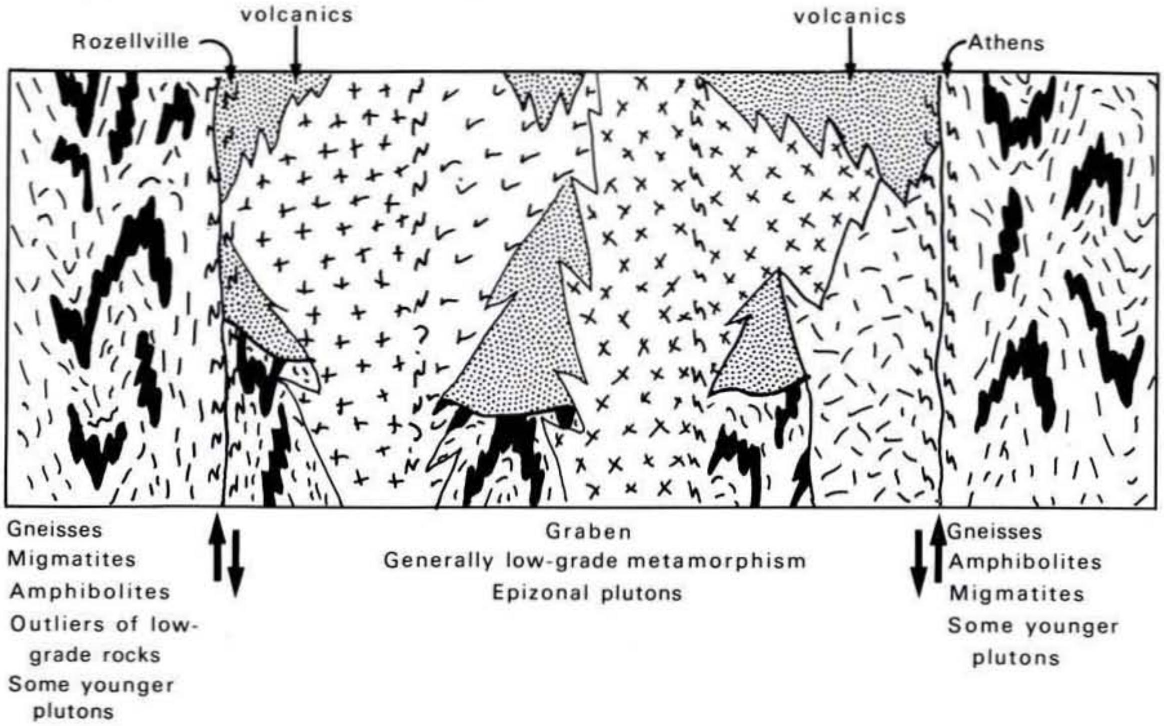

Figure 63.--Idealized north-south cross section across western Marathon County showing the postulated graben structure.

rent faulting along major zones of weakness which produced cataclastic foliation in the younger plutons. The faulting appears to be related indicated by the intrusion of granitic rocks into the major boundary faults, truncating broad zones of cataclasis, and subsequent cataclasis of parts of these plutons.

The major structure in Marathon County is a large "block" of greenschist facies volcanic and plutonic rocks in fault contact with amphibolite facies rocks. The juxtaposition of rocks of contrasting metamorphic grade along large-scale fault zones with contrasting structural styles and the presence of vertical lineations along the faults suggests that the greenschist facies rocks occupy a graben-like structure bounded by uplifted blocks of gneisses as shown in figure 63. The greenschist facies rocks within the graben have been folded, faulted and extensively intruded, producing a complex pattern of rock types.

Tectonic Interpretation

The distribution of rock types and field relations in Marathon County and elsewhere in central Wisconsin suggests a complex geologic history that is different from that reported for lower Proterozoic rocks elsewhere in the Lake Superior region. Recognition and understanding of the geological events in central Wisconsin is therefore important to synthesizing the geological history of a larger portion of the Lake Superior region. Specifically the geology in Marathon County suggests the existence of an orogenic event not previously reported in the Lake Superior region.

As described above, field relations

in and around Marathon County suggest the existence of two fundamental terranes: an amphibolite-facies terrane composed of gneisses, amphibolites and local migmatites; and a greenschist-facies terrane composed of volcanic and plutonic rocks with well preserved primary features. Rocks of intermediate metamorphic grades are rare. Thus the rocks exhibit a bimodal distribution of metamorphic facies. Structurally the gneissic rocks contain west-plunging lineations and locally refolded folds while lineations in the greenschist facies rocks plunge easterly with no refolded folds having been recognized. The amphibolite facies rocks therefore appear to have undergone at least two periods of deformation whereas only one deformation is recognized in the greenschist facies rocks.

Elsewhere in west central Wisconsin, Myers (1974, 1978, 1980) has reported isolated areas of greenschist-facies volcanic and volcaniclastic rocks surrounded by and unconformably overlying amphibolite-facies rocks in western Clark County and in Eau Claire County. These greenschist-facies rocks are folded about northeast-plunging fold axes. Therefore, the pattern recognized in Marathon County appears to be present over a large part of the State.

Isolated blocks of amphibolite-facies gneisses and amphibolites are present along some of the major fault zones in Marathon County: for example, at March Rapids (sec. 4, T. 27 N., R. 3 E.); east of Marshfield (sec. 31, T. 26 N., R. 4 E.); and several smaller blocks east of Mosinee (secs. 9, 17, 18, 19 and 20, T. 27 N., R. 8 E.). This suggests the presence of an amphibolite-facies basement on which the volcanic rocks were deposited. Blocks of this basement were evidently tectonically carried upward along some of the fault zones.

Xenoliths in some intrusions also have a bearing on the possible age of the gneissic rocks. Biotite schist and quartzite, mixed in various proportions with volcanic and mafic and ultramafic intrusive rocks, occur as xenoliths in the Wausau Syenite and less abundantly in other plutons. Quartzite inclusions are restricted to the 1,500 Ma (Van Schmus, 1976) Wausau syenite pluton. A quartzite xenolith in quartz syenite 3.2 km northwest of Wausau (SE¼SW¼ sec. 21, T. 29 N., R. 7 E.) contains up to 12 percent sillimanite. The sillimanite-rock layers are strongly foliated. Xenoliths of volcanic and plutonic rocks in the same intrusion are virtually unmetamorphosed, suggesting that the sillimanite was produced by an earlier metamorphic event, and not by contact metamorphism by the syenite. This suggests an upward transport of the quartzite from a high-grade metamorphic terrane at depth, perhaps the basement on which the volcanic rocks were deposited. The absence of quartzite xenoliths in older (1,850 Ma old) plutons suggests either a very restricted occurrence of the quartzite in the basement or that the quartzite is younger than the 1,850 Ma old plutons and was intruded only by the syenite. In the latter case, quartzite would represent foundered blocks from above and the sillimanite would necessarily be the result of contact metamorphism by the syenite. However, it seems unlikely that quartzite (with a specific gravity of 2.7) would sink in a magma that carried ultramafic xenoliths (with a specific gravity of about 3.4) upward. Therefore, we favor the interpretation that the sillimanite-bearing quartzite was carried upward from a high-grade metamorphic basement although we recognize that an alternative interpretation is possible. Since thick quartzites are uncommon in Archean sequences, the quartzite is more likely lower Proterozoic.

An especially significant exposure from the standpoint of the tectonic history of central Wisconsin is the conglomerate exposed along Hamann Creek (NW¼SE¼ sec. 35, T. 28 N., R. 3 E.). The conglomerate contains abundant boulders of quartzite and meta-volcanic rocks with subordinate amounts of jaspilitic iron-formation and granite. The conglomerate has been deformed along with the enclosing felsic to intermediate volcanic rocks, and thus appears to be the same age as the enclosing volcanics. The presence of quartzite boulders in the conglomerate requires the existence of a source area containing quartzite. Quartzites are common and widespread in Proterozoic sequences in the Lake Superior region, but are rare and of small extent in Archean terranes. Thus the presence of quartzite boulders in the conglomerate suggests the existence of an older Proterozoic succession that had undergone metamorphism, and was then uplifted and eroded during the deposition of the volcanic succession. This suggests two periods of Proterozoic metamorphism and deformation in central Wisconsin.

Quartzite and granite boulders are present in a deformed conglomerate near the west edge of Marathon City, and are also present in conglomeratic (laharic?) rhyolites interstratified with welded rhyolitic tuffs along the west side of the Wisconsin River between Brokaw and Wausau. The conglomerates are discontinuous and may be valley-fill (lahar?) deposits periodically covered by ash-flow deposits. The quartzite boulders must either have been carried laterally by streams or vertically from below by the volcanic eruptions, and therefore must be older than the volcanic rocks. This conglomerate-tuff sequence is cut by a prominent east-west fault exposed north of Brokaw (SW¼ sec. 34, T. 30 N., R. 7 E.). This, again, requires the existence of a quartzite sequence older than the volcanic sequence.

Thus, several lines of evidence point to an older sequence of amphibolite-facies rocks; erosion of this sequence; and then deposition of the volcanic-plutonic sequence and deformation and metamorphism of this younger sequence to greenschist facies.

Available radiometric ages in the area, however, are not consistent with the above interpretation. According to Van Schmus (1980) the gneisses and amphibolites in central Wisconsin are mainly 1,840 Ma old, or slightly younger than the 1,860 Ma old (Van Schmus, 1976) greenschist-facies volcanic-plutonic complex in Marathon County. Although Archean gneisses are recognized at Pittsville (in Wood County) (Van Schmus and Anderson, 1977) and Neillsville (Maass and Van Schmus, 1980), Maass and Van Schmus (1980) have interpreted the 1,840 Ma radiometric ages to suggest that the amphibolite-facies rocks represent the high-grade equivalents of the greenschist-facies rocks, in effect, a deeper level of the volcanic pile. They recognize only one early Proterozoic orogenic event in central Wisconsin which they correlate with the Penokean Orogeny. We believe that the dates are inconsistent with the structural and stratigraphic evidence, and that there are two orogenic events represented in the rocks in Marathon County. The stratigraphic evidence (quartzite boulders, and sillimanite-bearing quartzite xenoliths) suggest that both orogenic events are early Proterozoic. Archean rocks outside the immediate Marathon County area probably also record Archean orogenic events. The reason for the discrepancy between radiometric ages and field data is not known; however, we suggest that the widespread cataclasis associated with the block faulting may have effected and reset the isotopic systems, and therefore may have changed the apparent ages of the rocks.

It may be possible to correlate the two early Proterozoic events with events elsewhere in the Lake Superior region. It has long been recognized that a mild flexuring and erosion occurred during the deposition of the early Proterozoic sedimentary rocks exposed on the various iron ranges of the Lake Superior region (Van Hise and Leith, 1911). For example, the sequence of rocks containing the Kona, Randville and Bad River Dolomites (the Chocolay Group of the Marquette Range Supergroup of Cannon and Gair, 1970) underwent gentle flexuring and erosion prior to deposition of the less-deformed rocks of the Menominee and Baraga Group is generally referred to as the Penokean Orogeny. Deformation and metamorphism attributed to the Penokean Orogeny is generally greenschist facies except for nodes of higher grade metamorphism (James, 1955) around gneiss domes in northern Michigan, Wisconsin and Minnesota (Sims and Peterman, 1976). Deformation attributed to the Penokean Orogeny increases in intensity southward in the Lake Superior region (Morey and Sims, 1976). If, indeed, two early Proterozoic orogenies are represented in the region, the gneisses and amphibolites in central Wisconsin may be a manifestation of the post-Chocolay -- pre-Menominee deformation farther north. Whereas the pre-Menominee erosion appears to have cut down to amphibolite-facies rocks in central Wisconsin, it was much less pronounced on the iron ranges farther north. This metamorphic and tectonic event must have pre-dated the Penokean Orogeny by a substantial but unknown amount of time. The greenschist facies metamorphism, block faulting, and plutonic activity in the volcanic rocks in central Wisconsin would presumably represent the Penokean Orogeny in this part of the Lake Superior region.

The Middle Proterozoic Wolf River batholith and related syenite intrusions modified the earlier geology in Marathon County. However, the Early Proterozoic fault zones appear to have provided the boundaries for these younger intrusions. For example, the western edge of the Wolf River batholith parallels the major Eau Claire River fault zone, and subsequent movement on this zone has cataclastically deformed rocks of the Wolf River batholith along the Little Eau Claire River. The syenite bodies are elongate northeast, parallel with major fault zones in that area; and the Stettin pluton is bounded by two fault zones. Thus, the location and orientation of earlier structures controlled the orientation and location of later features in the county.

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APPENDIX 1.--DESCRIPTIONS OF ANALYZED SAMPLES

Metavolcanic Rocks

1. GN-3, basalt, from road cut in sec. 7, T. 29 N., R. 8 E. Anal. by PSU.

2. Sec. 33, andesite, from rock pile, N½SE¼ sec. 33, T. 29 N., R. 8 E. Anal. by PSU.

3. RRT-1, trachyte, from railroad cut southeast of Brokaw, sec. 2, T. 29 N., R. 7 E. Anal. by PSU.

4. SSW-12-2, sheared volcanic, unit fv, in SE¼NE¼ sec. 5, T. 27, N., R. 3 E. Anal. by K. Aoki.

5. WE-27-1, rhyolite tuff, from center of NW¼ Sec. 19, T. 29 N., R. 8 E. Anal. by PSU.

6. WE-56-2, andesite, from excavation along Michigan-Wisconsin Gas Pipeline in NE¼ sec. 5, T. 28 N., R. 8 E. Anal. by PSU.

7. 3M-68, rhyolite, from 3 M Quarry in sec. 11, T. 29 N., R. 7 E. Anal. by PSU.

8. 3975, rhyolite, from ledge above Wausau High School. Anal. by W.W. Daniells in Weidman (1907, p. 103).

9. WE-22-13, rhyolite, from house excavation in SE¼NW¼SW¼ sec. 20, T. 29 N., R. 8 E. Anal. by PSU.

10. 52T-1, rhyolite, from road cut, Highway 52 in W½SE¼SE¼ sec. 19, T. 29 N., R. 8 E. Anal. by PSU.

Quartz Diorites

11. HSW-16-6, unit qd, large xenolith in leucoratic granite in S½SE¼ sec. 19., T. 27 N., R. 9 E. Anal. by K. Aoki.

12. BSD-1, unit qd, from bridge on Colonial Drive over Big Sandy River in sec. 36, T. 29 N., R. 8 E. Anal. by PSU.

13. HSW-22-2, unit qd, from NE¼SW¼ sec. 31, T. 27 N., R. 9 E. Anal. by K. Aoki.

14. 4268, unit di, from Big Rib River at Marathon City. Anal. by W.W. Daniells in Weidman (1907, p. 160).

Quartz Monzonites

15. HSW-8-3, unit kqm, in S½SE¼ sec. 4, T. 29 N., R. 9 E. Anal. by K. Aoki.

16. WSW-1-1, unit qm, from southwest of overpass in NE¼NE¼NW¼ sec. 33, T. 26, N., R. 7 E. Anal. by K. Aoki.

17. WSE-6-1, unit qm, in SE¼NE¼ sec. 16, T. 27 N., R. 8 E. Anal. by K. Aoki.

18. WSW-2-1, unit qm, in SE¼NW¼ sec. 23, T. 27 N. R. 7 E. Anal. by K. Aoki.

19. SSW-7-12, unit qm, in NW¼NW¼ sec. 36, T. 28 N., R. 2 E. Anal. by K. Aoki.

20. CGR, unit cgr, from road cut on Highway N, NE¼NE¼ sec. 23, T. 28 N., R. 2 E. Anal. by K. Aoki.

21. GRAP, unit grap, from ditch on west side of road in NE¼NE¼ sec. 14, T. 28 N., R. 5 E. Anal. by K. Aoki.

Granites

22. HSW-3-12, unit lg, in SW¼SW¼ sec 31, T. 28 N., R. 9 E. Anal. by K. Aoki.

23. RG-1, unit ghg, from Cold Springs Granite Quarry in sec. 36, T. 30 N., R. 8 E. Anal. by PSU.

24. 5422, unit ghg, from Cohn's Quarry, Granite Heights. Anal. by W.W. Daniells in Weidman (1907, p. 180-181).

25. SNE-36-1, unit wgr, in NW¼SE¼ sec. 8, T. 28 N., R. 4 E. Anal. by K. Aoki.

26. LRG, unit lrg, in NW¼NE¼ sec. 8, T. 26 N., R. 3 E. Anal. by K. Aoki.

27. WE-57-1, unit gr, from King Farm in SW¼NW¼ sec. 35, T. 29 N., R. 8 E. Anal. by PSU.

28. EPGC, unit epg coarse phase, from south side of Eau Pleine Reservoir along Highway O in SE¼NE¼ sec. 21, T. 26 N., R. 6 E. Anal. by K. Aoki.

29. EPGF, unit epg fine phase, from north side of Eau Pleine Reservoir along Highway O in NE¼NW¼ sec. 10, T. 26 N., R. 6 E. Anal. by K. Aoki.

Miscellaneous Rocks

30. MF-40-2, mafic volcanic, chloride-actinolite schist, from west edge of SW¼NW¼ sec. 21, T. 26 N., R. 4 E. Anal. by K. Aoki.

31. MF-39-3 ultramafic rock, probably derived from a dunite, from road cut on east side of Highway M in NW¼NW¼SW¼ sec. 22, T. 26 N. R. 4 E. Anal. by K. Aoki.

32. ATH-8-6, metagabbro, in NE¼NE¼SE¼ sec. 27, T. 30 N., R. 4 E. Anal. by K. Aoki.

33. 75.69 hornblende diorite, in NE¼NW¼ sec. 15, T. 28 N., R. 5 E. Anal. by K. Aoki.

34. HSW-21-1, leucogranite unit lg, in W½SE¼ sec. 30, T. 27 N., R. 9 E. Anal. by K. Aoki.

35. Ma(SE)-20A, border phase of a granitic pluton, in SW¼SE¼ sec. 24, T. 27 N., R. 5 E. Anal. by K. Aoki.

36. WSE-6-1, unit qm, from gruss quarry near center of sec. 16, T. 27 N., R. 8 E. Anal. by K. Aoki.

Wolf River and Syenitic Rocks

37 through 40, from outcrops near Employers Mutual Insurance Company in NW¼SE¼ sec. 27, T. 29 N., R. 7 E. Anal. by TSL.

37. EW-5, brownish gray syenite.

38. EW-5, coarse, dark gray syenite.

39. NSI, pink syenite with volcanic xenoliths.

40. SEI, medium-grained syenite.

41 through 49, sequence of rocks from the stettin pluton. Anal. by K. Ramlal in Sood and others (1980, p. 29) and table 3.

41. 10, amphibole syenite from intermediate zone.

42. 70, do.

43. 503, do.

44. 108, do.

45. 6 + 504, pyroxene syenite from core zone.

46. 65, tabular syenite from wall zone.

47. 46, nepheline syenite from wall zone.

48. 2, do.

49. 92, do.

50. NMG, unit nmg, typical coarse grained granite of Ninemile swamp in NW¼NW¼NE¼ sec. 19, T. 28 N., R. 7 E. Anal. by K. Aoki.

51. HHG-2 Wolf River granite (Hogarty-Hornblende Granite), in SW¼NW¼SW¼ sec. 33, T. 30 N., R. 10 E. Anal. by K. Aoki.

APPENDIX 2.--CHEMICAL ANALYSES

Methods of Analysis

Samples identified by PSU were analysed at Pennsylvania State University by a combination of instrumental methods. The analysts were N.H. Suhr, Raver, Bodkin and Devine. S.S. Goldich of Northern Illinois University analyzed these samples for FeO, H_2O^+, H_2O^- and CO_2 by a combination of titrimetric and gravimetric methods.

Samples identified by K. Aoki were analyzed at Tohoku University by a combination of conventional and atomic absorption methods. The analyst was Ken-ichiro Aoki.

Samples identified by K. Ramlal were analyzed at University of Manitoba by a combination of conventional, atomic absorption and x-ray fluorescence methods. The analyst was Kenneth Ramlal.

Samples 37 through 40 were analyzed by Technical Services Laboratories (TSL) using Inductively Coupled Argon Plasma (ICAP) spectrographic methods.

	Metavolcanic Rocks									
	1	2	3	4	5	6	7	8	9	10
SiO_2	53.3	57.3	54.3	71.91	61.0	63.1	68.2	72.68	74.5	71.0
TiO_2	1.00	0.66	0.88	0.44	0.60	0.83	0.49		0.17	0.23
Al_2O_3	13.7	12.7	17.7	11.86	19.7	17.0	14.8	16.40	12.9	14.0
Fe_2O_3	0.52	2.36	1.27	1.01	3.23	1.85	2.17	0.99	0.64	1.33
FeO	12.85	7.10	5.29	3.88	1.51	4.11	2.74	1.53	3.48	4.25
MnO	0.18	0.17	0.12	0.05	0.07	0.05	0.05		0.04	0.02
MgO	7.32	6.95	2.03	1.50	1.42	1.01	0.57	0.48	0.31	0.30
CaO	4.65	7.05	5.70	1.28	0.82	2.12	1.62	1.56	0.39	0.70
Na_2O	3.04	1.95	4.74	3.37	0.46	4.71	4.06	3.85	3.32	3.92
K_2O	1.24	1.91	1.80	2.74	7.41	3.14	3.64	2.10	4.15	3.88
P_2O_5	0.13	0.23	0.43	0.17	0.20	0.23	0.06		0.06	0.09
H_2O^+	2.67	1.54	2.20	1.63	2.35	1.07	0.87	0.37	0.52	0.70
H_2O^-	0.18	0.12	0.11	0.10	0.14	0.09	0.07		0.09	
CO_2	0.14	0.03	3.89		0.06	0.06	1.12		0.05	
Cl										
S										
Total	100.92	100.07	100.46	99.94	98.97	99.37	100.46	99.96	100.62	100.42
Trace elements (parts per million)										
Rb										
Sr	85	340	680		n.d.	340	250		85	170
Ba	540	1070	900		1700	1790	1700		1520	1430
Zr										
unit										

	Quartz Diorites				Quartz Monzonites						
	11	12	13	14	15	16	17	18	19	20	21
SiO_2	49.60	60.8	65.48	47.68	70.06	70.43	71.57	72.62	74.38	73.74	75.17
TiO_2	1.18	0.78	0.62		0.38	0.28	0.31	0.25	0.18	0.17	0.16
Al_2O_3	18.03	14.5	16.26	21.78	13.96	14.19	13.97	12.75	12.31	13.12	13.45
Fe_2O_3	2.41	1.31	2.07	2.96	1.27	0.65	0.65	1.96	1.45	0.95	0.22
FeO	7.11	6.65	2.13	3.95	2.35	2.41	2.17	2.60	1.04	1.50	0.70
MnO	0.17	0.16	0.13		0.04	0.05	0.08	0.05	0.02	0.02	0.01
MgO	5.42	5.01	1.04	6.82	0.72	0.86	1.04	0.57	0.05	0.14	0.38
CaO	8.90	2.56	1.84	13.30	1.20	1.88	1.64	1.01	0.15	0.82	0.39
Na_2O	3.73	2.62	3.96	1.56	3.87	3.85	3.60	5.73	3.00	3.81	5.69
K_2O	1.48	3.70	4.62	0.21	4.66	4.51	3.70	0.94	6.50	5.30	2.63
P_2O_5	0.30	0.33	0.25		0.16	0.14	0.18	0.07	0.06	0.02	0.04
H_2O^+	1.77	0.90	1.11	1.00	1.63	0.88	0.86	0.98	0.80	0.51	0.63
H_2O^-	0.06	0.06	0.15		0.04	0.05	0.11	0.00	0.16	0.05	0.03
CO_2		.01	1.25								
Cl											
S											
Total	100.16	99.39	100.91	99.26	100.34	100.18	99.88	99.53	100.10	100.15	99.50
Trace elements (parts per million)											
Rb											
Sr		250									
Ba		1340									
Zr											
unit	qd	qd	qd		kqm	qm	qm	qm	qm	cgr	grap

	Granites								Miscellaneous Rocks						
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
SiO_2	73.19	75.7	76.54	72.51	75.04	70.7	73.20	73.76	39.40	39.74	50.28	54.19	70.33	72.09	72.32
TiO_2	0.03	0.07		0.20	0.16	0.28	0.13	0.03	1.53	0.07	0.65	0.33	0.21	0.18	0.09
Al_2O_3	13.91	12.2	13.82	13.20	12.48	14.0	13.73	14.05	10.29	1.54	14.06	14.47	14.90	13.44	14.53
Fe_2O_3	0.41	1.12	1.62	2.45	0.86	1.67	0.54	0.20	8.48	6.12	1.60	2.03	1.82	1.56	0.76
FeO	0.52	1.87		0.94	1.07	2.28	1.95	1.03	5.13	1.11	10.13	4.63	0.82	2.32	0.66
MnO	0.01	0.02		0.01	0.00	0.08	0.04	0.05	0.18	0.08	0.21	0.05	0.01	0.01	0.02
MgO	0.06	0.03	0.01	0.16	0.15	0.57	0.04	0.04	21.23	38.00	6.84	9.01	0.10	0.08	0.12
CaO	0.39	0.40	0.85	0.96	0.16	1.65	0.08	0.10	5.97	0.07	10.90	9.61	0.75	0.44	0.72
Na_2O	2.40	3.70	4.32	4.55	2.82	3.12	4.66	4.76	0.48	0.06	2.44	2.11	3.87	3.38	3.76
K_2O	8.10	4.61	2.31	4.25	5.92	4.10	5.20	4.62	0.00	0.00	0.32	0.72	6.39	5.05	6.30
P_2O_5	0.04	0.04		0.05	0.07	0.11	0.03	0.03	0.10	0.06	0.08	0.12	0.09	0.08	0.05
H_2O^+	0.45	0.22	0.20	0.88	0.75	0.82	0.57	0.68	6.95	12.74	2.71	2.50	0.45	1.33	0.63
H_2O^-	0.00			0.15	0.08	0.21	0.12	0.16	0.28	0.68	0.00	0.04	0.05	0.14	0.06
CO_2						0.05									
Cl															
S															
Total	99.51	99.98	99.67	100.31	99.56	99.69	100.29	99.51	100.02	100.27	100.22	99.81	99.79	100.10	100.02
Trace elements (parts per million)															
Rb															
Sr		42				250									
Ba		1075				1340									
Zr															
Unit	lg	ghg	ghg	wgr	lrg	gr	epg	epg							

	Wolf River and Syenitic Rocks														
	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51
SiO_2	63.05	63.55	63.90	64.10	66.10	65.20	64.70	61.95	59.75	61.50	57.45	56.95	54.10	70.36	67.99
TiO_2	0.78	0.54	0.47	0.48	0.72	0.42	0.27	0.32	0.75	0.31	0.59	0.38	1.32	0.20	0.41
Al_2O_3	12.60	15.16	14.14	15.17	13.24	15.59	15.86	16.04	16.23	16.62	16.93	21.02	16.32	14.22	14.01
Fe_2O_3	1.91	1.25	5.42	4.58	2.61	2.36	2.45	3.13	2.55	5.20	2.58	2.93	3.41	0.47	0.91
FeO	7.72	3.48	1.32	1.44	4.12	2.22	2.10	2.70	5.66	1.68	5.98	2.12	7.08	1.95	3.18
MnO	0.34	0.16	0.14	0.12	0.23	0.12	0.15	0.18	0.26	0.22	0.30	0.07	0.29	0.01	0.05
MgO	0.41	0.16	0.45	0.09	0.43	0.01	0.02	0.08	0.14	0.24	0.21	0.07	1.22	0.11	0.66
CaO	2.66	1.72	1.35	1.50	0.70	0.50	0.95	1.10	2.15	1.43	2.64	0.51	4.03	1.06	1.61
Na_2O	4.80	5.52	6.32	5.17	5.92	6.92	7.07	6.51	5.97	6.49	6.71	7.81	5.81	4.04	3.03
K_2O	4.22	5.67	6.34	5.57	4.31	5.11	5.19	5.51	5.67	5.15	5.02	5.99	4.84	6.13	6.43
P_2O_5	0.22	0.06	0.05	0.06	0.11	0.04	0.06	0.07	0.13	0.07	0.13	0.50	0.49	0.05	0.17
H_2O^+	0.76	0.42	0.56	0.26	0.73	0.83	0.70	1.95	0.51	0.63	0.98	1.43	0.77	0.97	0.99
H_2O^-														0.10	0.06
CO_2	0.28	1.92	0.62	0.09	0.38	0.35	0.36	0.40	0.22	0.17	0.18	0.40	0.09		
Cl					0.013	0.024	0.010	0.010	0.010	0.345	0.02	0.025	0.02		
S					0.004	0.003	0.008	0.008	0.008	0.009	0.023	0.000	0.044		
Total	99.75	99.61	101.08	98.63	99.61	99.45	99.89	99.95	100.00	99.98	99.73	100.20	99.81	99.67	99.56
Trace elements (parts per million)															
Rb	154	118	80	80		199		152	66	133	115		102		
Sr	78	83	67	42		44		105	174	109	57		345		
Ba	840	590	215	320		640		1340	1430	920	770		820		
Zr	1640	840	460	530	755	1400	1925	1160	810	740	1410	7	1540		
Unit															

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Cover photo: Eau Claire Dells, Marathon County, Wisconsin

Courtesy of the Wausau Area Chamber of Commerce

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