

STRATIGRAPHY AND STRUCTURE OF THE
MCCASLIN DISTRICT, WISCONSIN

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
Joseph John Mancuso
1960



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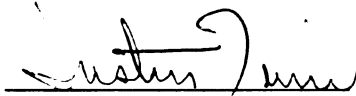
STRATIGRAPHY AND STRUCTURE
OF THE McCASLIN DISTRICT,
WISCONSIN

presented by

JOSEPH JOHN MANCUSO

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of the requirements for

PhD degree in GEOLOGY


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By
JOSEPH JOHN MANCUSO

AN ABSTRACT

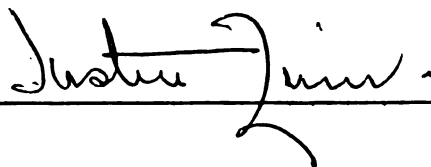
Submitted to the School for Advanced Graduate Studies
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the requirements for the degree of

DOCTOR OF PHILOSOPHY

Department of Geology

1960

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Joseph John Mancuso

ABSTRACT

A combined field and laboratory study was carried on to determine the stratigraphy and structure of the McCaslin district of northeastern Wisconsin. The district lies along the parallel $45^{\circ} 21'$ north latitude and between the meridians $88^{\circ} 11'$ and $88^{\circ} 48'$ west longitude.

The dominant structure in the district is the McCaslin syncline which trends approximately east-west. The trough opens to the west and appears to close to the east but is disrupted by the intrusive High Falls granite.

The oldest rocks in the district are the Waupee series which is distributed about the outer borders of the trough. The series is a complex of metamorphosed volcanic flows, agglomerates and tuffs with large included bodies of granite and diorite.

The McCaslin formation lies unconformably upon the Waupee series. It is composed of a basal conglomerate which grades upward into clean quartzite. The formation reaches a maximum thickness of close to 5000 feet. The McCaslin formation furnishes the structural framework for the regional syncline.

The Hager rhyolite porphyry lies unconformably upon the McCaslin formation. It flowed out onto a terrain of fairly high relief and is confined mainly to the synclinal trough.

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The youngest rocks in the district are the intrusive High Falls and Belongia granite masses. The High Falls granite was seen in direct contact with the McCaslin formation in six different localities and shows definite intrusive relationships. A well developed metamorphic aureole related to the High Falls granite can be traced by progressive metamorphic changes in the Hager, McCaslin and Waupee formations. The metamorphic mineral assemblages indicate a maximum temperature of 700 degrees centigrade for the granite intrusion and a maximum depth of 15 feet for penetration of granite fluids into the quartite.

A petrofabric and a joint study were made to supplement the structural data obtained in the field. Both agree with the major structure and indicate that the direction of maximum stress release was nearly horizontal and parallel to the strike of the bedding.

The exact stratigraphic position of the Precambrian formations of the district can be determined only approximately and conjecturally because of their isolation and complete separation from the main Precambrian regions to the north. The Waupee series is considered Lower Precambrian and a possible correlative of the Quinnesec formation of Iron and Dickinson Counties, Michigan. The McCaslin formation is considered to be Middle Precambrian or Huronian, but its exact position in the Huronian system is not clear.

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The extrusion of the Hager rhyolite porphyry and the intrusion of the High Falls and Belongia granites along with the regional deformation are thought to be part of a great post-Huronian--pre-Keweenawan orogeny (Killarney revolution?) which occurred about 1000 to 1100 million years ago.

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Figure 1. View of McCaslin Mountain

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INTRODUCTION

Northeast Wisconsin contains large areas of relatively unexplored Precambrian rock sequences. One of these areas, the McCaslin district of Marinette, Langlade, Oconto and Forest Counties is described here. This research was undertaken because there is reason to believe that deposits of valuable minerals may exist in this part of Wisconsin; concentrations of pyrrhotite are found near Mountain, and concentrations of molybdenum are located near Middle Inlet. No deposits of minable size have been found to date, but the local concentrations constitute evidence that economic bodies of valuable minerals may occur in the vicinity. A detailed field and laboratory study of the exposed rock formations is considered the logical approach to the detection of economic mineral deposits.

After having spent three field seasons studying the Precambrian formations of northern Wisconsin, the author and an assistant completed the field work during the summer of 1959. This field season was devoted to mapping the outcrops and to a study of the geologic structure and stratigraphy of the McCaslin region. During the academic year 1959-1960, laboratory investigations were made at Michigan State University to supplement the field data.

Acknowledgments

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To Samual Alguire the writer is deeply indebted for capable assistance in the field. Appreciation is due to Dr. Justin Zinn, Dr. James Trow, Dr. William Hinze, Dr. B. T. Sandefur and Dr. H. B. Stonehouse for their constructive criticism and interested guidance.

The writer would also like to acknowledge the use of facilities and the helpful assistance of the United States Forestry station at Lakewood, Wisconsin.

Previous Investigations

The quartzite of the McCaslin range is briefly mentioned in the Wisconsin Geological Survey publication Geology of Wisconsin, 1873-1879, but a detailed geological exploration was not undertaken by the geological survey at that time.

In 1943, F. V. Hoffman compiled a geological map of McCaslin Mountain from aerial photographs. General outcrop locations and rock descriptions were based on field work by O. M. Wheelwright. Hoffman concluded that the northern and southern ridges of the eastern range were the limbs of a local syncline.

Roberts, 1951, concluded that the High Falls granite is the result of granitization of an impure quartzite. He maintained that structural activity was a major factor in the granitization process.

In 1957, the author mapped the rock exposures in the vicinity of Mountain, Wisconsin, and concluded that the rock sequence exposed was the southern limb of a large regional syncline. The author also conducted a general reconnaissance of the geology of northeast Wisconsin.

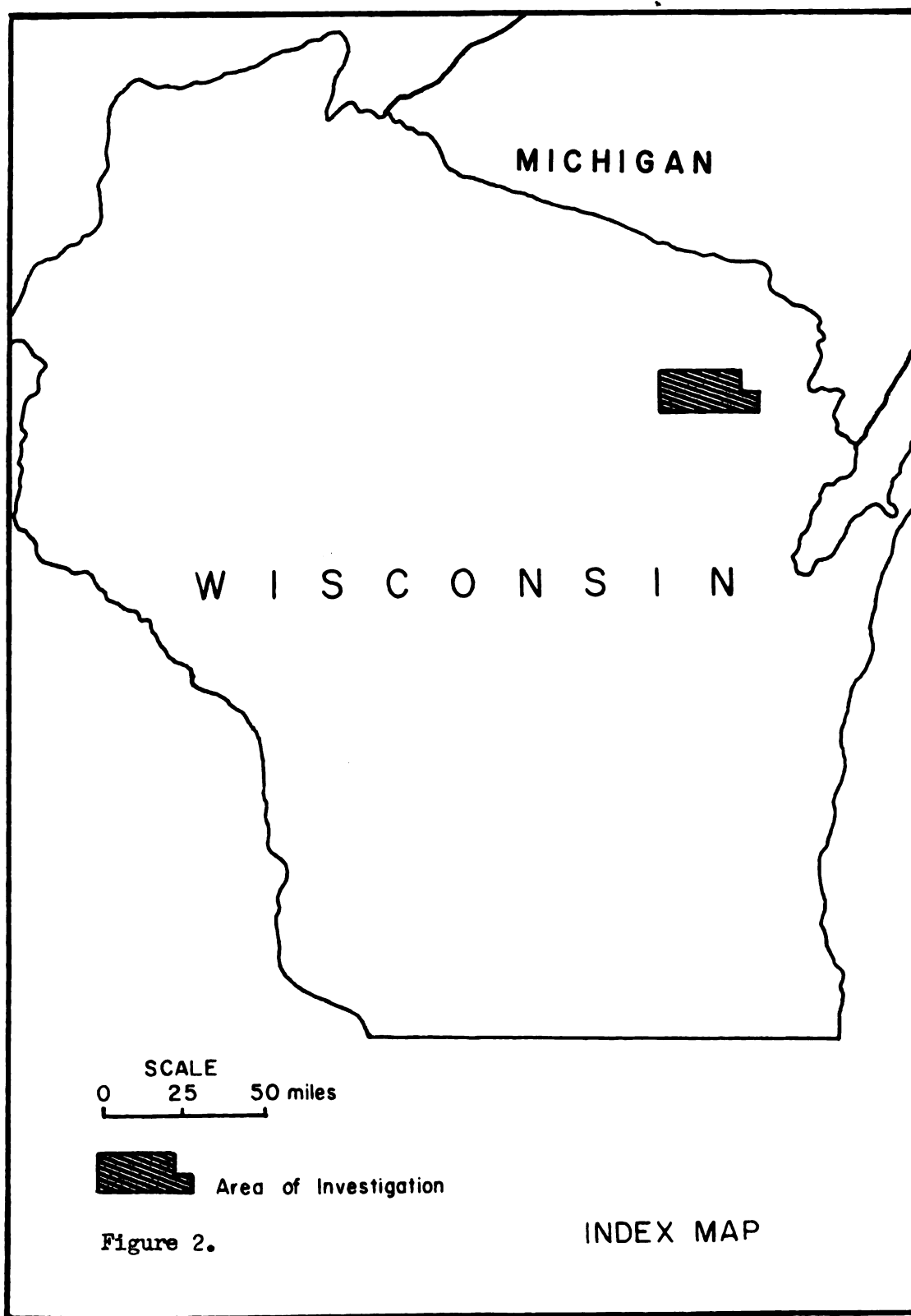
In addition, general geological and geophysical surveys have been made in the McCaslin region by a number of mining companies, but their findings are not available.

Geography and Topography

The McCaslin district lies in northeast Wisconsin along the parallel $45^{\circ} 21'$ north latitude and between the meridians $88^{\circ} 11'$ and $88^{\circ} 48'$ west longitude south of the Menominee River and northwest of Green Bay (Figure 2).

The district, as described in this report, occupies parts of Marinette, Langlade, Forest and Oconto Counties and contains topographic features such as McCaslin Mountain, Deer Lookout Tower Hill and Thunder Mountain which are underlain by massive quartzite and conglomerate. The district covers an area of approximately 375 square miles.

McCaslin Mountain is the main topographic feature of the area forming a ridge of moderate relief rising up to 300 feet above the surrounding countryside and trending N. 60° - 90° E. It ranges from two to five miles in width and extends laterally for a distance of



approximately 25 miles in Tps. 33 and 34 N., Rs. 14, 15, 16, 17 and 18 E. The highest altitude on the ridges is slightly in excess of 1500 feet at the McCaslin lookout tower in the SE 1/4 sec. 25, T. 34 N., R. 16 E.

Deer Lookout Tower Hill which occupies most of sec. 2, T. 34 N., R. 16 E. is an isolated circular knob that rises 200 feet above its surroundings.

Thunder Mountain is a ridge trending slightly west of north and rising 300 feet above the adjacent countryside in secs. 30 and 31, T. 33 N., R. 18 E. and secs. 25 and 36, T. 33 N., R. 17 E.

The entire region has been glaciated and the topography has been modified by abrasion and deposition of glacial material. Pre-glacial drainage has been disrupted by the drift, so that swampy ground and lakes are common in the region. Principal streams, such as the Peshtigo, North and East Branches of the Oconto, Knowles, Otter and McCaslin rivers, all emptying into Green Bay, occupy channels that are a combination of pre- and post-glacial drainage. The thickness of the glacial drift is not uniform, and over large areas the ice has removed the mantle and exposed scoured and polished bedrock. Large portions of the area where quartzite lies at or near the surface are covered with hardwood forests. Farming, lumbering and tourists provide the principal occupations in the region. The principal town is Wabeno with a population of 800. Lakewood, Carter and Townsend are smaller

unincorporated communities in the district. The Chicago and Northwestern Railway is the only railroad crossing the region. State highways 32 and 64 are the main thoroughfares servicing the district.

Regional Geology

The stratigraphy of the Precambrian of northeast Wisconsin is still a matter of dispute because of the extensive cover of glacial drift, the lack of distinctive rock units and the lack of concentrated geologic study. In general, as shown on the geologic map of Wisconsin, revised by E. F. Bean, 1949, the regional stratigraphy is as follows: Upper Cambrian sandstones and dolomites lap over undifferentiated Huronian and Laurentian rocks (chiefly granites, gneisses, gabbros, porphyries, metasediments and metavolcanics). Scattered outliers of Keweenawan igneous rocks (basic lava flows, gabbros, diabases and acid extrusives) and Upper, Middle and Lower Huronian (quartzites, slates and iron formations) occur in the undifferentiated Huronian and Laurentian of northern Wisconsin.

GEOLOGY OF THE McCASLIN DISTRICT

Waupee Volcanics and Granite Complex

A sequence of rocks outcropping near Mountain, Wisconsin and designated as the Waupee volcanics was described by the author following field work done during the summer of 1957 as follows:

The Waupee volcanics are a thick sequence of tuffs, agglomerates, basalts, and basalt porphyries which have been cut by two separate granite intrusives, metamorphosed to the amphibolite facies, and in part silicified. The volcanics are extensively exposed in the area drained by the Waupee Creek, west of the Little Waupee Swamp in T. 31 N., R. 16 and 17 E., east of Mountain, Wisconsin.

The composition of the volcanics ranges from 100 percent hornblende in the amphibolites to almost pure quartz in the silicified areas. Feldspar is often absent, but may be present to the extent of 50 percent as an essential constituent or as phenocrysts in the porphyries. The grain size ranges from less than 1 mm to over 5 mm. Thin banding or bedding is common, but in many cases the rock is dense and massive. The general trend of the banding and bedding is from N. 50° E. to N. 80° E. with steep dips to the north and south, but forming no apparent anticlinal or synclinal folds. Many local dips and strikes vary from this general trend, but they are probably the result of the distortion during one or the other of the granite intrusions.

The Waupee volcanics are cut by and appear as inclusions in the Macauley granite, a gray foliated hornblende granite which is typically exposed along the Macauley Creek in sec. 5, T. 31 N., R. 17 E., east of Mountain, Wisconsin. The foliation of the Macauley granite and the alignment of volcanic inclusions follow the same general N. 50° E. to N. 80° E. trend, but again, there are many local deviations. The Macauley granite is of 2 to 5 mm grain size and varies greatly in composition, ranging from that of quartz diorite to that of mafic syenite. The mafic minerals, mainly hornblende with minor biotite, amount to 70 percent in extreme cases.

In the McCaslin district, rocks similar in lithologic character to the Waupee series crop out north of the main McCaslin quartzite ridge and also east of the Thunder Mountain quartzite exposures. The exposures are widely separated and vary greatly in extent, some consisting of one small or large outcrop and others of several separated outcrops near one another.

Exposures north of the main McCaslin ridge are found near the center of sec. 28, T. 34 N., R. 16 E.; in the S and SE 1/4 sec. 23, T. 34 N., R. 16 E.; and in the NE 1/4 sec. 5, and the N 1/4 sec. 4, T. 33 N., R. 15 E. Exposures are most numerous and largest east of Thunder Mountain in secs. 31, 32, and 33, T. 33 N., R. 18 E., the NW 1/4 sec. 5, T. 32 N., R. 18 E. and the SE 1/4 sec. 25, T. 33 N., R. 17 E.

The rocks grouped under the general heading of Waupee volcanics and granite complex include a variety of types. Megascopically they are gray-black, finely banded or massive rocks which appear to be rich in fine grained quartz. The grain size seldom is more than 2 mm. The rock characteristically shows iron staining on the weathered surface and is very hard, and breaks under a stroke of the hammer producing a sharp conchoidal fracture. The fine banding, where evident, is best observed on the weathered surface and is the result of differential weathering of quartz rich and mafic mineral rich layers less than 5 mm in

SEQUENCE OF ROCKS IN THE McCASLIN DISTRICT

Pleistocene	Glacial drift
	UNCONFORMITY
	High Falls granite
	Intrusive contact
	Hager rhyolite porphyry
Precambrian	Unconformity
	McCaslin formation
	Unconformity
	Waupee volcanics and granite complex

Table 1.

width. Individual layers are not traceable over great distances because of the fineness of the banding and scarcity of continuous outcrops. Near the center sec. 28, T. 34 N., R. 16 E. a massive, equigranular rock of diorite composition with grain size less than 3 mm is interbedded with the finely laminated portions of the Waupee. The diorite exhibits a slightly pink color on the weathered surface. A small exposure in the S 1/4 sec. 23, T. 34 N., R. 18 E. is fine-grained, dark and does not show banding or foliation.

In sec. 4 and 5, T. 33 N., R. 15 E. the Waupee complex takes on a coarser, igneous appearing texture and varies in composition from granitic to dioritic. The grain size is 3-5 mm, the color is slightly pink and the rock is massive. The outcrop as a whole, however, contains a boxwork of veins two inches and less in width filled with either epidote, quartz, pink granite or granite pegmatite. In the NE 1/4 sec. 5 the rock is a hornblende diorite with an average grain size of 5 mm. Hornblende laths in small zones attain lengths of 1-2 inches and may comprise as much as 40-60 percent of the rock. Pyrite occurs as a visible accessory of less than one percent in small scattered patches. A small outcrop in this area shows a complex relationship of amphibole rich host rock invaded by a complex of light pink granite veins.

The relationship of the Waupee complex to the overlying quartzite in the McCaslin district is that of an unconformable

base upon which the quartzite was deposited. The basal phase of the quartzite is a coarse, dark conglomerate containing pebbles of material similar to that of the Waupee complex. Dips and strikes of the Waupee are not generally conformable with those of the basal conglomerate or the quartzite.

Numerous outcrops of the Waupee complex are found immediately east of the Thunder Mountain quartzite exposures. The Waupee is characteristically finely banded, dark gray-black, very dense and exhibits a conchoidal fracture. The grain diameter is generally less than 2 mm. The fine banding is traceable over the length of the outcrops, which may be a distance of 300 feet. The strike of the banding is N. 10° W. and the dip is 55° W. The attitude is conformable with that of the overlying basal conglomerate and that of the main quartzite body which underlies this topographic high. Faint cross bedding in an exposure in the SE $1/4$ sec. 32, T. 33 N., R. 18 E., indicates that the top of the formation is to the west and that the general source of sediments is from the north. The general source direction and tops of beds as indicated by cross-bedding in the Waupee corresponds to that in the later quartzite. Portions of the Waupee series in this area probably represent water-laid volcanic materials interbedded with the flows and pyroclastics.

McCaslin Formation

The McCaslin formation consists of two kinds of rock, the quartzite which makes up the bulk of the range and the conglomerate at its base. Three separate ranges of exposures occur in the district; the McCaslin Mountain exposures, those at Deer Lookout Tower Hill and those at Thunder Mountain.

McCaslin Mountain is a narrow (1-3 miles) range of continuous exposures that extend in a N. 60° - 90° E. direction for a distance of some 25 miles. The western portion which extends from the Ada Lake lookout tower in sec. 4, T. 33 N., R. 14 E. to Knowles Creek in sec. 4, T. 33 N., R. 16 E. consists of a single ridge which rises 100-300 feet above the surrounding countryside. Outcrops are fairly sparse, but the prominent elevation of the ridge and the abundance of large boulders of conglomerate and quartzite leave little doubt as to the presence of quartzite or conglomerate very near to the surface.

The eastern portion of the range which trends N. 70° - 90° E. from Knowles Creek in sec. 4, T. 33 N., R. 16 E. to the Peshtigo River in T. 34 N., R. 17 E. consists of a distinct ridge to the north and another to the south separated by a narrow lowland less than one mile wide occupied by lakes and swampy ground. The north ridge, composed mainly of conglomerate, trends N. 70° - 90° E. and disappears beneath glacial drift in sec. 20, T. 34 N., R. 17 E.

The south ridge, mainly made of hard gray to white, vitreous quartzite, extends in a N. 70° E. direction to a large rift in sec. 28, T. 34 N., R. 17 E. East of the rift the ridge trends approximately east to the vicinity of a pronounced bend in the Peshtigo River where it is terminated in sec. 25 and 26, T. 34 N., R. 17 E. by the intrusive High Falls granite.

The Deer Lookout Tower Hill exposures in sec. 2, T. 34 N., R. 16 E. consist of two N. 5° - 10° W. trending ridges of clean, gray-white quartzite separated by an arm of intrusive granite 300 feet in width. A few pebbles are scattered through the quartzite, but no continuous conglomeratic layers were seen. Glacial drift borders the knob of quartzite on all sides.

The Thunder Mountain exposures extend in a N. 0° - 10° W. direction for a distance of 1.5 miles from sec. 31, T. 33 N., R. 18 E. to sec. 25, T. 33 N., R. 17 E. The quartzite is conformable with the Waupee complex to the east and is terminated by the High Falls granite to the north. Exposures of conglomerate at the east portion of Thunder Mountain give way to a fine vitreous gray-white quartzite to the west.

Quartzite--The great bulk of the McCaslin formation is a hard, brittle, vitreous quartzite which was originally sandstone that was changed through the processes of metamorphism. The texture varies from rounded grains of quartz of medium size

cemented together by secondary interstitial quartz to a recrystallized mosaic of interlocking quartz grains with little or no interstitial material. There is a general increase in grain size and decrease in interstitial quartz from west to east because of more intense metamorphism as the vicinity of the High Falls granite is approached.

The color of the quartzite is generally white, varying through gray and pink to purplish-red and at some places brick red. The latter is due to finely disseminated hematite.

Bedding is apparent in many exposures because of slight changes in grain size, color or hematite staining. Bedding joints are often well developed even where true bedding is inconspicuous. Cross-bedding is very common throughout the district. On the McCaslin range cross-bedding indicates that the tops of the beds are to the south, and that the general source of sediments or current direction is from west to northwest. Ripple marks are extremely well preserved in the S 1/4 sec. 29, T. 34 N., R. 17 E. They are of the oscillation type and indicate that the top of the beds is to the south. Cross bedding at Thunder Mountain indicates that the top of the quartzite is to the west and that the source or current direction is from the north.

Silty or clayey material was not found interbedded with the quartzite in the district. If it does exist, it is most likely hidden by the vegetation cover or has been removed more deeply



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Figure 3. Cross-bedded quartzite in McCaslin formation.



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Figure 4. Quartzite resting on conglomerate, McCaslin formation.

by selective erosion. Therefore, fracture cleavage, drag folds and boudinage structure, common in other quartzite areas such as the Baraboo Hills of Wisconsin, were not seen in the district.

The quartzite in places (EC 1/4 sec. 27, T. 34 N., R. 18 E.; NE 1/4 sec. 28, T. 34 N., R. 17 E.; SE 1/4 sec. 29, T. 34 N., R. 17 E.; SW 1/4 sec. 35, T. 34 N., R. 16 E.; S 1/4 sec. 34, T. 34 N., R. 16 E.; NW 1/4 sec. 4, T. 33 N., R. 15 E.) consists of a mass of angular fragments of gray quartzite firmly cemented by white, secondary quartz. The brecciated areas are generally linear in extent and parallel to the bedding direction. In general, they are located along the southern border of the range or near areas of inferred cross flexing or faulting. The breccia is of deformational origin and developed by differential movement of the brittle quartzite layers during the regional folding and the intrusion by the High Falls granite.

Conglomerate--The conglomerate exposed at the base on the McCaslin formation is a true basal conglomerate. It is abundant and shows conclusively the unconformable position of the sedimentary series above the rocks of the Waupee complex. The conglomerate is found as a fairly continuous series of exposures along the northern border of the western McCaslin range and on the north ridge of the eastern McCaslin range. An exposure in the SE 1/4 sec. 30, T. 33 N., R. 18 E. indicates that conglomerate lies to the east and below the clear gray quartzite and stratigraphically above the Waupee complex in the Thunder Mountain area.

Gray and red quartzite and white vein quartz make up by far the dominant portion (50-70 percent) of the pebbles in the conglomerate. The remainder is a mixture of fragments of the Waupee complex, banded hematite iron formation and red jasper.

The pebbles attain a maximum size of seven inches in diameter at the west end of the western range in sec. 4, T. 33 N., R. 14 E. Other outcrops indicate that the pebbles are coarsest (4-5 inches in diameter) at the extreme northern border of the ranges which is the base of the formation and become finer in the upper beds eventually giving way to clean gray quartzite.

The proportion of quartzite and quartz pebbles increases from less than 50 percent at the base of the formation to almost 100 percent in the finer conglomerates above the base. This change is easily recognized by the color gradation from dark gray or black at the base to clear white or light gray toward the top.

The degree of roundness and sphericity is maximum for the quartzite and quartz pebbles, but varies from angular to sub-rounded for the Waupee and iron formation pebbles. This suggests a distant source for the quartz pebbles and a fairly close source for the pebbles of Waupee complex and iron formation. Outcrops of Waupee are within 500 feet of the conglomerate in sec. 5, T. 33 N., R. 15 E. and the SE 1/4 sec. 23, T. 34 N., R. 16 E., and many others are seen within one-half mile to the north of the quartzite. No outcrops

of iron formation are found in the district, but iron rich layers were noted in the Waupee complex south of Mountain, Wisconsin, thus it is quite possible that they may also exist in the Waupee complex north or west of McCaslin. No possible source of quartzite or quartz was seen in the immediate vicinity of the McCaslin district, however, exposures of quartzite are quite common in the Florence, Menominee, Iron River and Crystal Falls districts less than fifty miles to the north.

The matrix of the conglomerate is a mixture composed of fine grains of rounded quartz, quartzite and dark rock fragments. The proportion of dark fragments decreases from the base upward, thereby causing a change in overall color from dark gray-black at the base to light gray or white toward the top.

Interbedded with the conglomerate layers are beds ranging in composition from dirty gray or red arkose to clean white quartzite which increases in number in higher horizons. Cross-bedding in the finer grained beds indicates a general source of the sediments from the west and northwest, and that the top of the formation is to the south.

At Thunder Mountain the general trend of the conglomerate layers is N. 0° - 10° W. Pebbles become smaller and are more quartzitic and the matrix becomes cleaner with less dark fragments toward the west or from the bottom to the top of the formation. Cross-bedding in the beds of finer material between conglomerate layers indicates a general source from the north and west, and that the tops of the beds are to the west.

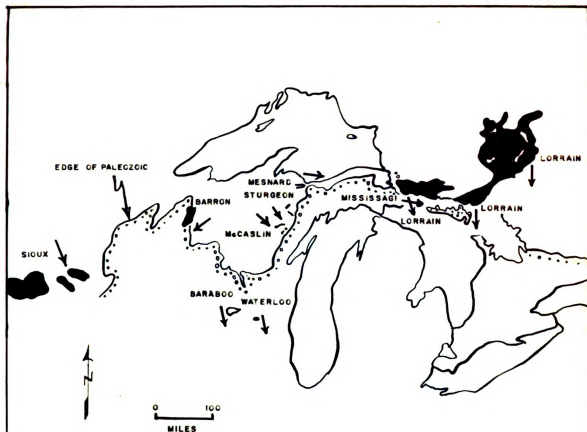


Figure 5. Paleo-current map of Precambrian quartzites of the Lake Superior region (from Pettijohn, 1957). Areas shown in black are principally quartzite. Mean-current azimuth is shown by arrows. The McCaslin quartzite has been added to Pettijohn's original map.

Environment of Deposition--The composition and sedimentary structures of the McCaslin formation indicate that the sediments were deposited upon the bottom of a shallow but extensive body of water. The sediments do not seem to be fluvial deposits, as the sands which form a large part of the unit are generally clean, well sorted and, in general, well stratified. Furthermore, such fluvial characteristics as cut-and-fill and the development of lenticular beds on a limited scale are not apparent.

The sedimentary conditions that existed in the McCaslin basin of deposition were similar to those existing in present standing bodies of water. Gravels would be localized along beaches and would, ideally, grade outward toward deeper water into a fine, clean sand. From the stratigraphic position of the conglomerates and clean quartzitic sediments, and from the location of the logical source area to the north, it appears that the McCaslin formation was deposited in a sea transgressing northward over a Waupee terrain of low relief and fed by streams from the north and west (Figure 5). However, the exact shore and the direction of the encroachment of the seas is still a matter of conjecture because of inadequate information from the conglomerate exposed in the Mountain area to the south. Furthermore, the deposition of over 5000 feet of gravel and sand indicates that the site of deposition probably was subsiding.

Structure of the McCaslin Formation--The overall extent and attitude shown by the McCaslin formation indicate the structural framework of the district as a whole. Frequent reference should be made to the accompanying geologic map (Map I).

The discussion of the structure might well begin with the western portion of the McCaslin range in the vicinity of the Ada Lake lookout tower. The north and south ridges of the eastern range, Deer Lookout Tower Hill and Thunder Mountain will be treated in consecutive order.

The western exposures of the McCaslin formation extend in a general easterly direction from the Ada Lake lookout tower in sec. 4, T. 33 N., R. 14 E. to Knowles Creek in sec. 33, T. 34 N., R. 16 E. Conglomerate is the dominant rock exposed along the western range although a few exposures of fairly clean quartzite were noted along the southern slopes of the ridge. Cross-bedding indicates that the beds are right side up.

A structural interpretation of the extreme western portion of the range in secs. 4, 3, 2 and 1, T. 33 N., R. 15 E. and sec. 6, T. 33 N., R. 15 E. is difficult because of poor and questionable outcrops, but the continuity of the formation is fairly evident because of the continuous range of hills trending east which rises abruptly 100-300 feet above the surrounding lowlands. The lithology of many large boulders on the ridge indicates that it is underlain by conglomerate and quartzite.

In sec. 4, T. 33 N., R. 15 E. outcrop relationships indicate that a right hand fault trending approximately N. 30° W. and with a lateral displacement of $1/4$ to $1/2$ mile transects the western range. A deep valley, through which pass State Highway 32 and the Chicago and Northwestern Railroad, crosses the range in this area. The ridge is offset at this place to the south on the east side of the valley. A comparison of the attitudes of the beds on the two sides (less than $3/4$ miles apart) indicates that lateral offset has taken place. The strike of the bedding changes abruptly from N. 35° - 80° W. on the west side of the valley to N. 73° E. on the east side. When projecting the trend of the bedding of the most northerly conglomerate exposures on the west side of the valley across the lowland to the east side, exposures of the Waupee complex are encountered, indicating that the stratigraphic sequence on the east side of the valley has been offset $1/4$ to $1/2$ mile to the south. Brecciated quartzite cemented by secondary white quartz found on both sides of the valley supports the fact that movement has taken place. A large exposure in the SW $1/4$ NE $1/4$ sec. 4, T. 33 N., R. 15 E. consists of very intensely brecciated conglomerate and quartzite. The breccia grades to the south into unbrecciated quartzite and conglomeratic layers. An examination of the transition zone shows that the initial forces causing the brecciation produced a joint system with one set of joints striking N. 10° W. and dipping very steeply to the SE, and another set striking N. 70° W. and dipping very steeply to

the NE. More intense movement caused fracturing and rotation of the quartzite fragments so that the original pattern of jointing is not discernable in the intensely brecciated northern portion of the outcrop. Later solutions filled the joints and open spaces between the fragments with secondary white quartz. Also, evidence of brecciation was noted on the west side of the valley in an outcrop located a few hundred feet south of the Carter lookout tower in the NE 1/4 sec. 5, T. 33 N., R. 15 E. Joints 1-2 feet wide trending north and dipping 63° E. filled by clean, white quartz cut the quartzite and inter-bedded conglomerate. Fragments of quartzite up to 10 inches in size are imbedded in the joints and indicate by their position that they have been moved and rotated.

Exposures are rather scarce in secs. 3, 2 and 1, T. 33 N., R. 15 E. in the region where the North Branch of the Oconto River crosses the western range, but the general topography of the region suggests that the ridge is fairly continuous. The strike of the bedding ranges from N. 90° E. to N. 73° E., and the dips are to the south at 50-67 degrees. An exposure of exceptionally well preserved cross-bedding near the center of sec. 3, T. 33 N., R. 15 E. (Figure 3) indicates that the beds are right side up and that the source of the sediments or current direction was from the west.

There are many good outcrops along the western range from the valley of the North Branch of the Oconto River eastward to the valley of Knowles Creek. Outcrops, together with the topographic expression of the ridge, indicate that the quartzite ridge widens from less than

1/4 mile at the valley of the North Branch of the Oconto River to over 1 1/4 miles in the vicinity of Knowles Creek. This change in thickness of the ridge is not caused by divergence of the beds but appears to be related to the encroachment of the quartzite from the south by the overlying Hager rhyolite porphyry because of a post-McCaslin--pre-Hager erosion of the quartzite formation. Conglomerate is most abundant along the northern portions of the ridge giving way to clean white quartzite to the south. The gradation is especially marked in a large outcrop near the center of NW 1/4 sec. 6, T. 33 N., R. 16 E. The conglomerate has a dirtier matrix and a greater percentage of dark pebbles on the northern portion of the outcrop. The matrix becomes cleaner, quartz pebble content increases and interbedded clean quartz sand becomes more abundant to the south, and finally, the southern extremity of the outcrop is made up of clean vitreous quartzite with no pebbles. The gradation from conglomerate to clean quartzite from the base upward is also apparent in the vicinity of Knowles Creek. Outcrops near the center of sec. 33, T. 34 N., R. 16 E. are entirely conglomeratic; whereas outcrops in the SE 1/4 NW 1/4 sec. 4, T. 33 N., R. 16 E. are entirely clean white quartzite.

The strike of the bedding varies from N. 90° E. to N. 60° E. and the dips range from vertical to 55° S. Good cross-bedding of the interbedded quartzite layers in the conglomerate and in the non-conglomeratic quartzite indicates that the tops of the beds are to the south.

The eastern portion of the McCaslin range which extends from Knowles Creek eastward to the vicinity of the Peshtigo River valley consists of two ridges separated by a swampy lowland.

The northern ridge is underlain mainly by conglomerate with a few interbedded thin quartzite layers. In the NW 1/4 sec. 34, T. 34 N., R. 16 E. outcrops of conglomerate form the east bank of Knowles Creek. The strike is N. 70° E. and the dip is 80° S. A short distance to the east in sec. 26, T. 34 N., R. 16 E. the prevailing strike is N. 80° E., while the prevailing strikes in the NE 1/4 sec. 25, and the SE 1/4 sec. 24, T. 34 N., R. 16 E. are N. 80°-90° W. There appears, therefore, to be a slight flexing or bending of the north ridge. The dips are consistently to the south ranging from 35° to 80°. In general, the moderate dips are along the northern edge of the ridge and the steeper dips to the south. The separate topographic expression of the north ridge terminates abruptly near the western margin of sec. 20, T. 34 N., R. 17 E.

The southern ridge of the eastern portion of the range is composed of clean, vitreous quartzite. It forms the most impressive topographic feature of the district. The strike of the beds varies from N. 67° E. near Knowles Creek to N. 90° E. near the rift in the NE 1/4 sec. 28, T. 34 N., R. 17 E. to N. 65° W. on the east side of the rift. The dip of the beds is to the north ranging from 40° to 80°. However, many scattered exposures of good cross-bedding and a series of ripple

marked surfaces in the SE 1/4 SW 1/4 sec. 29, T. 34 N., R. 17 E. indicate that the tops of the beds are to the south; therefore, the quartzite beds which make up the south ridge are overturned.

In the NE 1/4 sec. 28, T. 34 N., R. 17 E. a large rift trending approximately N. 30° W. transects the quartzite range. Nearly vertical cliffs of quartzite 100 feet high are separated by 500 feet of flat swampy ground. The opposite walls of the rift, as viewed from an air photo, appear to match except for a slight southward adjustment of the eastern wall. Trends of the quartzite bedding are, in general, N. 70°-80° E. on the west side of the rift, but change to N. 65°-80° W. on the east side of the rift. The topographic expression of the quartzite bedrock, as also noted on air photos, indicates very clearly that the segment of the range east of the rift has been bent southward. In the immediate vicinity of the rift, the base of the quartzite is in direct contact with the intrusive High Falls granite and has been brecciated and later recemented by secondary white quartz. The relationship of the quartzite to the granite will be discussed in a later section.

A large outcrop of highly fractured quartzite healed by secondary quartz is found in the NE 1/4 SE 1/4 sec. 27, T. 34 N., R. 17 E. The general strike of a faint bedding or banding is N. 35° W. and dips 75° SW. The anomalous attitude in this exposure suggests that this large outcrop may not be in place, but detached from the main range and rotated somewhat during the intrusion of the High Falls granite.

Isolated portions of the south ridge are found in the NW 1/4 SW 1/4 sec. 26, T. 34 N., R. 17 E. and in the SW 1/4 NE 1/4 sec. 25, T. 34 N., R. 17 E. The latter is in direct contact with the High Falls granite and is bordered by it on the west and north. These outcrops are interpreted as being large xenoliths detached from the main quartzite range and moved to the present position by the granite intrusion.

The group of quartzite exposures at Deer Lookout Tower Hill appear to be isolated from the main McCaslin Mountain range. The attitudes of the quartzite bedding are extremely varied and unrelated to the east-northeast regional trend, and cross-bedded exposures at close intervals give contrasting and anomalous results concerning the tops of the beds and the source of the sediments. The quartzite is cut by a 300 foot wide arm of intrusive granite, and the conclusion is that the Deer Lookout Tower Hill quartzite is a very large xenolith which was detached from the main McCaslin range and carried to its present position by the motion of the intruding High Falls granite.

The quartzite exposures on Thunder Mountain offer an important clue to the regional structural interpretation of the McCaslin district, which is discussed in detail in a later section. The strike of the quartzite beds is consistently N. 0° - 10° W., and the dips are 50° - 70° W. Cross-bedding indicates that the beds are right side up and that the source of the sediments or current direction was from the

north and northwest. The consistent overall agreement of dips and strikes and cross-bedding at various locations on Thunder Mountain and the conformable relationship to the underlying Waupee complex indicate that the Thunder Mountain exposures are "in place" with respect to the regional structural pattern which is synclinal.

Hager Rhyolite Porphyry

The Hager rhyolite porphyry was originally described by the author near Mountain, Wisconsin (Mancuso, 1957).

The main body of the Hager is a distinct rock type, easily recognized by the quartz phenocrysts that exhibit a rounded appearance on a broken or weathered surface. Under the microscope, the groundmass appears to be a mosaic of anhedral quartz, orthoclase, plagioclase (An_{15-20}) and biotite. The quartz is late and occurs filling the interstitial spaces between the feldspars and as myrmekitic intergrowths with the feldspars. Brown pleochroic biotite occurs as laths or aggregates that are aligned to give the rock a definite flow structure. The foliation bends around the phenocrysts. Accessory sphene is associated with the biotite. The phenocrysts are rounded and embayed due to resorption, and fractures in the phenocrysts are filled by the crystalline groundmass. The few plagioclase and microcline phenocrysts are mottled with quartz and biotite inclusions.

The nature of the rock type and its origin was established in the M. S. thesis:

The coarse grain size and great thickness of the Hager rhyolite porphyry may suggest that it is an intrusive granite, but field evidence seems to indicate a volcanic origin. Contact relationships with the conglomerate are those of an extrusive flow and not that of the ordinary intrusive. No dikes of the Hager were seen cutting the conglomerate or any of the formations to the south, and no xenoliths of the conglomerate were seen in the Hager. Flow lines and the general bedded

appearance of the Hager conform to the general trend of the underlying contact. A large outcrop in the NE 1/4 sec. 21, T. 32 N., R. 17 E. exhibited a breccia pattern with cement and fragments of the same general material. This is interpreted as a brecciated flow top with fractures filled by a later flow.

The rather coarse grain size could result from slow cooling in the central portions of this very thick flow.

The Hager rhyolite porphyry in the McCaslin district is seen as a fairly continuous string of exposures along the southern border of the main McCaslin range and west of the quartzite exposures at Thunder Mountain. The rhyolite porphyry was not seen in direct contact with the quartzite, but in the NW 1/4 sec. 6, T. 33 N., R. 16 E. The WC 1/2 sec. 4, T. 33 N., R. 16 E.; the SE 1/4 sec. 35, T. 34 N., R. 16 E.; the NW 1/4 sec. 31, T. 34 N., R. 17 E. and the NW 1/4 sec. 32, T. 34 N., R. 17 E. it outcrops within 100 feet of quartzite exposures.

The age of the Hager rhyolite porphyry with respect to the McCaslin formation was definitely established in an exposure in the SE 1/4 NW 1/4 sec. 6, T. 33 N., R. 16 E. Angular fragments of the quartzite are engulfed in the rhyolite porphyry (Figure 6). The rhyolite exhibits a good flow banding of mafic minerals and phenocrysts trending N. 70° W. and dipping 48° NE. The foliation flows around the inclusions. The quartzite inclusions, up to 6 inches in diameter, generally are scattered at random throughout the rhyolite outcrop, but in a few cases a series of inclusions are aligned parallel to the flow banding. The contacts are extremely sharp with no apparent change or alteration of the quartzite or rhyolite.



Figure 6. Quartzite inclusions in the Hager rhyolite porphyry.

In the vicinity of the North Branch of the Oconto River, a marked thinning of the western range is apparent. Outcrops of Hager rhyolite porphyry are found immediately south of the quartzite exposures (less than 200 feet) and exhibit a flow banding which trends parallel to the outline of the quartzite ridge. An outcrop of rhyolite north of the quartzite on the east side of Forestry Road No. 2349 in the NW 1/4 sec. 29, T. 34 N., R. 16 E. indicates that the rhyolite completely crossed the quartzite ridge possibly by way of an ancient erosional valley now reformed in the less resistant rhyolite and occupied by the North Branch of the Oconto River.

The age of the Hager rhyolite porphyry with respect to the High Falls granite is not definitely established, but evidence suggests that it is older than the granite. They were not seen in direct contact with each other in the district, but they outcrop in close proximity in secs. 27 and 28, T. 34 N., R. 17 E. There is an increase in the grain size of the groundmass of the rhyolite from west to east and the phenocrysts show signs of secondary enlargement and recrystallization near the granite. The position or locality of the rhyolite seems to have been controlled by the structure of the quartzite, and both in turn have been modified by the force of the granite intrusion. Therefore, the extrusion of the Hager rhyolite porphyry followed or was synchronous with the deformation of the quartzite, but preceded the intrusion of the High Falls granite. The possibility does exist,

however, that the Hager rhyolite porphyry and the High Falls granite stem from the same original source and were part of a long orogenic period in the later Precambrian. The relationship of the Hager rhyolite porphyry to the High Falls granite will be discussed in detail in a later section.

High Falls Granite

This research does not attempt a complete study of the High Falls granite. Only those portions that extend into the McCaslin district and that affect the structural interpretation of the McCaslin formation will be discussed in detail.

The granite is found as a series of large and small exposures scattered throughout the vicinity of the High Falls and Caldron Falls Reservoirs in west-central Marinette County. It terminates the McCaslin district on the north and east.

A pink granite with an average grain size of 5-10 mm containing laths of orthoclase up to 1/2 inch in length outcrops near the High Falls Reservoir in the SW 1/4 sec. 19, T. 33 N., R. 18 E. The composition averages microcline-perthite-albite 60 percent, quartz 25 percent and biotite 15 percent. Accessory minerals include zircon, fluorite, apatite, and titanite. This exposure probably represents the true composition of uncontaminated High Falls granite. The texture is hypidiomorphic granular.

Westward, toward the east end of the McCaslin range and

Thunder Mountain, the granite contains numerous inclusions of the Waupee complex in various stages of digestion (Figures 12 and 13). The color varies from red to gray-black, and the texture is gneissic with segregation and alignment of the mafic constituents due to flow (Figure 11). Isolated outcrops, such as those found in the NW 1/4 sec. 19, T. 33 N., R. 18 E. and secs. 28, 29, 32, and 33, T. 34 N., R. 18 E., indicate by the attitude of their flow banding and the number of inclusions that the general locality of the main granite body is to the east and northeast of the McCaslin district.

The granite was seen indirect contact with the McCaslin formation in several localities. In an outcrop in the bed of the Peshtigo River near the center of sec. 25, T. 34 N., R. 17 E., the contact is extremely sharp with very little penetration of the quartzite by granite veins (Figure 7). The granite becomes porphyritic, dark gray-red in color and fairly syenitic in composition at the contact. The mafic mineral content increases and flow banding parallels the trend of the contact. The quartzite appears highly recrystallized and at the immediate contact contains stringers and scattered grains of pinkish orange microcline, perthite and albite. The extreme straightness and sharpness of the contact suggests that it was controlled by original fractures or joints in the quartzite. From the field location and relationship to the regional structural picture, it seems that the quartzite in this outcrop may be part of a large block completely engulfed by the granite and detached from the main body of the quartzite range.

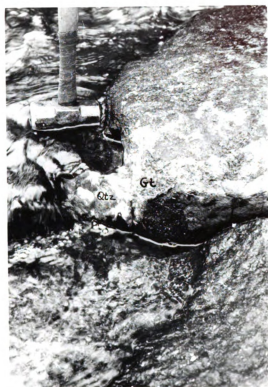


Figure 7. High Falls granite (Gt)-McCaslin formation (Qtz) contact exposed in the bed of the Peshtigo River in sec. 25, T. 34 N., R. 18 E.



Figure 8. High Falls granite (Gt)-McCaslin formation (Qtz) contact exposed in the rift in sec. 28, T. 34 N., R. 17 E.

In the NE 1/4 sec. 28, T. 34 N., R. 17 E., associated with a large rift transecting the quartzite range, the granite is again in direct contact with the quartzite. Here again the granite becomes dark and syenitic with a decrease in grain size and an increase in mafic mineral content, mainly biotite. At the northeast corner of the rift, small exposures of the granite-quartzite contact indicate that joints or fractures in the quartzite played a major part in governing the avenues of granite invasion; however, veins and stringers of pink feldspar and granite are numerous throughout the quartzite forming the east wall of the rift.

The most interesting and revealing granite-quartzite contact exposures are found on the west side of the rift at the base of a large mass of highly brecciated quartzite cemented by secondary white quartz (Figure 8). In the vertical wall of the rift a continuous transition exists from granite to quartzite invaded by large granite veins and dikes, to quartzite breccia healed by later secondary quartz. At the base of the rift wall granite predominates and contains numerous inclusions of quartzite; however, no quartz healed quartzite breccia inclusions were seen in the granite. Flow banding in the granite follows around the quartzite inclusions. Upward from the base of the cliff quartzite predominates but is invaded by numerous veins and stringers of granite up to 2 feet wide which exhibit a flow banding that very closely parallels the walls of the veins. From the mid-point to

the top of the rift wall the granite veins and stringers are no longer seen. The quartzite becomes a mass of brecciated fragments, some of whose outlines match, cemented by clean white quartz. In a few cases the white secondary quartz can be traced downward to an origin in a granite vein or stringer. The transition zone to the northwest, where brecciated quartzite passes into massively bedded unbrecciated quartzite, indicates that the brecciation began with the development of two major fracture or joint sets whose strikes and dips respectively are: N. 20° E., 48° NW. and N. 80° W., 15° SW. More intense pressure and movement caused intense fracturing and rotation of the quartzite blocks between the original fractures or joints.

In sec. 36, T. 34 N., R. 16 E., on the northern border of the south ridge of the eastern range and in the rift in sec. 28, T. 34 N., R. 17 E., the granite lies directly adjacent to the quartzite. The granite typically is dark in color, deficient in quartz and flow banded parallel to the quartzite contact. The quartzite is very highly recrystallized near the contact and, under the microscope, exhibits secondary microcline perthite and albite that have grown between the original quartz grains at the expense of the muscovite. These exposed contacts along with the evidence cited below suggest that the area between the north and south quartzite ridges is occupied by the High Falls granite. The granite most probably intruded along a bedding plane of the quartzite and caused the splitting of the ridges, a flexing

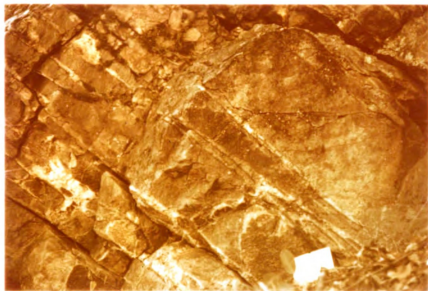
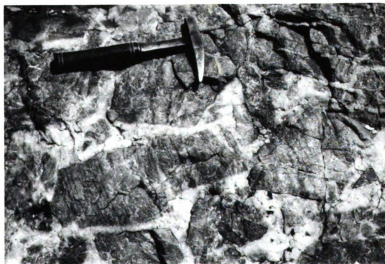


Figure 9. Joint fractures in quartzite filled with secondary quartz, McCaslin formation.



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Figure 10. Brecciated quartzite cemented by secondary quartz, McCaslin formation.

of the northern ridge and overturning of the south ridge. The relationship of the granite to the structure of the quartzite is discussed in detail in a later section.

An indirect evidence of granite intrusion is found along the sharp bend of Knowles Creek near the east boundary of sec. 33, T. 34 N., R. 16 E. The quartzite is highly jointed and recrystallized, contains numerous small veins and stringers of pink granite and is stained pinkish-orange in color similar to quartzite exposures that occur in direct contact with the granite. Fine secondary microcline, perthite and albite occupy the interstices between the quartz grains.

At Deer Lookout Tower Hill an arm of granite 300 feet wide transects the quartzite in a N. 10° W. direction with a dip of 80° to the southwest. The granite is highly banded parallel to the contact, porphyritic and fairly dark in color. The quartzite has a variable attitude, but appears to have a pronounced secondary foliation parallel to the granite body due to the alignment of secondary muscovite flakes and sillimanite.

At Thunder Mountain, 700 feet west of the northeast corner of sec. 25, T. 33 N., R. 18 E., a granite sill three feet wide invades an outcrop of banded Waupee complex. The trend of the Waupee and the granite sill is north-south and dips 35° to 50° to the west. The granite has a grain size of 1/4 inch or more, is pink in color and contains coarse books of muscovite.

Structure of the McCaslin District and the Relationship
of the High Falls Granite to the Areal Distribution
of the Quartzite Ranges

The broad regional structure of the McCaslin district can best be described as the northern limb of a large synclinal trough, the southern limb of which is found in the vicinity of Mountain, Wisconsin, approximately fifteen miles south of the main McCaslin range of hills. The axial line of the regional structure trends N. 60° - 90° E. and plunges slightly to the west. The quartzite exposures at Thunder Mountain probably represent part of the broad eastern nose of the syncline. The High Falls granite batholith terminates the syncline to the east and northeast.

From the granite-quartzite relationships described on the preceding pages, the following conclusions seem justified concerning the relationship of the High Falls granite to the regional structure of the McCaslin district and to the areal distribution of the quartzite ranges.

The main body of the High Falls granite lies to the east and northeast of the McCaslin district. The granite has invaded the rocks of the McCaslin district by forceful injection, stoping and assimilation. The Waupee complex and the McCaslin formation vary greatly in physical and chemical characteristics; therefore, they reacted differently and offered unlike resistance to the granite intrusion.



Figure 11. Flow foliation in the High Falls granite.

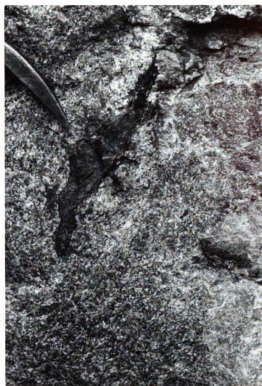


Figure 12. Flow foliation and inclusion in the High Falls granite.



Figure 13. Waupee inclusions in the High Falls granite.

The Waupee complex offered little resistance to the granite body; veins and dikes seem to have invaded the Waupee with seemingly little regard for original fracture systems, bedding planes or other controls inherent in the Waupee rocks. Inclusions of the Waupee because of their greater density, sank into the mass of the granite and were assimilated and digested. Near the extremities of the granite body, the process of assimilation was not carried to completion and the granite contains Waupee inclusions in various stages of digestion (Figure 13).

The quartzite, however, offered resistance to the force of the intrusion as a massive unit. The avenues of the granite intrusion were primarily governed by pre-existing weaknesses in the quartzite such as joints, fractures or bedding planes. Therefore, the quartzite suffered flexing, bending and fracturing on a regional scale with local areas of brecciation in zones of differential movement.

The region between the north and south ridges of the eastern range is occupied by an intrusive arm or sill of granite which intruded along the plane of the bedding. The force of the intrusion caused a spreading of the two ridges, a flexing of the northern ridge, and overturning of the southern ridge. The large zones of brecciation noted in outcrops in the NW 1/4 NE 1/4 sec. 3, T. 33 N., R. 16 E.; the SW 1/4 sec. 35, T. 34 N., R. 16 E. and the SE 1/4 sec. 29, T. 34 N., R. 17 E. are found near the southern border of the range

and are most probably caused by the differential movement of brittle quartzite layers during the process of overturning.

The granite terminates the quartzite range to the northeast where large blocks were detached from the main body of the quartzite, floated away in the intrusive or carried along by the force of the granite flow because of the lesser density of the quartzite. Much of the quartzite has since been removed by erosion, but remnants such as those at Deer Lookout Tower Hill and those near the Peshtigo River in secs. 25, 26 and 27, T. 34 N., R. 17 E. remain isolated from the main quartzite mass and surrounded by granite.

Relationship of the High Falls Granite to the Hager Rhyolite Porphyry

The High Falls granite and the Hager rhyolite porphyry appear to be genetically related although the Hager rhyolite porphyry definitely was extruded and crystallized prior to the granite intrusion, for it shows, in part, unmistakable effects of contact metamorphism. The granite and rhyolite exhibit a striking similarity in their overall mineral composition, chemical analyses and accessory mineral suites.

The essential minerals of both rocks consist of the feldspar assemblage microcline-perthite-oligoclase and quartz which occur in about the same general proportions in each rock type. The dominant mafic mineral in each case is biotite with minor hornblende and secondary chlorite.

ANALYSES OF THE HIGH FALLS GRANITE

	Normal High Falls granite		Contact Phase High Falls granite			Belongia granite Mountain, Wisconsin	
	Sample J-41	Sample J-63	Sample J-60	Sample J-82	Sample J-69	Sample 20,098	Sample 20,099
SiO ₂	67.75 ¹	66.46	59.81	61.38	58.83	63.19	64.43
Al ₂ O ₃	18.99	20.05	23.61	22.50	23.94	20.54	20.32
K ₂ O	11.19 ²	10.71	12.66	13.51	14.31	13.91	13.21
CaO	0.54	0.60	0.48	0.51	0.47	0.23	0.37
Na ₂ O	1.40	1.56	1.24	1.25	1.28	0.60	0.96
(Mg,Fe)O	0.12	0.59	2.07	0.78	1.09	1.48	0.69
H ₂ O	0.01	0.03	0.11	0.06	0.06	0.05	0.02
P ₂ O ₅	tr. ³	tr.	tr.	tr.	tr.	tr.	tr.
Zr ₂ O ₃	tr.	tr.	tr.	tr.	tr.	tr.	tr.
TiO ₂	tr.	tr.	tr.	tr.	tr.	tr.	tr.
F	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Total	100.01	100.00	99.98	99.99	99.98	100.00	100.00

1. Weight percents obtained by converting from volume percents which were determined by the "Rosin method" employing a 6-axis integrating stage.
2. K₂O is abnormally high and Na₂O and CaO are low because all microcline and perthite were calculated as KAlSi₃O₈.
3. Trace

Table 2.

ANALYSES OF THE HAGER RHYOLITE PORPHYRY

	McCaslin Mountain			Thunder Mountain	Mountain, Wisconsin
	Sample J-86	Sample J-34	Sample J-78	Sample J-67	Sample 20,061
SiO ₂	58.95 ¹	58.87	62.16	59.37	60.11
Al ₂ O ₃	22.20	22.27	21.03	22.26	21.54
K ₂ O	14.86 ²	14.15	15.10	14.22	14.08
CaO	0.50	0.59	0.20	0.57	0.53
Na ₂ O	0.93	1.06	0.52	1.10	0.92
(Mg, Fe)O	1.32	1.57	0.97	1.27	1.45
H ₂ O	0.02	0.02	0.03	0.02	0.02
Fe ₂ O ₃	1.23	1.47	tr.	1.19	1.35
P ₂ O ₅	tr. ³	tr.	tr.	tr.	tr.
Zr ₂ O ₃	tr.	tr.	tr.	tr.	tr.
TiO ₂	tr.	tr.	tr.	tr.	tr.
F	tr.	tr.	tr.	tr.	tr.
Total	100.01	100.00	100.01	100.00	100.00

1. Weight percents obtained by converting from volume percents which were determined by the "Rosiwal method" employing a 6-axis integrating stage.
2. K₂O is abnormally high and Na₂O and CaO are low because all microcline and perthite were calculated as KAlSi₃O₈.
3. Trace

Table 3.

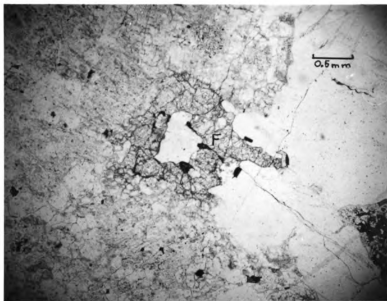


Figure 14. Fluorite (F) in the High Falls granite, plain light (Sample 41).



Figure 15. Fluorite (F) in the High Falls granite, crossed nicols (Sample 41).

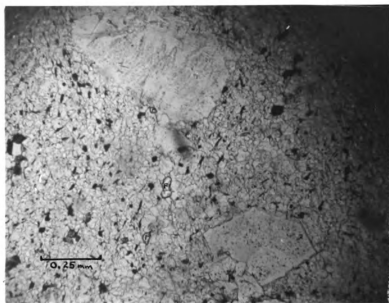


Figure 16. Fluorite (F) in the Hager rhyolite porphyry, plain light (Sample 74).

The accessory minerals are fluorite, zircon, magnetite and apatite with minor sphene and leucoxene. In both rock types zircon and fluorite are by far the dominant accessory minerals and respectively exhibit very similar properties and modes of occurrence. The zircons occur as elongate prisms usually doubly terminated by pyramid faces with fairly sharp crystal angles. They commonly show an internal zoning which is parallel to the external crystal shape. Most of the zircons are very clear and colorless, although some are yellowish. The birefringence is very strong. The majority of the zircons would be classified as the "normal" type zircons characteristic of post-Huronian rocks of the Lake Superior Precambrian (Tyler, Marsden, Grout, Thiel, 1940).

The fluorite (Figures 14, 15 and 16) is found as irregular grains that are comparable in size to the essential mineral constituents. It is colorless to purplish-pink and exhibits the characteristic high negative relief. Its mode of occurrence in both the granite and the rhyolite suggests that it crystallized late and filled the interstices between the quartz and feldspar grains.

The remarkable similarity between the High Falls granite and the Hager rhyolite porphyry may be attributed to coincidence, however, a more plausible explanation is that they originated from the same magma reservoir at depth. During the early stages of the post-quartzite (Killarney?) revolution the rhyolite found its way to the surface through passageways which were formed by the initial stages

of the deformation. The main avenues of extrusion appear to have been through the central portions of the synclinal trough which most likely was highly fractured and weakened at depth.

The granite, on the other hand, worked its way slowly upward by stoping, assimilation and forceful injection and did not reach the proximity of the Hager rhyolite porphyry until after the latter had completely crystallized. The heat and fluids related to the intruding High Falls granite then initiated the pronounced sequence of changes in the rhyolite which are discussed in the subsequent section on metamorphism.

METAMORPHISM

The metamorphic zones in the McCaslin district are spatially and genetically related to the High Falls granite intrusive. The width and shape of the metamorphic zones and the degree of metamorphic response was to a great extent governed by the distance along strike or across strike respectively from the granite contact and by the original texture and composition of the country rock. The mineral assemblages developed by metamorphism were determined by temperature and by the bulk chemical composition of the country rocks. The metamorphic changes were primarily recrystallization and reconstitution of original rock materials except in a narrow zone less than 15 feet wide at the immediate granite contact where potash and soda were added to the quartzite from the granite intrusive.

Beyond the immediate contact aureole the country rocks lie in the quartz-albite-muscovite-chlorite subfacies of the greenschist facies¹ of regional metamorphism as evidenced by the very slight amount of recrystallization of the quartzite and rhyolite, the occurrence of fine sericite in the interstices of the quartzite and the completeness of the reactions by means of which the original pyrogenetic mineral assemblage of the diorite (sample 5) was converted to secondary products.

¹The metamorphic facies designations used in this paper are those defined by Turner and Verhoogen, 1960.

The principal secondary minerals are chlorite, pale green actinolitic hornblende, epidote and sericite (Figure 18).

An albite-epidote hornfels facies and a hornblende hornfels facies, which make up the contact metamorphic aureole of the High Falls granite, are superimposed onto the regional greenschist facies. The mineral assemblages of the individual facies varies greatly, however, because of the bulk chemical composition differences of the various rock formations.

A general description of the metamorphic changes is described on the following pages with reference to the various rock formations. Frequent reference should be made to the index map of sample locations on page 53 (Figure 17).

Waupee Volcanics and Granite Complex

The composition of the Waupee series varies considerably from area to area because of the complex of lithologic rock types classified under the general heading of Waupee volcanics and granite complex. Among the rock types included are basalts, andesites, agglomerates, acid and intermediate tuffs possibly with interbedded water laid volcanic sediments and granite and diorite masses whose origins are attributed to a combination of the processes of intrusion and granitization. However, the zones of metamorphism in the Waupee complex are here described in terms of rocks that originally had essentially equivalent overall bulk chemistry; that of an acid to intermediate volcanic tuff.

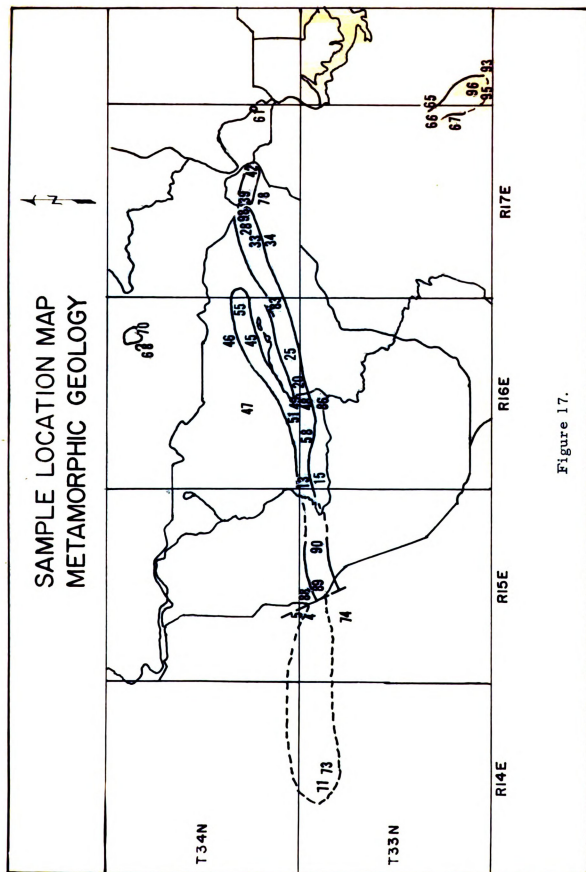


Figure 17.

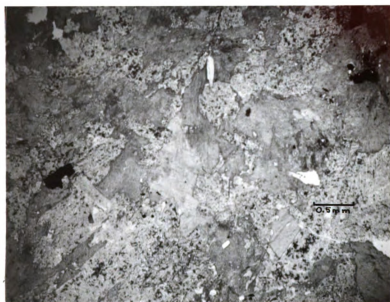


Figure 18. Diorite of the Waupee series altered to mineral assemblage characteristic of greenschist facies (Sample 5).

METAMORPHIC MINERAL ASSEMBLAGES

	Greenschist	Albite-epidote hornfels	Hornblende hornfels	Contact zone
McCaslin formation	Slightly recrystallized quartz Sericite	Recrystallized quartz Coarse muscovite Fine andalusite	Highly recrystallized quartz Coarse muscovite Coarse andalusite Sillimanite	Highly recrystallized quartz Albite- perthite- microcline Coarse muscovite
Waupee complex	Chlorite Muscovite Epidote Actinolitic hornblende	Almandine garnet Biotite Muscovite Zoisite	Sillimanite Dark green hornblende Biotite Albite- perthite- microcline	Not exposed
Hager rhyolite porphyry	Feldspars not overgrown	Feldspars overgrown .20 to .25 mm	Feldspars overgrown .40 to .50 mm	Not exposed

Table 4.

Megascopically, sample 47 resembles a finely banded acid to intermediate tuff. The grain size as measured with the micrometer ocular is less than .08 mm. The essential primary minerals are quartz, orthoclase and minor oligoclase in proportions much as they are in the unmetamorphosed rock. The original grain boundaries have been modified by recrystallization to form an interlocking mosaic texture. Muscovite in the form of laths and aggregates of shredded flakes along with small irregular grains of zoisite showing "anomalous blue" interference colors and minor chlorite are aligned to give the rock a pronounced lineation (Figure 19). The latter three minerals together with isolated subhedral crystals of almandine garnet appear to be later than the primary quartz and feldspar. The suite of minerals described indicates that the rock is in the albite-epidote-hornfels facies.

The Waupee rock of sample 46 has the same general megascopic appearance as 47, however under the microscope, textural and mineralogical differences are readily seen. The overall grain size of the primary minerals, mainly quartz and orthoclase, has increased to 1 mm. The muscovite laths are much larger and intermixed with blades of light brown pleochroic biotite. The micas are aligned to give the rock its lineation. Zoisite and aggregates of fine muscovite as seen in sample 47 are rare. In their place occurs a fine mosaic of secondary microcline, perthite and albite (Figures 20 and 21). The microcline, perthite and albite occur as fine grained aggregates associated

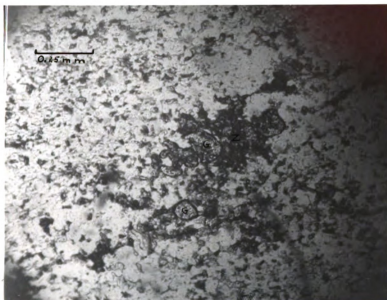


Figure 19. Garnets (G) and zoisite (Z) in the Waupee volcanics (Sample 47).

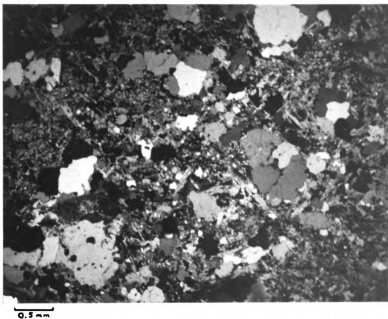


Figure 20. Feldspar assemblage microcline-perthite-albite in the Waupee volcanics (Sample 46).

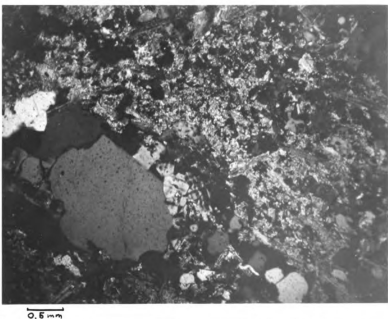


Figure 21. Feldspar assemblage microcline-perthite-albite in the Waupee volcanics (Sample 46).

with the muscovite laths between the larger grains of primary quartz and orthoclase. The mineral assemblage of this rock places it in the class of rocks with excess potash and silica in the hornblende hornfels facies. An observation which was consistently noted throughout the district is that no feldspar more calcic than albite was formed by contact metamorphism, and all of the potash feldspar which formed exhibits microcline twinning. The above feldspar assemblage has important implications concerning the temperatures reached during the metamorphism. According to Laves, 1952, and others the feldspar assemblage microcline-perthite-albite would form and be stable only at temperatures below 700° centigrade.

The general megascopic aspect of the Waupee rocks at localities 65 and 93 at Thunder Mountain is similar to that of 46 and 47 north of the McCaslin range except that the banding is more regular and persistent at Thunder Mountain. The regularity and persistence of the banding along with cross-bedded layers imply that the rock materials, although volcanic in origin, were deposited in water. The essential primary minerals of sample 93 are quartz, orthoclase and oligoclase ($ab_{80}an_{20}$). Secondary laths of muscovite and brown pleochroic biotite along with minor chlorite lie in segregated bands and are aligned to give the rock its lineation (Figure 22). A few isolated subhedral grains of almandine garnet also are seen in the section. The Waupee in the vicinity of sample 93 is in the albite-epidote hornfels facies.



Figure 22. Biotite (B) and muscovite (M) in the Waupee volcanics (Sample 93).

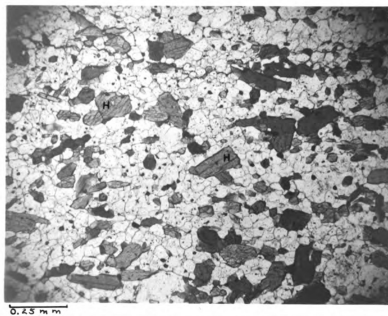


Figure 23. Hornblende (H) in the Waupee volcanics (Sample 65).

In locality 65 the Waupee is characterized by primary quartz, orthoclase and plagioclase ($ab_{70}an_{30}$). Micas and chlorite are completely absent. Dark green pleochroic hornblende is the only mafic mineral present and occurs as elongate laths showing good rhombic cross-sections with characteristic amphibole cleavage directions (Figure 23). A few fine sillimanite needles occur along the grain boundaries of the quartz. The mineral assemblage of this sample puts it in the sillimanite zone of the hornblende hornfels facies.

Hager Rhyolite Porphyry

The progressive increase in metamorphic rank toward the High Falls granite is again very clearly shown by textural changes in the Hager rhyolite porphyry. The mineralogical composition does not lend itself to diagnostic changes, however, the increase in grain size and the change in mineral relationships are a clear indication of the progressive metamorphism.

Outcrops of Hager rhyolite porphyry beyond the realm of influence of the High Falls granite, exemplified by samples 74 and 15, are typical of many rhyolite porphyries. Quartz, microcline, perthite and oligoclase phenocrysts up to 3 mm in size lie in a groundmass that is a mosaic of quartz, orthoclase and oligoclase along with minor muscovite, biotite and hornblende. The grain size of the groundmass is .04-.08 mm. The quartz phenocrysts, which show no signs of strain or recrystallization, are rounded and embayed due to resorption

and exhibit distinct and smooth grain boundary relationships to the groundmass. The feldspar phenocrysts are subhedral and show rather sharp grain boundaries with very slight evidence of secondary overgrowth (Figure 24).

Progressing generally toward the High Falls granite at locality 86, the mineralogy remains essentially the same, but the grain size of the groundmass has grown to .2 mm. The quartz phenocrysts show signs of recrystallization in that they are made up of aggregates of grains whose boundaries are no longer smooth but intergrown into the groundmass. The feldspars show a distinct fringe .25 mm wide of optically continuous overgrowth material crowded with inclusions of fine groundmass. The overgrowth material on all feldspar phenocrysts is restricted to microcline or perthite. Oligoclase phenocrysts are overgrown with microcline or perthite, not oligoclase, although oligoclase is abundant in the groundmass. This suggests that plagioclase feldspar more calcic than albite could not form in the metamorphic aureole of the granite.

Nearer the High Falls granite contact (34 and 78) the affect of the granite is very apparent (Figure 25). The grain size of the groundmass has increased to .4 to .5 mm and the grains are intergrown and highly recrystallized. The quartz phenocrysts are recrystallized, strained and fragmented with very irregular borders intergrown into the groundmass. The original outlines of the quartz

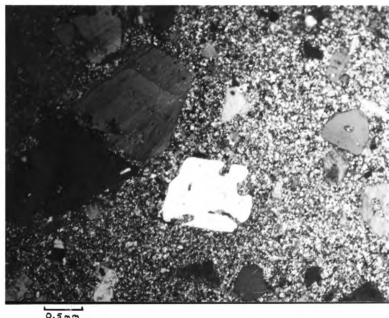


Figure 24. Fine grained groundmass and phenocrysts with sharp boundaries, Hager rhyolite porphyry (Sample 74).

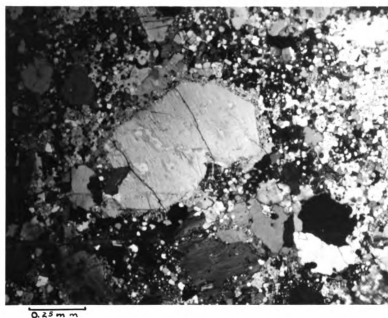


Figure 25. Recrystallized groundmass and overgrown feldspar phenocrysts, Hager rhyolite porphyry (Sample 78).

grains within the larger recrystallized masses are delineated by a zone of liquid inclusions and dust particles. The feldspar phenocrysts have been enlarged by overgrowths up to .5 mm in width which are filled with incorporated fine groundmass. The original borders of the feldspar grains are sharp and relatively free of inclusions, while the overgrowth is crowded with incorporated fine groundmass. The original size of the groundmass can be inferred from the size of the grains included in the feldspar overgrowths. It compares very closely (.05 mm) to the grain size of the groundmass of the unmetamorphosed rhyolite at localities 74 and 15. Oligoclase phenocrysts are more common than before but are overgrown by microcline or perthite rather than oligoclase.

The outcrop of Hager rhyolite porphyry west of Thunder Mountain (sample 67) exhibits a stage of recrystallization entirely consistent with the metamorphic pattern for its distance from the High Falls granite. The groundmass attains a grain size of .02 mm and shows signs of slight recrystallization. The boundaries of the quartz phenocrysts are irregular and intergrown with the groundmass. The feldspar phenocrysts are overgrown to the extent of 0.08 mm, and the overgrowths are crowded with inclusions of fine groundmass. The grain size of the phenocrysts is 2 mm.

In all cases where overgrowths appear on the feldspar phenocrysts, it seems that they have grown at the expense of the finer

feldspar grains in the groundmass. The fine groundmass which remains entrapped in the overgrowths is primarily quartz rather than a mixture of quartz and feldspar as is found in the original groundmass. The fine feldspar grains appear to have been recrystallized to form the optically continuous overgrowths of the phenocrysts.

McCaslin Formation

The assignment of the metamorphic effects in the McCaslin formation to definite metamorphic facies is difficult because of the lack of diagnostic minerals in the extremely pure quartzite. However, the change in the texture and grain size of the quartz grains together with the change in mineralogy of the limited interstitial material is an adequate indication of the progressive metamorphism from west to east as the High Falls granite is approached.

The conglomeratic quartzite of the extreme western end of the range is but slightly metamorphosed (samples 71 and 73). Megascopically the individual grains and pebble outlines are quite distinct, and the rock has the general appearance of a friable sandstone although it is firmly indurated. Under the microscope the rock resembles an orthoquartzite. The individual grain boundaries are rounded and distinct, and are only slightly intergrown with one another (Figure 26). The intergranular spaces are occupied by aggregates of sericite stained with iron oxide. The sericite most likely represents original shaley material deposited with the quartz grains.

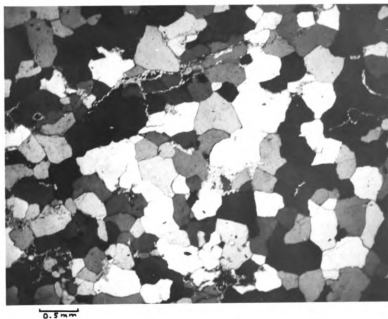


Figure 26. Slightly recrystallized quartz with interstices filled with fine sericite, McCaslin formation (Sample 73).

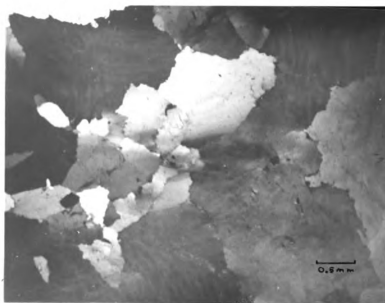


Figure 27. Highly recrystallized quartz exhibiting undulatory extinction, McCaslin formation (Sample 42).

The conglomerate at locality 4 resembles that of 71 and 73 very closely in that the individual rounded grains and pebbles are readily distinguishable in hand specimen and under the microscope. The coarser quartzite and quartz pebbles are fairly well rounded and weather out on the face of weathered outcrop joint faces. Under the microscope the grains are not intergrown and pebble boundaries are sharp and easily recognizable. The intergranular muscovite remains in the form of fine aggregates, but it is slightly coarser and distinct laths are fairly common.

Immediately west of the inferred fault in sec. 4, T. 33 N., R. 15 E. (sample 89), the individual sedimentary grain outlines are no longer distinguishable even with the aid of the microscope being recrystallized and intergrown to form an interlocking mosaic texture. Many of the quartz grains show undulatory extinction patterns which may have been caused by strain during faulting. The intergranular spaces are occupied by fine shreds of muscovite along with larger distinct laths.

The first important mineralogical change is noted in sample 90. Andalusite makes its appearance as an intergranular mineral. It has formed at the expense of the fine muscovite and occurs in the form of minute columnar aggregates. However, the dominant intergranular mineral continues to be fine shreds and laths of muscovite.

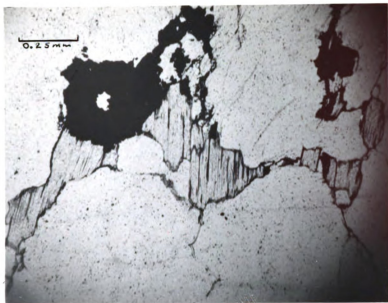


Figure 28. Coarse, optically continuous muscovite filling interstices between adjacent quartz grains, McCaslin formation (Sample 39).



Figure 29. Andalusite filling interstices between quartz grains, McCaslin formation (Sample 51).

The appearance of andalusite rather than orthoclase at the expense of muscovite reflects the deficiency of potash in the original clayey cementing material, but also precludes a loss of potash upon formation of andalusite. The rock texture is that of an interlocking mosaic of recrystallized quartz grains less than 3 mm in size showing little evidence of strain.

Samples 13 and 58 which are respectively nearer to the High Falls granite contact are characterized by strongly recrystallized quartz grains that are fractured and exhibit strong cross-hatched undulatory extinction patterns. The interlocking quartz grains have very rough irregular boundaries. Columnar andalusite which has formed from intergranular muscovite is well developed and plentiful, but still less plentiful than muscovite. The muscovite occurs in larger flakes, one of which may occupy an entire intergranular space.

Within a mile of the granite contact, the quartzite (51) is very coarse grained (up to 5 mm) and highly recrystallized. Intergranular andalusite is dominant over muscovite and appears as fairly large columns which may be rimmed by fine muscovite (Figure 29). Muscovite remains plentiful and appears as very large laths. One optically continuous lath of muscovite may occupy as many as 4 adjacent intergranular spaces.

Within 3-5 feet of the granite contact important mineralogical differences and the influence of the granite intrusive are evident. The quartz grains are very highly recrystallized and attain sizes up to 5 mm.

The rock is stained with hematite. The intergranular spaces are occupied by microcline, perthite and albite. The feldspars are fine grained and poorly developed and are associated with remnant fine muscovite. The occurrence at the immediate contact of intergranular microcline, perthite and albite (instead of andalusite) formed at the expense of muscovite indicates that potash and soda must have been supplied by the intrusive granite body. The only occurrences of microcline, perthite and albite in the entire quartzite body are restricted to the immediate contact. Evidence which will be described later indicates that penetration of soda and potash must have been restricted to less than 15 feet into the massive quartzite. The feldspar assemblage microcline-perthite-albite suggests that even at the immediate granite contact the temperature must have been restricted to less than 700°C (Laves, 1952).

The northern limb in the eastern part of the range (samples 45 and 55) is characterized by interlocking quartzite grains averaging 2 mm in size which show little evidence of strain. Andalusite is present but rare. The interstices of the quartz grains are mainly occupied by large muscovite flakes. Three to five adjacent quartz interstices may be occupied by one optically continuous muscovite lath.

The overturned south limb of the east range generally is characterized by highly strained interlocking quartz grains exhibiting pronounced undulatory extinction. The grain size of the quartz, the

relative ratio of andalusite to muscovite in the intergranular spaces and the appearance of microcline, perthite and albite are directly related to the High Falls granite contacts.

Samples 48 and 20 are extremely clean quartzite. Intergranular material is rare, but where seen consists of fine muscovite along with minor andalusite. The quartz grains attain sizes up to 7 mm and show signs of severe strain. Sample 25 is very similar; however, poorly developed andalusite and muscovite are present in approximately equal proportions filling the intergranular spaces. In sample 33 andalusite is more abundant than muscovite, but it is still fine-grained and poorly developed.

Samples 28 and 98 are very clean and therefore offer little in the way of diagnostic mineral changes. The quartz grains are highly strained and attain a maximum size of 10 mm. Foreign material is confined to iron oxide stain and fine sericite which is concentrated along secondary fractures and therefore, has been interpreted as having been introduced rather than formed by recrystallization of primary clay material.

Sample 83, which was taken less than 3 inches from the granite contact in sec. 36, T. 34 N., R. 16 E., is similar to sample 49 in that the intergranular spaces usually occupied by muscovite or andalusite are filled by microcline, perthite and albite (Figure 32). Muscovite and biotite are also present in minor quantities. This

restrictive occurrence of interstitial feldspar to the immediate granite contact again attests to the fact that only with the addition of potash and soda from the granite could feldspar form rather than andalusite at the expense of the muscovite. The specific assemblage microcline-perthite-albite again suggests that the maximum temperature even at this short distance from the contact must have been less than 700 degrees centigrade.

The quartzite represented by sample 39, taken from the east wall of the rift at a distance of less than .25 miles from the nearest exposed granite contact, is very highly recrystallized and attains a grain size of 10 mm. The intergranular spaces are occupied by large muscovite laths, which may be optically continuous in interstices as much as 10 mm apart (Figure 28).

Sample 42 represents the quartzite breccia at the extreme eastern end of the rotated segment of the south limb west of the rift. The quartz grains are highly recrystallized and fractured exhibiting extremely rough and irregular borders. The undulatory extinction is marked and appears in irregular cross-hatched patterns (Figure 27). Interstitial material is very scarce, although a few laths of muscovite fill entire interstitial spaces.

Sample 61 was taken from an outcrop in the bed of the Peshtigo River in what appears to be a large xenolith of quartzite within the High Falls granite. The sample was taken 15 feet from the contact. The quartz grains, up to 9 mm in size, are highly

recrystallized and intergrown with neighboring grains, although evidence of strain is not apparent. The quartzite is extremely clean, but a minor amount of andalusite is present formed at the expense of muscovite laths. A few minute sillimanite needles were seen along the boundaries of the quartz grains. This sample is significant in that it shows a possible limit to the depth of penetration of potash and soda from the granite into the quartzite. All other samples of quartzite taken well within the 15 foot distance from the contact show microcline, perthite and albite, but not andalusite, forming from muscovite. Therefore, the penetration of potash and soda must have been limited to less than 15 feet by the massive quartzite.

At Thunder Mountain the metamorphism is again apparent in the vicinity of the High Falls granite outcrops to the north. Sample 95 consists of recrystallized quartzite up to 5 mm in grain size. The grain borders are fairly rough and irregular. Scattered individual grains show slight undulatory extinction patterns. The intergranular spaces are filled dominantly by muscovite; however, poorly developed columnar aggregates of andalusite have formed at the expense of the muscovite. A few isolated small needles of sillimanite were also noted along the quartz boundaries.

Samples 96 and 66 were taken from finer layers in the conglomeratic base of the quartzite and contain a greater amount of interstitial material. Therefore, they afford a much better appraisal of the mineralogical changes related to the progressive metamorphism.

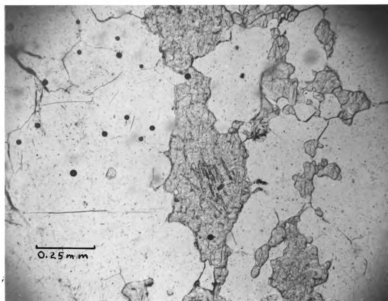


Figure 30. Coarse sillimanite needles formed within andalusite, McCaslin formation (Sample 66).

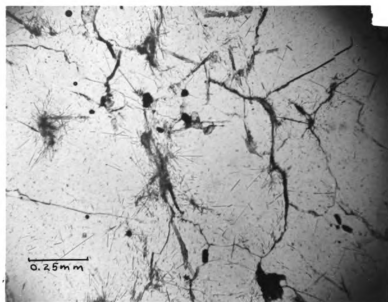


Figure 31. Fine sillimanite needles formed along quartz boundaries from remnant sericite, McCaslin formation (Sample 66).

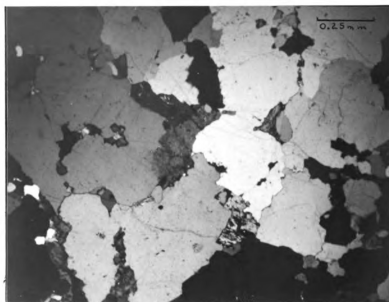


Figure 32. Feldspar assemblage (F) microcline-perthite-albite occupying interstices between quartz grains, McCaslin formation at High Falls granite contact (Sample 83).

The quartz grains of sample 96 attain a maximum size of 1 mm. They are generally elongated parallel to the bedding and stained with red hematite. The interstices between the quartz grains are filled mostly by coarse bladed aggregates of muscovite. Slightly pleochroic andalusite columns up to .2 mm in size and clouded with inclusions of iron oxide have formed at the expense of the muscovite and occupy about one-third of the total intergranular area. A few sillimanite needles are apparent forming generally at the expense of muscovite and located along quartz boundaries.

Proceeding to locality 66 which is approximately one mile along strike from known granite outcrops (the exact contact, however, is probably much nearer), the quartz grains attain sizes up to 2.5 mm. The interstitial spaces are occupied by large, up to 1 mm, well developed columnar grains of andalusite. They are generally clear but contain coarse iron oxide inclusions. Muscovite is almost completely lacking except for a minor amount rimming the andalusite grains. Coarse sillimanite needles lie within andalusite grains and have formed at its expense (Figure 30). Fine sillimanite needles are numerous and well developed along quartz borders where they have formed at the expense of fine remnant sericite (Figure 31). The presence of sillimanite indicates the hornblende hornfels facies.

The exposures of quartzite at Deer Lookout Tower Hill show an extreme stage of the metamorphism observed in the general

McCaslin region. Megascopically, a secondary foliation caused by large flakes of muscovite is readily apparent parallel to the intrusive arm of granite cutting the quartzite. Under the microscope sample 68 is a quartz-sillimanite schist. Interstitial large muscovite flakes have been largely replaced by needles of sillimanite. The needles are aligned parallel to the foliation caused by muscovite laths and elongated quartz grains. The quartz grains of sample 70 which is located approximately one mile across strike from the granite is characterized by large intergranular muscovite flakes which are optically continuous in 4-5 adjacent quartz interstices. Minor andalusite has formed at the expense of the muscovite.

Temperature of Metamorphism and Granite Intrusion

The metamorphic zonation in the McCaslin district is due to thermal gradients that were set up by the High Falls granite intrusive during or immediately following the post-Huronian--pre-Keweenawan orogenic interval (Killarney revolution?).

The concept of different metamorphic facies produced at one temperature level because of variations in water content of the rocks (Yoder, 1952) is not applicable, inasmuch as the isograds cross lithologic units that had nearly uniform composition before metamorphism.

The source of the heat required for metamorphism is clearly evident as the metamorphic zones are symmetrically distributed with respect to the High Falls granite.

The distribution of the metamorphic zones shows a complete lack of correlation with the regional structure. The metamorphic gradient rises continuously to the east along the main McCaslin range and to the northeast at Thunder Mountain with no correlation to formation boundaries or lithologic changes, but showing close correlation to the proximity of the granite body.

The relative intensity of deformation is generally related to the intensity of metamorphism in that both were to a large extent directly controlled by the granite intrusion. However, metamorphic rank in areas of equal deformation may vary markedly with proximity to the intrusive granite contact as shown by the rapid metamorphic changes along strike at Thunder Mountain and along the strike of equally deformed portions of the northern and southern limbs of the eastern McCaslin range.

The general aspect of the mineral assemblages formed by metamorphism and their proximity to the granite contacts are an important indication of the maximum temperature of the granite intrusion and the maximum limit to the penetration of fluids from the granite into the quartzite. These observations also have important bearing on hypotheses concerning the lower temperatures at which a granitic magma can remain in a fluid state and the ease of granitization of a clean, massive quartzite body. One of the most significant indications of maximum temperature conditions is the feldspar assemblage which

forms during metamorphism. In each of the three rock types, the Waupee volcanics, the McCaslin quartzite and the Hager rhyolite porphyry, feldspars have formed during metamorphism. In each, the occurrence and the source of the materials from which the feldspars formed is quite different. In the Waupee, the feldspar assemblage has formed at the expense of zoisite and aggregates of fine muscovite. In the quartzite, the feldspars have formed from interstitial muscovite plus soda and potash added from the granite. In the Hager rhyolite porphyry, the feldspar assemblage which forms the overgrowths on the feldspar phenocrysts has grown by reconstitution of fine oligoclase, microcline and perthite from the groundmass. The feldspar assemblage which has formed in all three cases is microcline-perthite-albite. No plagioclase more calcic than albite was formed during metamorphism, even though adequate amounts of calcium were present as shown by the occurrence of zoisite in the Waupee and oligoclase in the Hager. Also, it is very likely that the fluids originating from the High Falls granite contained calcium, for the granite is rich in oligoclase and fluorite. It is important also to note that all of the potash feldspar which formed during metamorphism exhibits microcline twinning or is intergrown with albite in the form of perthite.

According to Laves, 1952, and other sources, the feldspar assemblage microcline-perthite-albite would form and be stable only at temperatures below 700 degrees centigrade. Above this temperature the potash feldspar would be sanidine, and the plagioclase would be more calcic than albite.

The maximum temperature of 700 degrees centigrade proposed here for contact metamorphism related to the High Falls granite body also agrees favorably with Turner and Verhoogen, 1960, who place the temperature of granitic contact metamorphism between 300 and 800 degrees centigrade. It also agrees with Goranson's findings, 1932, that a rock of granitic composition with 6.5 percent water at 1000 bars pressure may be partly molten at 700 degrees centigrade. The presence of abundant fluorite in the High Falls granite indicates that the amount of volatiles and water might well have been greater than 6.5 percent, and therefore, would maintain a fluid state at temperatures below 700 degrees centigrade. The texture of the granite within inches of the quartzite contact indicates that it was in a semi-crystallized state at the time of intrusion, containing about 30 percent crystallized material which persists in the present completely solidified mass as large phenocrysts in a fine groundmass. The phenocrysts are somewhat rounded and embayed by resorption and, in a few cases, are fractured, most likely by crushing during the movement of the crystal mush.

The occurrence of sillimanite is also an important indication of temperature conditions. According to Rosenquist's conclusions, 1952, modified by H. L. James, 1955, the general level for the sillimanite zone at depths of 0-15 km would range upward from about 600 degrees centigrade. The general occurrence of sillimanite in the McCaslin district is outside of the zone of penetration of fluids from the granite

into the quartzite and would therefore be in a slightly lower temperature range than the immediate contact zone.

Samples of quartzite taken within inches to a few feet from exposed granite-quartzite contacts contain microcline-perthite-albite within the quartz interstices; whereas samples taken as near as 15 feet from the contact contain andalusite and sillimanite in the quartz interstices. The relationship of the feldspars and the andalusite-sillimanite to the granite contact is a direct indication of the penetration of fluids from the fluorite rich granite into the massive quartzite. In the McCaslin formation the penetration was restricted to less than 15 feet.

The relationships cited previously imply that granitization of a clean, massive quartzite body such as the McCaslin formation is difficult to attain even under contact metamorphic conditions where an ample source for granitization fluids is readily available and abundant, unless secondary avenues such as shale partings, joints or fractures are present and abundant for the penetration by granitic fluids. The completeness of the transformation would also depend to a large extent on the purity of the quartzite and the bulk chemistry of the interstitial material. An impure quartzite or arkose might be changed to a granite appearing rock simply by recrystallization and reorganization of the original rock materials providing that the bulk chemistry and temperature conditions are adequate. Under temperature conditions postulated in

the McCaslin district, the quartz of the quartzite did not enter into any of the reactions but was simply recrystallized.

From the evidence presented it seems that the High Falls granite has had a magmatic history and is not the result of granitization of the McCaslin formation as Roberts, 1951, concluded.

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ANALYSES OF JOINTS

The joints of the McCaslin quartzite formation were analyzed in six groups, each of which represents a portion of the range which more or less reacted as an individual unit to the forces of deformation. Joints from the following portions of the range were grouped as separate units: (1) The portion of the range in the vicinity of Knowles Creek, (2) The north segment of the eastern range, (3) The south segment of the eastern range, (4) The south segment of the eastern range immediately west of the rift, (5) The portion of the eastern range east of the rift and (6) Thunder Mountain.

Face poles of 20 to 35 joints from each portion were plotted on separate equal area nets. The grouping of the face poles showed clearly that each portion of the range contains three distinct joint sets. The attitude of the most prominent joint set is generally parallel to the bedding. In many places it is slickensided indicating differential movement after joint formation. The slickensides probably formed by differential movement of adjacent quartzite layers during the regional folding of the quartzite.

The remaining two joint sets make up a conjugate joint system. If these two joint sets in the brittle quartzite are assumed to be compressional, the bisector of the acute angle of the two joint sets is equal to the direction of maximum compression or the tectonic C-axis (S. B. Hills, 1957). The bisector of the obtuse angle is the

tectonic A-axis or the axis of maximum strain, and the line determined by the intersection of the two joint planes is equal to the tectonic B-axis or the axis of intermediate strain.

The A, B, and C tectonic axes were determined from the conjugate joint system in each portion of the range and are shown on map number II.

The joints of the conjugate system are high angle joints, greater than 70° dip, and, in general, they are symmetrical with respect to the bedding and the bedding joints. The strike of the bedding and the bedding joints very nearly bisect the obtuse angle formed by the intersection of the conjugate joint sets, and, therefore, corresponds to the direction of the tectonic A-axis or the axis of maximum stress release. A petrofabric study which is discussed in the next section also indicates that the direction of maximum readjustment was parallel to the strike of the bedding.

Along the main McCaslin range the joint system consists of one set which strikes within the range N. 0° - 60° W. and another which strikes within the range N. 0° - 45° E. The bisector of the acute angle formed by the intersection of the two joint sets is in each case within the range N. 25° W. to N. 1° E. The deviation within the ranges seems to be closely related to changes in the attitude of the bedding.

At Thunder Mountain the conjugate joint system consists of one set which strikes N. 50° E. and another that strikes N. 56° W.

The strike of the bisector of the acute angle is N. 93° W.

In every case the plunge of the bisector of the acute angle (tectonic C-axis) determined from the intersection of the conjugate joint planes is within 10° of horizontal and very nearly perpendicular to the strike of the bedding. This is evident along the main McCaslin range as well as at Thunder Mountain. If it is assumed that this direction corresponds to the direction of maximum stress, it is difficult to understand the relationship of the stress field operating on the main McCaslin range and that at Thunder Mountain. However, this difficulty is overcome if it is assumed that the stresses were applied from below possibly related to the rising High Falls granite body while the quartzite formation was still in a horizontal or nearly horizontal position. Therefore, the applied stress was vertical, and the direction of maximum stress release was in the plane of the bedding and pointing toward the present position of the main High Falls granite mass.

PETROFABRIC ANALYSES

A petrofabric study has been made of five samples of the McCaslin formation and four samples of the Hager rhyolite porphyry to supplement the structural data obtained in the field. The positions of these samples relative to the major structure is shown on map III.

It is not considered necessary to give an elaborate discussion of the theory and procedures of petrofabric analysis. These subjects are treated thoroughly by Fairbairn (1954), Billings (1954), Hietanen (1938) and many others.

All samples were oriented in the field. Two thin sections from each specimen were cut for study, one perpendicular to the other. A petrographic microscope of the Leitz type and a 4-axis universal stage were used for the petrofabric analysis. From each sample of quartzite, a study was made of the orientation of the C-axes of 300 quartz grains. From each sample of the rhyolite a separate analysis was made of the orientation of the C-axes of the quartz grains in the groundmass and those occurring as phenocrysts. Three hundred C-axis orientations from grains in the groundmass were determined, and approximately 150 C-axes of quartz phenocrysts were determined from each sample. The plotting was done on the lower hemisphere of an equal-area net. Concentrations of the C-axes were determined by standard center and peripheral counters of 1.0 cm radius. Counting was spaced by grid distances of 1.0 cm. The diagrams which resulted

from the study of the thin sections have been rotated into a horizontal plane and are plotted on map III.

The most significant features of the fabric diagrams from quartzite samples 58, 45, 28 and 95 which are within the realm of the granite's influence is that they are very nearly parallel to the strike of the bedding and to the tectonic A-axes which were determined from the study of the joint system in the McCaslin formation. The maxima which range from 5 to 8 percent may be related merely to residual sedimentary fabric, but more probably to bedding plane shear related to the regional deformation and the intrusion by the High Falls granite. Sample 4, taken outside the realm of the granites influence, shows very nearly a random distribution with just a very slight suggestion of a horizontal girdle. It seems to show no relationship to the attitude of the bedding or to the granite intrusion.

The fabric diagrams obtained from the quartz grains in the groundmass of the Hager rhyolite porphyry are inconclusive in that they do not show girdles or point maxima which can be related to any macro- or micro-structures in the rhyolite. The diagrams obtained from the quartz phenocrysts, however, may reach maxima of 6-7 percent and seem to be vaguely related to the attitude of the foliation in the rhyolite. The preferred orientation of the C-axes of the quartz phenocrysts is probably related to the residual fabric produced during the extrusion of the partially crystallized rhyolite lava.

GEOLOGIC HISTORY

The oldest rocks of the McCaslin district are the volcanic flows, pyroclastics and sediments of the Waupee series distributed about the outer borders of the quartzite ranges. The extrusions and volcanic sedimentation was followed by a period of deformation and igneous intrusion. It is quite possible, however, that a large portion of the granitic and dioritic masses associated with the Waupee volcanics were formed by granitization.

For a long period these intrusives and volcanic rocks formed the land surface of the district and were subjected to the usual geological processes common to land areas the world over. The earlier formed rocks were eroded and beveled to form a terrain exhibiting at least locally, low to moderate relief.

The old land surface sank below the level of the seas and the overlying McCaslin series was deposited on it. The first rock deposited in the oncoming sea was the conglomerate forming the base of the McCaslin formation, and this was followed by the succeeding beds of finer ripple-marked and cross-bedded sands which make up the bulk of the formation. The extreme thickness, 3000 to 5000 feet, of the shallow water sediments implies that the basin of deposition was subsiding during sedimentation.

The lateral size variations of the boulders and pebbles in the basal conglomerate and the attitude of the cross-bedding and ripple

marks indicates that the current direction and source of sediments was from the west and northwest. The lithologic types and shapes of the boulders and pebbles in the basal conglomerate, i. e. quartzite, quartz, Waupee fragments and iron formation, imply a varied and wide ranging source. The quartzite and quartz are well-rounded indicating a fairly distant source whereas the Waupee and iron formation pebbles are angular to sub-rounded indicating a nearer source.

A long hiatus is believed to exist between the McCaslin formation and the overlying Hager rhyolite, however, the geologic history can only be inferred from a few scattered inclusions in the Hager rhyolite porphyry and from the study of rock sequences in similar geologic districts such as the Baraboo district of Wisconsin and the Marquette district of Michigan. In each case the evidence suggests a gradual change of conditions in which the sand gave way to the deposition of finer sediments.

This interval includes a sedimentary period of unknown duration which was followed by a period of erosion. The erosion removed the overlying formations and in places much of the McCaslin formation itself leaving a region of fairly high relief. In the Mountain region only a thin conglomerate remains. The McCaslin formation and associated rocks suffered minor deformation which preceded or initiated the Killarney? revolution.

The Killarney? revolution was initiated in the McCaslin area by more intense folding of the McCaslin formation, intrusion by

rising igneous bodies from below and by the extrusion of the Hager rhyolite porphyry onto the mature erosional terrain which was controlled primarily by the structure of the resistant McCaslin formation.¹ The rhyolite did not spread over a wide area but was more or less confined to the proximity of the feeding conduits by its extreme viscosity and by the terrain which reflected the structure of the McCaslin formation. The above accounts for the very thick mass of rather coarse grained rhyolite limited to a relatively small areal extent.

Inclusions of dark, fine grained materials are found in the central and deeper portions of the thick rhyolite mass which have been exposed by subsequent stream and glacial erosion. The inclusions probably represent the finer sediments overlying the quartzite which were incorporated in the extruding rhyolite, or they may represent fragments torn from the walls of the feeding conduits or roofs of the underlying magma reservoirs.

The igneous activity of the Killarny? revolution continued with the upward movement of the High Falls granite which advanced through the wall rocks by a combination of the processes of forceful injection, stoping and assimilation. The Waupee volcanics offered little resistance to the progress of the granite. They were easily penetrated by the granite, and because of their greater density, sank

¹Gates, 1942, from his work in the Baxter Hollow region of the Baraboo syncline concluded that folding and intrusion of the Huronian Baraboo series progressed simultaneously and that the Baxter Hollow granite is intrusive into and therefore younger than the Baraboo series.

into the granite mass and were assimilated. The massive quartzite, however, acted as a barrier to the rising granite mass and was deformed and fractured on a very large scale. The force of the rising intrusion caused the regional deformation of the quartzite to form its present structural configuration. The deformation consisted mainly of regional flexing and fracturing, however, large blocks of quartzite such as those at Deer Lookout Tower Hill and that in the bed of the Peshtigo River represent portions of the quartzite mass which were detached from the main body of the formation and floated to their present position by the force of the granite intrusion. When the heat of the intrusion was finally dissipated, the High Falls granite batholith and its associated metamorphic aureole was frozen to form the structural relations seen today.

Following the Killarney? revolution the region was subjected to long periods of erosion and later to possible deposition of Keweenawan and younger sediments which were subsequently removed by erosion.

During the Pleistocene the area was subjected to glacial erosion and deposition, and, later, to post-glacial and present weathering and erosion.

REGIONAL GEOLOGY AND CORRELATION

The known Precambrian geology of northeast Wisconsin, taken from several references is plotted on map IV. The integrated geologic picture shows the existence of a large Precambrian syncline in northeast Wisconsin which the author has named the McCaslin syncline. The trough opens to the west and appears to close to the east, but is disrupted by the High Falls granite intrusive. The formation which furnishes the structural framework for the syncline is the middle Precambrian McCaslin quartzite formation.

The sequence of rocks exposed in the McCaslin and Thunder Mountain areas is repeated with slight variations in the vicinity of Mountain, Wisconsin, approximately fifteen miles south of the main McCaslin range. The geology of the Mountain area has been described in detail by the author (Mancuso, 1957). A brief résumé of the geology of the Mountain area is as follows: The thick Waupee volcanic sequence and associated Macauley granite is overlain to the north by the Baldwin conglomerate. The conglomerate in turn is unconformably overlain by the Hager rhyolite porphyry. The sequence of rocks was concluded to represent the southern limb of a large regional syncline, the extent of which was unknown until the present mapping program was completed. The Baldwin conglomerate is considered to be correlative with the McCaslin formation because of the similarity of rock types and lithologic sequence, although it reaches a thickness only slightly in excess of 300 feet.

CORRELATION OF McCASLIN DISTRICT
TO IRON AND DICKENSON COUNTIES, MICHIGAN

	Iron and Dickenson Counties	McCaslin District
Upper Precambrian	Keweenawan series	Missing
Middle Precambrian	Granitic intrusive rocks and diabase dikes	High Falls granite Belongia granites Hager rhyolite porphyry
	Paint River group	McCaslin formation
	Baraga group	
	Menominee group	
	Chocolay group	
Lower Precambrian	Gneissic granite and other crystalline rocks	Macauley granite and diorite
	Quinnesec formation	Waupee volcanics

Table 5.

In several monographs and other publications concerning the Lake Superior iron bearing districts, the general character and relations of the Precambrian series have been fully described. The nearest districts of well-mapped and adequately dated and correlated Precambrian sedimentary formations are in the Iron River, Crystal Falls and the Menominee districts of Michigan located 30-45 miles to the north. The exact stratigraphic position of the Precambrian formations in the McCaslin district can be determined only approximately and conjecturally because of their isolation and complete separation from the main Precambrian successions to the north.

The general correlations suggested in this paper are based upon rock similarity, lithologic sequence and association to igneous rocks. The author recognizes the shortcomings of these methods and, therefore, proposes the following correlations as tentative rather than final until such time as absolute age determinations are made available or the mapping is extended northward to join the dated Precambrian areas to the north.

Various separate correlations are possible because of the very limited number of geologic formations and the lack of diagnostic lithologic sequences in the McCaslin district. In the district there are only three unconformable Precambrian series; the Waupee complex, the McCaslin formation and the overlying Hager rhyolite porphyry.

The Waupee series of the McCaslin district is very similar with respect to general lithologic character, comparative deformation and metamorphism to the Quinnesec formation of Southern Dickinson and Iron Counties, Michigan. W. C. Prinz, who mapped in detail the type area of the Quinnesec formation, concluded that it is lower Precambrian. His conclusion is supported by Allen Cain (1960, written communication) who mapped the southward continuation of the Quinnesec formation in northern Marinette County, Wisconsin. Some workers, however, have suggested that the Quinnesec formation is a more highly metamorphosed phase of basic extrusives in the Michigamme formation and, therefore, is Huronian in age, and other workers would even have the Quinnesec formation as young as Keweenawan. The possibility exists also that the Waupee formation is not a correlative of the Quinnesec formation but of the Hemlock or the Badwater volcanic formations of Iron and Dickinson Counties. These comparisons are highly speculative and without supporting evidence.

The McCaslin quartzite formation may be a correlative of any one of a number of quartzite formations in the Huronian sequences. The general lithology is similar to each of them and it rests on a volcanic sequence as do many of them. If an attempt were made to correlate the McCaslin formation with a particular formation in Iron or Dickinson Counties, it is seen that it may be compared to the

Sturgeon quartzite resting on a pre-Huronian basement, or a quartzite which overlies the Hemlock volcanics (Goodrich?), or a quartzite that overlies the Badwater volcanics. From the above comparisons, one may place the McCaslin formation in either the lower, middle or upper Huronian.

The McCaslin quartzite has a particularly close resemblance in lithology, metamorphism and total thickness to the Baraboo quartzite of Sauk and Columbia Counties, Wisconsin. However, the Baraboo formation has not been dated precisely except that it is placed in the Huronian, so it offers no further aid to the correlation of the McCaslin formation.

It seems to the writer that it is sufficient to use the term Huronian for the McCaslin formation and Lower Precambrian for the Waupee complex.

The Hager rhyolite porphyry, the High Falls granite and the Belongia granite are definitely post-quartzite in age and, therefore, post-Huronian. The author postulates that the Hager rhyolite porphyry, the High Falls granite and the Belongia granite are part of a post-Huronian--pre-Keweenawan epoch of diastrophism, metamorphism and granite intrusion (Killarney revolution?) which radioactive dating methods will probably show to have occurred about 1,000 to 1,100 million years ago.

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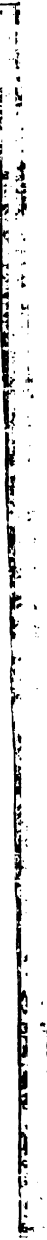
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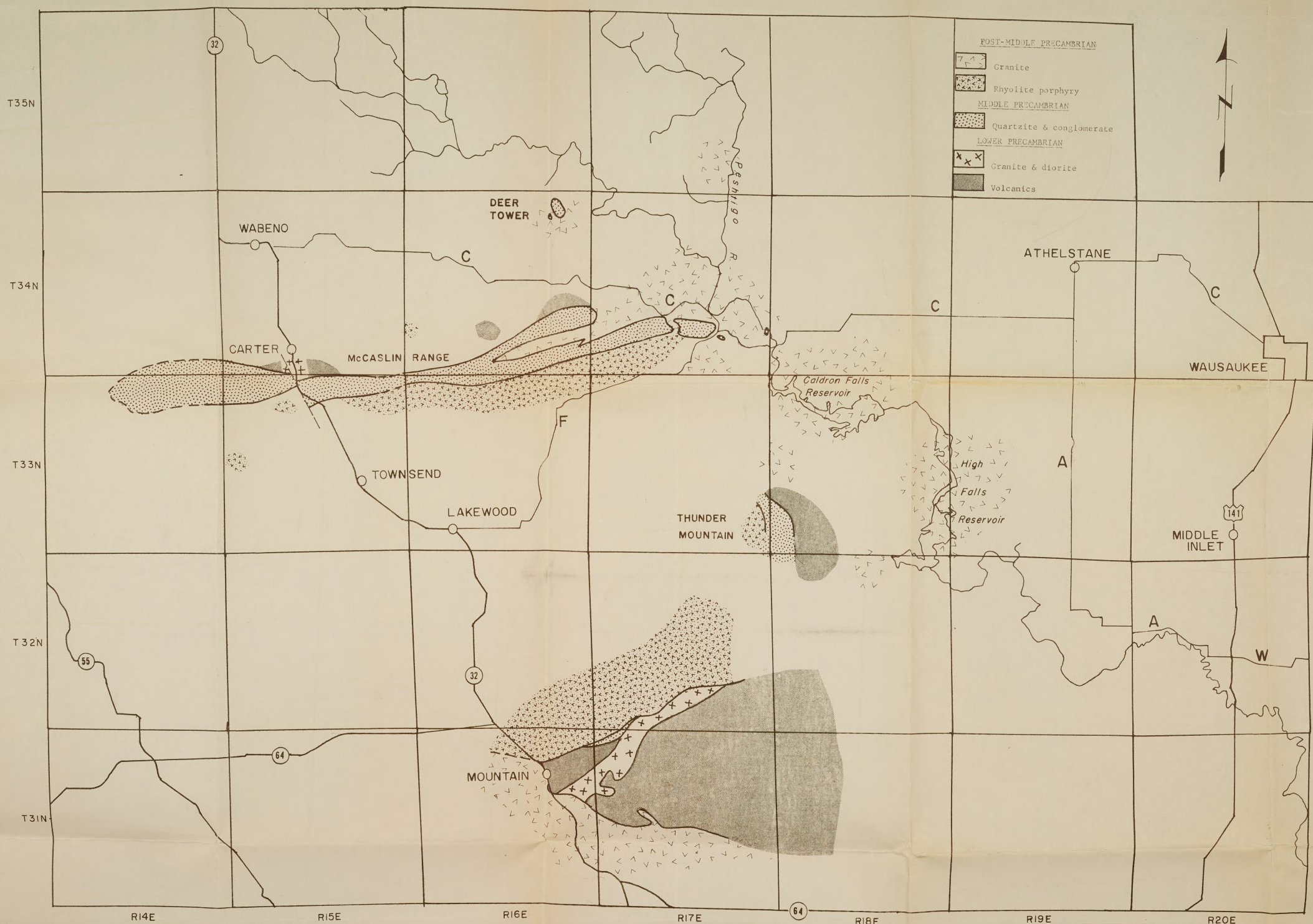
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