Geology of the Little Commonwealth area

Florence County, Wisconsin

by

Robert W. illiam Johnson, Jr., 1924 -

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ABSTRACT

The Little Commonwealth exploration in northeastern Florence County, Wisconsin, is underlain by highly ferruginous clastic rocks that are stratigraphically equivalent to vitreous quartzite. The relationship between these rocks is one of abrupt facies change, with complete gradation between facies. This stratigraphic unit is conformably underlain by sericitic phyllite and unconformably overlain by slate and graywacke of the lower part of the Dunn Creek formation of upper Animikie age.

The strata are vertical, and minor structures due to tectonic movement are present. Some of the deformation may be of pre-diagenetic origin.

Metamorphism of the Little Commonwealth rocks has developed abundant stilpnomelane, garnet, and martite. Metasomatism is indicated by the occurrence of tourmaline, pyrite, chalcopyrite, and arsenopyrite. The area is probably in the biotite zone of regional metamorphism.

INTRODUCTION

Scope of the present investigation and relationship of this report

The lithology, structure, and stratigraphy of Florence County, Wisconsin, have not been adequately understood to be compatible with the conditions observed in neighboring iron-bearing districts to the east and northwest. The results of previous investigations have been indeterminate largely because of widespread cover by glacial deposits that obscure critical parts of the area. In addition, there is a high degree of lithologic uniformity in the rocks of the area, and subtle textural or compositional features of the rocks which might be used as stratigraphic markers change rapidly, both laterally and stratigraphically.

The present study of northeastern Florence County was begun in 1955 by the United States Geological Survey, in cooperation with the Wisconsin Geological and Natural History Survey, to be coordinated with a broad study of the iron-bearing formations and associated rocks in southern Iron County, and southern Dickinson County, Michigan.

According to Dutton (1950):

"The objective of this work has been a better understanding of the lithology, stratigraphy, and structure in each of the districts, by means of detailed geologic mapping, and a compilation of all available basic data. An essential part of the program is that much information becomes recorded and, if not confidential, may be used by other geologists interested in clarifying the concepts for the districts and for the region."

In general, geologic mapping that has been completed in neighboring districts indicates a convergence of geologic trends towards northeastern Florence County. A brief discussion of the problems and implications arising from this structural convergence, which bear on the present mapping project, is given by Dutton (1950, p. 7).

During the course of the present study the geology in this district is being clarified by making use of recently published data from neighboring districts and by mapping in great detail. As the work has progressed there have been recognized a number of unit problems, each of which must be resolved before an adequate appraisal of the geology of larger areas can be made. One of these local problems occurs in the Little Commonwealth Exploration area.

Acknowledgments

Grateful appreciation is expressed for permission to use in this report data from the cooperative study and from the files of the Wisconsin Geological and Natural History Survey.

An expression of thanks is due to C. E. Dutton, with whom the author worked in the Florence district study during the period 1955-1958; he suggested the problem, gave much assistance in the field and in the office, and critically reviewed the manuscript. Thanks are also due to Professors S. A. Tyler, R. C. Emmons, and G. P. Woollard of the staff of the Department of Geology, University of Wisconsin,

for discussion and suggestions. X-ray determinations were made in the Department of Geology by Professor S. W. Bailey. Numerous visitors to the area offered many helpful suggestions and criticism. Among these thanks are due R. F. Black, G. F. Hanson, H. L. James, and K. L. Wier.

Location, geography, and topography

The Little Commonwealth exploration is located in northeastern Florence County, Wisconsin, about 2 miles southwest of the village of Florence, (fig. 1). It occupies the extreme southwestern part of

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Figure 1. Map showing location of Little Commonwealth exploration and generalized geology of the Crystal Falls, Michigan, and Florence, Wisconsin, area.

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sec. 32, T. 40 N., R. 18 E., and extends westward for about 800 feet into the southeast quarter of sec. 31. The exploration proper consists of two exploratory shafts, together with numerous test pits and trenches. Bedrock is exposed in small patches over much of the area and has been further exposed in many of the trenches (pl. 1).

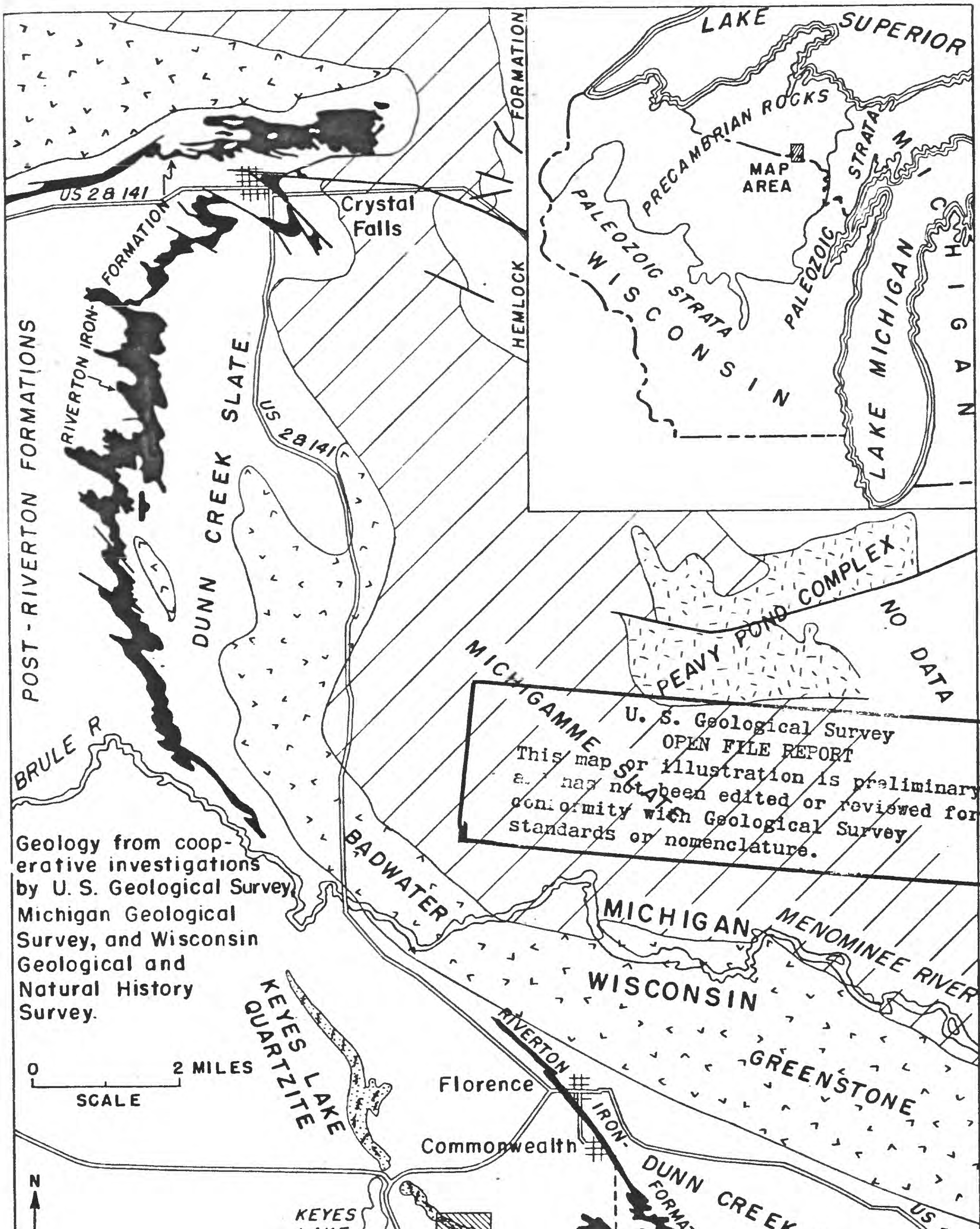

Figure I. Map showing location of Little Commonwealth exploration and generalized geology of the Crystal Falls, Michigan, and Florence, Wisconsin, area.

This exploration lies at the east end of a bedrock ridge which crosses sec. 31 in a northwesterly direction. The area is relatively inaccessible. It lies about a third of the way between Keyes Lake and County Trunk "N", and the only access roads are poorly maintained wood roads which can be driven over with difficulty in dry weather. One of these wood roads enters the area from the west, leaving Wisconsin Route 101 at the U. S. Forest Service Ranger Station. The other approaches from the east, leaving County Trunk "N" about a quarter of a mile north of the southwest corner of sec. 34, T. 40 N., R. 18 E. A third wood road has recently been re-opened which approaches the area from the south, via the Lake Emily road. This road extends northward within an eighth of a mile of the exploration. None of these roads is recommended for vehicles, except trucks, these preferably with four-wheel drive.

Topographic maps are not available for most of Florence County, and the elevations of the few bench marks that have been set in the area have not been computed. Hotchkiss (1920, unpublished report) mentions that the greatest local difference in relief is about 250 feet and gives the following approximate elevations:

	Feet
Commonwealth Hill (center, sec. 33, T. 40 N., R. 18 E.)	1550
Eagle Hill (near the Florence mine, 20-40-18)	1430
Florence railway station	1290
Sand plains east of Florence	1150-1200

The source of these data is not known.

In panorama, the crest of the ridge in sec. 31, T. 40 N., R. 18 E., does not appear to be of appreciable difference in elevation from Commonwealth Hill. The highest point on this ridge lies at the terminus of the wood road from the west and just west of the exploration area. For purposes of this report, this elevation is assumed to be of the order of 1,500 feet. The elevation of the ridge line in sec. 31 is irregular, generally diminishing northwestward in a series of 20-foot benches. In the northwest quarter of sec. 31 the ridge terminates abruptly in a 50- to 60-foot bluff; a ridge reappears in the southeast quarter of sec. 25, T. 40 N., R. 17 E., terminating in a similar bold bluff. Keyes Lake lies in and just to the south of this gap in the ridges. The outcrop portion of the ridges averages some 40 to 60 feet higher than the lower slopes. These lower slopes, mantled with glacial material, gradually diminish in elevation to the north and south.

In general, the area is poorly drained, the result of immaturity of the drainage pattern developing on the extensive glacial deposits. In consequence, large and small swamps are found at all but the highest elevations. The streams, except for the major drainage to the north and south, are small and sluggish. Numerous lakes of glacial origin occur to the west and south of the Little Commonwealth area.

The pre-glacial relief of this part of Florence County was much greater than that of the present. Hotchkiss (1920, unpublished report) estimates this pre-glacial relief to exceed 700 feet in places. The land forms which are now controlled by bedrock distribution are those underlain by the more resistant of the observed rock types and probably existed in much the same topographic distribution in pre-glacial time. Their present emergence is largely because they probably received little if any glacial cover.

Geologic setting

No satisfactory explanation of the geology of Florence County has been published. In 1911 Van Hise and Leith (1911, p. 321) state: "As yet ... the district has not been studied with sufficient exhaustiveness to definitely establish the succession and structure." This mention in publication is the last available, except for brief reference in progress reports on investigations in northern Michigan (Dutton, 1950).

The study now in progress has proved continuity of rocks of the Paint River group (James, 1958) of the upper Animikie series (Huronian of earlier reports) southeastward from the Iron River-Crystal Falls district into Florence County. The stratigraphy of these rocks is given in table 1. The basal part of the Paint River group in Florence County, Wisconsin, is underlain to the north by a thick series of basic volcanic flows. Because of extensive cover by glacial deposits, the character of the footwall and hanging wall sequence in the district is poorly known, except in the vicinity of the iron-formation. In general these rocks occupy a tightly folded syncline which is an extension of the basin of the Iron River-Crystal Falls district. The beds within this fold, wherever observed in the Florence district, are seen standing vertically or very steeply inclined. The Riverton iron-formation within this syncline has been mapped beyond the town of Florence and is known to occupy the keel of the syncline in sec. 34, T. 40 N., R. 18 E., the site of the Commonwealth group of mines. Little is yet known concerning the southwest limb of the Florence syncline beyond sec. 33, T. 40 N., R. 18 E.

Table 1.
Lithologic sequence of Precambrian rocks in Iron and Dickinson Counties, Michigan[1]

Precambrian	Upper Precambrian	Keweenawan series	Diabase dikes and sills (probable age about 1100 million years)		
			Intrusive contact		
	Middle Precambrian		Granitic intrusive rocks (probable age at least 1400 million years)		
			Intrusive contact		
			Metadiabase and metagabbro		
			Intrusive contact		
		Animikie[2] series	Paint River group	Fortune Lakes slate	
				Stambaugh formation	
				Hiawatha graywacke	
				Riverton iron-formation	
				Dunn Creek slate with Wauseca pyritic member	
			Baraga group	Badwater greenstone	
				Michigamme slate	
				Fence River formation	Amasa formation
				Hemlock formation with Mansfield iron-bearing slate member and Bird iron-bearing member	
				Goodrich quartzite	
			Unconformity		
			Menominee group	Vulcan iron-formation	Loretto slate member
					Curry iron-bearing member
					Brier slate member
					Traders iron-bearing member
				Felch formation	
			Unconformity		
			Chocolay group	Randville dolomite	Saunders formation
				Sturgeon quartzite	Saunders formation
				Fern Creek formation	
			Unconformity		
	Lower Precambrian		Gneissic granite and other crystalline rocks		
			Intrusive or replacement contact		
			Dickinson group	Six-Mile Lake amphibolite	Quinnesec formation (position indeterminate)
				Solberg schist, with Skunk Creek member	Quinnesec formation (position indeterminate)
				East Branch arkose	Quinnesec formation (position indeterminate)
			Unconformity		Quinnesec formation (position indeterminate)
			Granite gneiss		Quinnesec formation (position indeterminate)
			Quartzite and schist (small bodies included in granite gneiss)		Quinnesec formation (position indeterminate)

1/ After James (1958).
2/ Huronian of older reports.

To the west and northwest of sec. 33, in the expected position of the southwest limb of the syncline, there occurs a ridge-making white vitreous quartzite--the "Keyes Lake" quartzite of earlier reports (Hotchkiss, 1920; Aldrich, 1932). This is an outstanding formation both because of its topographic prominence and its stratigraphic, lithologic, and structural incompatibility with the normal conditions of the district. Lithologically, it bears resemblance to the Sturgeon quartzite in the lower part of the Animikie series. Aldrich (1932) refers to the "Keyes Lake" quartzite as an "orphan formation," and the enigmatic stratigraphic and structural position of this quartzite has been one of the major deterrents to successful investigations in Florence County. Details of distribution, stratigraphic position, and structure of this formation are beyong the limits of this report; however, the study now in progress tentatively indicates a pre-Paint River age.

Reconnaissance studies of the area southwest of the "Keyes Lake" quartzite indicate a stratigraphic succession which, except for rise in metamorphic grade, is not greatly different from that of the Florence trough, and hence, these rocks may be of Paint River age. The areal geology, so far as is known at present,is shown in figure 1.

The geology south of the Florence syncline is mostly unknown. Extensive glacial cover and rise in metamorphic grade in this direction contribute to the complexity of the area. Results of recent studies in southern Dickinson County, Michigan (Bayley, 1957), indicate that rocks of the Baraga group (James, 1958, p. 35-37), and possibly older strata, underlie this southern sector. Farther south, beyond the metasedimentary and metavolcanic rocks, lies a large body of acidic and intermediate plutonic rocks. These rocks are reasonably well exposed along the Pine River and southward, but the field relations have not yet been studied in detail.

Historical sketch of the exploration

The only published report that specifically mentions the area of the Little Commonwealth exploration is that of Brooks (1880). He notes, in part:

> "The natural exposures of ferruginous rock and strong magnetic attraction, which were first observed by Col. Chas. Whittlesley at this locality [SW¼ sec. 32, T. 40 N., R. 18 E.], many years ago, drew attention to its promise of merchantable ores; but it was not until test pits were sunk by H. D. Fisher, under auspices of the Commonwealth Iron Company ... in the summer of 1876, that a workable deposit was found in Sec. 34 [T. 40 N., R. 18 E.] ... " (p. 490).

At some time between 1877 and 1879 a shaft was sunk at a point about 800 feet northeast of the southwest corner of sec. 32. In his report Brooks refers to this as the "Sec. 32 shaft" and notes that slates of varied lithologies were encountered in nearby test pits. Subsequently, probably in 1883, the area just west of the initial work was explored by numerous test pits, trenches, and a second deep shaft. All of this exploration was presumably done by the Commonwealth Iron Company.

During the period 1910-11, the Florence district was mapped by field parties of the Wisconsin Geological Survey, and a study of the field notes compiled by these parties indicates numerous visits made to the Little Commonwealth area in the effort to understand the geology (Hotchkiss, 1920, unpublished report). Aldrich, working from maps of the Hotchkiss survey, revisited the district in 1931, made a geologic and geophysical reconnaissance, and prepared a report that is unpublished (Aldrich, 1932).

In 1951 five diamond drill holes were completed in the eastern part of the exploration by the M. A. Hanna Company. A planimetric map of the exploration and a dip-needle survey were also made at that time. All of these data have been made available for use in the present study.

The origin of the name of the exploration is obscure but probably has reference to the Commonwealth Iron Company, which was operating the Commonwealth mine in sec. 34, T. 40 N., R. 18 E.

Methods utilized in the present investigation

A new map was made using the compass and pace method. All measurements were made using closed loops tied to an established base line that was sighted into the area from the high quartzite knob to the west and stations marked at hundred-foot intervals. East of this base line the access road served as a base of measurements. The position of all test pits, trenches, shafts, drill holes, and outcrops was established by running north-south traverse lines spaced at hundred-foot intervals, originating along the base line. Adjustments were made for closure errors.

Strong magnetic declination in the area of the exploration rendered the magnetic compass useless, and determination of direction was by sun-dial compass. This compass was calibrated at least twice daily by reoccupation sight taken along a north-south road outside the area, and by check sights along blazed north-south lines established within the area.

The south common corner between secs. 31 and 32 was recently re-established and is a 4-inch-diameter steel pipe, painted yellow, and capped with a titled brass plaque. This corner has been tied to the present survey of the exploration area within the limits of accuracy of compass and pace methods. The section lines as shown on the base map (see pl. 1) are diagrammatic.

A total of about eight weeks was spent in detailed examination and mapping during the summers of 1956 and 1957. The locations of all outcrops, test pits, trenches, and shafts have been indicated on the map. Much of the area along the north slope of the ridge is lightly covered crumbled rock but has not been so designated on the map, principally because the outcrops beneath are so deeply weathered that they add little to understanding of the rocks even if uncovered. Much better exposures are found along the trenches and in the test pits, many of which have exposed bedrock.

Specimens were taken of all representative rock types to illustrate general and specific features. Numerous thin sections have been prepared, and a petrographic study of the rocks has been made. Identification of some minerals has been confirmed by X-ray methods.

In June of 1957 drill core from the area was examined, re-described, and numerous specimens selected for preparation of thin sections.

The investigation of the Little Commonwealth area has been an integral part of the district mapping project, and some concepts drawn upon to explain the geology of this small, nearly isolated, area have been developed as a result of the general district study. The following limits of the Little Commonwealth area are electively proposed: A natural north boundary is at the edge of extensive cover of glacial deposits, and hence the northernmost test pits and trenches; the south limit is the approximate position of the section line; the east limit is the easternmost northeast-southwest wood road, beyond which there are no known outcrops for over a quarter of a mile; and the west boundary is the north-south portion of the wood road, including the fork north of the quartzite ridge. To pursue the discussion of local geology beyond these limits increases the probability of bringing up additional problems, unsolved at present, which concern the over-all geology of the Florence district and do not materially add to the study of Little Commonwealth. Liberal reference will therefore be made to localities outside the area of the exploration proper, since stratigraphic units recognized at Little Commonwealth have been traced westward and northwestward and, in some instances, are better developed outside the area.

STRATIGRAPHY

Rocks within the Little Commonwealth area give rise to an intense magnetic anomaly, which has aroused interest from very early times. Through several previous studies there has been disagreement concerning both the stratigraphic position of the vitreous quartzite and its relationship to the complex group of rocks with which it is associated at Little Commonwealth. Current detailed studies within the area have clarified some of these relations. These results constitute the subject of this report.

Generalized stratigraphy of the Little Commonwealth area

The occurrence at Little Commonwealth of a number of different rock types in close association with a vitreous quartzite has led to various interpretations of the relationships. Brooks (1880, p. 489-490) considered the quartzite to occupy the core of an eastward-plunging anticline overlain by iron-rich rocks and probably truncated to the east by a fault. Hotchkiss (1920), after a detailed field and petrographic study of the area, concluded that the quartzite "frays out into the Little Commonwealth iron-formation." Later, Aldrich (1932), working from Hotchkiss' maps and notes, restudied the area and concluded that the quartzite is younger than the "iron-formation" and locally contains fragments derived from destruction of the "iron-formation".

In the present restudy of the area, using a new base map on which are located all recognizable outcrops and exploratory excavations, the distribution of rock types is more adequately known. There are very few valid structural or textural features within the area that might be used to determine tops of beds. Thin pebble bands occur in the quartzite and, more often, suggestions of crossbedding; but the east end of the quartzite is extensively recrystallized, and these original features of the rock are obliterated over much of the area. Farther to the northwest, however, in secs. 24 and 25, T. 40 N., R. 17 E., where the quartzite is better exposed and less recrystallized, determination of tops of beds is possible by use of both crossbedding and graded bedding near and in the conglomeratic strata. All data indicate that the tops of the beds of quartzite are to the southwest. At Little Commonwealth, pebble bands could be identified with reasonable certainty in three places, and tops of beds are consistently southwest. Crossbedding is less useful in the Little Commonwealth area because it is extremely difficult to distinguish between this feature and the extensive joint system which is developed within the quartzite.

The oldest rocks in the area are soft gray sericitic phyllite and quartzose phyllitic slate. These underlie the quartzite and associated rocks in numerous places extending from Little Commonwealth northwestward into sec. 24, T. 40 N., R. 17 E. The phyllite is conformably overlain by the vitreous quartzite, except within the Little Commonwealth area where the quartzite passes gradationally eastward into a number of more ferruginous rock types that are thought to conformably overlie the phyllite.

The quartzite is unconformably overlain by a black fine-grained slate of varied composition. Black graphitic slate grading to gray fissile siliceous slate with graphitic partings comprises the bulk of the unit, and parts are highly chloritic, especially near the base. Some beds of this slaty unit are quite quartzose, resembling graywacke, but insofar as is now known, these coarse-grained phases are not laterally persistent. A conglomerate occurs locally at the base of the formation near the contact with the quartzite.

These rocks are conformably overlain by an interbedded series of dull gray-green graywacke and fine-grained, highly fissile gray slate. To the west and northwest a fine-grained buff to brown "cherty" slate is recognized within this group of rocks. On weathering these rocks show red to red-brown alteration products.

No higher stratigraphic units are known to occur in the Little Commonwealth area; however, the two units which overlie the quartzite in this area have been traced northwestward. Reconnaissance studies indicate that these beds may be overlain by black graphitic slate and gruneritic cherty iron-formation near the northwest corner of sec. 35, T. 40 N., R. 19 E. These latter two formations are tentatively thought to be the Wauseca graphitic slate member of the Dunn Creek formation and Riverton iron-formation, respectively. In such case, the lower rocks that unconformably overlie the quartzite may be of basal Dunn Creek age (James, 1958, p. 37-38, and table 2).

Lithologic descriptions

Sericitic phyllite

The lowest observed rocks of the stratigraphic succession in the Little Commonwealth area are mainly fine-grained light to dark gray soft phyllite. Small, scattered quartz grains are present in the fine gray matrix. This rock is not known to crop out within the Little commonwealth area but is found in test pits and trenches all along the North side of the exploration. It is commonly highly weathered to a very soft, fissile, pink to brownish-red lustrous rock. On sections broken perpendicular to the fissility there are noticeable random spots generally less than .5 mm in size, which are composed of limonitic or hematitic material.

Petrographic determination of the mineral constituents is difficult because of the extreme fineness of grain. The matrix is composed mainly of finely crystalline, well-oriented, non-pleochroic white mica of moderate to high birefringence and is presumably sericite. In close association with the sericite are lesser amounts of chlorite in small ragged pale-green flakes and clusters. Scattered, small (< .5 mm) embayed quartz grains are randomly distributed in the matrix. A few ragged flakes of moderately pleochroic brown biotite are oriented perpendicularly to the fissility direction and are usually of a poikiloblastic texture. Locally, specimens of this rock show numerous small stumpy prisms of blue-green tourmaline.

Owing to the poor exposure within the area and highly weathered condition of this rock, variations within the formation are poorly known. Observations farther to the northwest, along the northeast side of the quartzite, indicate that this sericitic phyllite is interbedded with a more quartzose rock and that the contact with the overlying quartzite may be of a gradational nature. The actual contact is covered and has not been observed. Highly oxidized specimens of this more quartzose phase of the formation occur in the trenches north of the large quartzite outcrop knob that lies 1,200 feet north and 850 feet west of the southeast corner of sec. 31.

No estimate of thickness for this formation is possible since it has been observed only in close proximity to the quartzite and is obscured by glacial cover to the north. A series of test pits in the north-central part of the mapped area (pl. 1) indicates that the rock is present for a distance of 500 feet north of the quartzite.

Vitreous quartzite

The vitreous quartzite in the Little Commonwealth area constitutes the east end of the "Keyes Lake" quartzite of former reports. It is a highly resistant rock and glacially polished outcrops are abundant. The exposures are probably less extensive than at the time of the Hotchkiss survey (1920), since it was discovered during the recent study that large parts of outcrops are covered with moss and grass to a depth of less than 3 inches. Removal of this mantle revealed polished quartzite beneath, and, on occasion, features of bedding and structure were discovered in this way.

In the Little Commonwealth area the quartzite is a massive finely recrystalline vitreous rock. It varies in color from white through shades of faint grayish-pink to faint gray. There are extensive outcrops which are so thoroughly recrystallized that no original features remain. Locally, however, thin conglomeratic bands are present in which the clasts rarely exceed one inch in diameter. Where bedding can be determined with reasonable certainty, it is massive, with individual beds having a thickness of 4 to 6 feet. A finely laminated phase of the quartzite has been observed to the northwest, and other beds within the formation are known locally to contain angular slate fragments. Hotchkiss describes accessory minerals associated with the quartzite, including hematite veinlets, mica, and garnet. Vein quartz is abundant in areas of deformation within the quartzite.

A confusing feature of the quartzite is a diffusion color-banding which has no systematic relation to bedding. It is commonly red to red-brown and may be developed along bedding planes, joints, or distributed in small and large irregular patches that transgress both bedding and jointing. This staining is usually restricted to the exposed surface and rarely penetrates the rock more than an inch or two, and its presence can make appraisal of bedding and, hence, structure quite difficult.

In thin section the quartzite consists dominantly of a mosaic of fine-grained quartz with uncommon suggestions of original grain boundaries. Scattered thinly in this mosaic are plates and stringers of micaceous minerals, mainly sericite and muscovite, but locally chlorite. Large and small metamict(?) zircons occur as detrital accessories, with not more than one or two grains to a given thin section. Rarely, there are small cataclastic garnet grains, and locally prismatic crystals of blue-green tourmaline occur in random orientation. The rock appears to be thoroughly recrystallized (fig. 2),

Figure 2. Photomicrograph of vitreous quartzite showing mosaic texture and scattered flakes of sericite and muscovite. Crossed nicols.

and estimates of original grain size or constituent distribution would be highly tenuous.

Since the attitude of the bedding within the Little Commonwealth area is everywhere nearly vertical, estimates of thickness for the strata may be made from measurements on the plan map (pl. 1). Where the quartzite enters the area from the northwest and folding is minimum, the thickness appears to be about 300 feet.

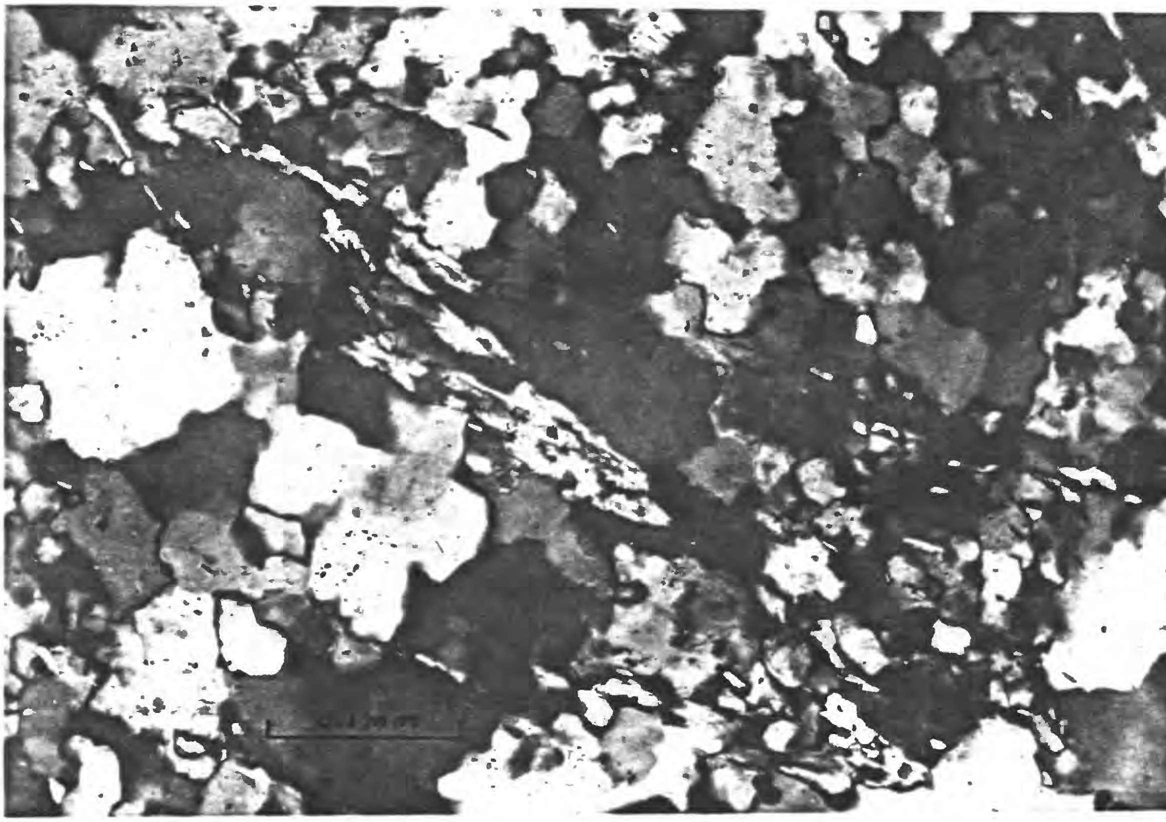

Figure 2. Photomicrograph of vitreous quartzite showing mosaic texture and scattered flakes of sericite and muscovite. Crossed nicols.

Martitic quartzite

The most interesting lithologic unit at Little Commonwealth, mainly in the central and eastern parts of the area, is a highly quartzose rock which locally contains an abundance of a dark, metallic, iron-oxide. This rock and the associated ferruginous rocks into which it grades have previously been called the "Little Commonwealth iron-formation" (Hotchkiss, 1920; Aldrich, 1932).

The rock is of varied composition but is best characterized by delicate interbedding of thin laminations or lenses of quartzite and dark-brown fine-grained slaty rock (fig. 3), which usually contains large amounts of metallic blue to black crystalline iron-oxide. The thickness of the quartzose laminations varies widely, from very thin stringers of clastic quartz grains to beds and lenses greater than 5 or 10 feet thick. Figure 4 shows the characteristic irregular

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Figure 3. Polished section of thinly laminated fine-grained quartzite and brown argillite. Note lensing of lamination in center of specimen. Gray scattered blebs in lower argillitic bed are martite.

Figure 4. Laminated quartzite-argillite of the martite-quartzite facies. Dark areas are reddish brown. Glistening grains in dark matrix are martite.

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bedding of the quartzitic layers as this rock grades towards vitreous quartzite. Within the dark-brown slaty layers, isolated "floating" quartz grains are not unusual. Locally, the quartzose rock is fragmented and strewn within the slaty portion. This gives the appearance of a

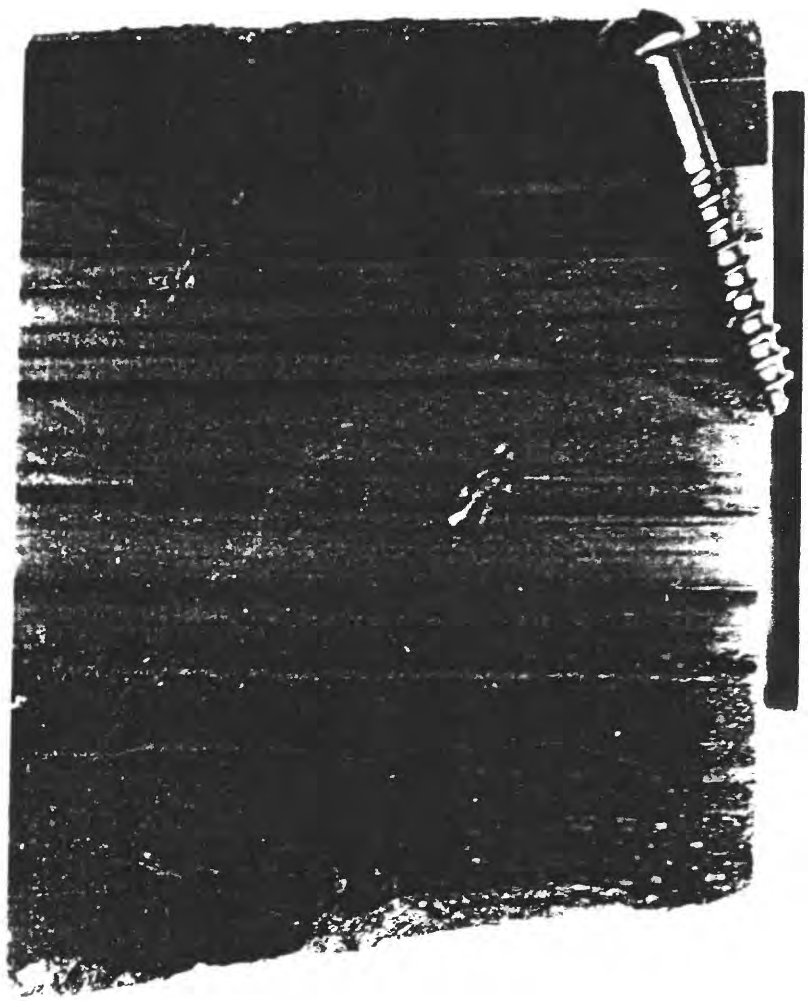

Figure 3. Polished section of thinly laminated fine-grained quartzite and brown argillite. Note lensing of lamination in center of specimen. Gray scattered blebs in lower argillitic bed are martite. Screw is 1/2 inch long.

Figure 4. Laminated quartzite-argillite of the martite-quartzite facies. Dark areas are reddish brown. Glistening grains in dark matrix are martite.

breccia or a very angular conglomerate. The distribution of the metallic iron-oxide is erratic. In places it is not noticeable in the rock, whereas it can elsewhere be present in such amounts as to constitute the entire mass of the dark interbeds.

Petrographic study has revealed the rock to be basically a quartzite, with a matrix consisting largely of a mosaic of quartz of irregular granularity. Strewn in this quartzose matrix are iron silicates, garnet, mica, and martite, and occasional tourmaline crystals. Locally, the microcrystalline platy mineral aggregates and mica flakes are restricted to certain laminae but are more commonly chaotically distributed within the rock. The mica minerals are mainly chlorite, but locally there are noticeable concentrations of sericite or muscovite and, rarely, pale-brown biotite. Crushed globular clusters of anhedral pale-pink to red garnet are not uncommon. The distribution and relationships of martite in and to this rock will be discussed with metamorphism.

Throughout most of this unit, quartz grains are unidentifiable in the quartzitic phase, but in the slaty phase they are not unusual. One specimen, in which there were more numerous rounded quartz grains, showed penetration of the quartz grains by an acicular iron silicate, with resulting fracture and strain developed within the grains, indicating a possible mechanism for the destruction of quartz grains (fig. 5).

Figure 5. Photomicrograph of martite-quartzite showing embayed quartz grains in a martite-silicate matrix. Note penetration of quartz grains by acicular crystals of stilpnomelane and other iron silicate. Plane light.

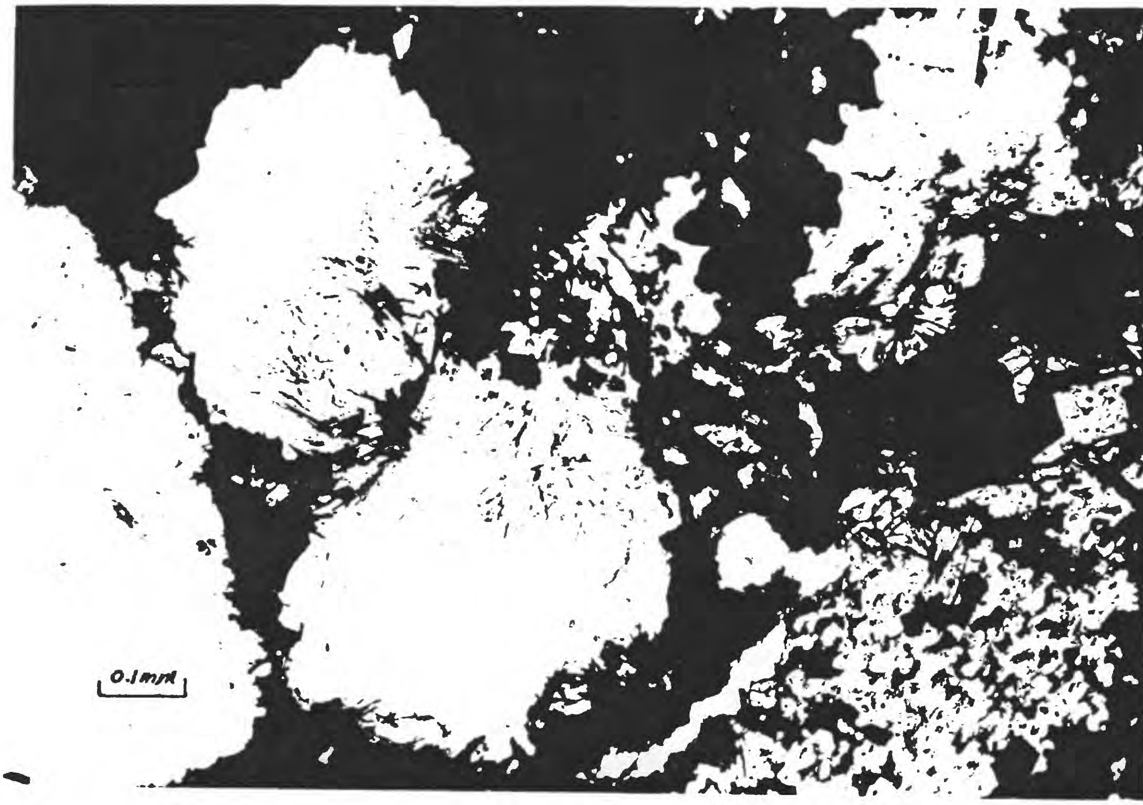

Figure 5. Photomicrograph of martite-quartzite showing embayed quartz grains in a martite-silicate matrix. Note penetration of quartz grains by acicular crystals of stilpnomelane and other iron silicate. Plane light.

The most characteristic feature of the martitic quartz is the occurrence of large to small crystals and granular aggregates of an opaque iron-oxide. Where best crystallized the mineral is in the form of octahedra. In hand specimen it has a dark-red streak and at the surface is non-magnetic. Inasmuch as some magnetite has been recognized in this rock unit near the northwestern part of the mapped area and has been encountered at depth in the drilling, this iron-oxide is probably martite: hematite pseudomorphous after magnetite. The two localities where this mineral is most abundant are near the two exploratory shafts. Elsewhere in the mapped area the actual martite distribution is conjectural since broad exposures of bedrock are not present.

Quartzose phyllite and garnet quartzite

The quartzose phyllite and garnet quartzite are grouped together mainly because they belong essentially with the more ferruginous rocks of the martite quartzite and stilpnomelane slate but differ sufficiently for field recognition in that they have fewer visible iron-bearing minerals. Detailed studies have shown that these rocks grade imperceptibly into their more ferruginous counterparts; however, there are places in which they can be exclusively recognized, and hence constitute a functional mappable unit within the Little Commonwealth area. They can be described as transition types and may include small lenses or beds of lithologies similar to rocks into which they grade.

The gray quartzose phyllite is largely restricted to the central portion of the mapped area, in a thin belt near the position 850 feet north, 450 feet west of the southeast corner of sec. 31. It is exposed in several trenches and test pits, and there are small patches of highly weathered crumbled ledge that most closely resembles this rock.

The westward continuation of this phyllite is largely unknown, as it is poorly exposed; however, it may grade laterally into vitreous quartzite, or possibly persist as a phyllitic interbed in the quartzite sequence. Brooks (1880, p. 491) specifically mentions: "... argillaceous or chloritic slate in a bed 8 feet thick, imbedded in quartzite near the top of the hill. Strike N. 65° W., dip 80° south, ..." and Hotchkiss (1920) also refers to slaty interbeds within the main mass of vitreous quartzite.

To the east, in the vicinity of drill holes FC-101 and Fc-103, south of the main road, this phyllitic phase is very closely associated with the martitic quartzite and garnet quartzite.

The gray quartzose phyllite is a compact, finely laminated, very fine grained lustrous rock with scattered lenses of fine-grained quartzite. It is usually medium to dark gray in color and weathers to a dull red or reddish-brown. Slaty cleavage is well developed; however, exposures are not so extensive as to allow study of cleavage-bedding relationships. Locally, the cleavage is modified by a delicate cross-crenulation.

Microscopically, the rock is composed of a very fine grained matrix of roughly equal amounts of mosaic quartz and ragged flakes of chlorite. Very little martite is identifiable in the thin sections, though it may occur sparingly in very fine dusty dissemination. Locally the mica mineral is dominantly sericite or muscovite, taking the place of the chlorite. The more quartzose phases closely resemble the vitreous quartzite, except for notably more sericite. This sericitic phyllite is seen in thin section to contain blue-green tourmaline in well-developed small columnar crystals (see fig. 18, p. 85). Occasional small grains of zircon are not uncommon.

The second less-ferruginous gradational unit recognized in this investigation is a massive to poorly laminated medium-grained gray quartzite which is noticeably garnetiferous. On weathering, this rock becomes dark reddish-brown or brownish-gray. Isolated rounded glassy grains of quartz, usually about 0.1 to 0.5 mm in diameter, are common throughout the rock. Granular metallic martite is conspicuously absent in hand specimens. Pale-reddish garnets occur abundantly, both in scattered equant anhedral crystals and in irregular granular clusters which apparently follow bedding planes. In specimens of drill core, thin dark-green ferrostilpnomelane laminae occur and are most abundant near the base of the unit.

In thin section all specimens of this rock show a very fine grained matrix that is dominantly mosaic quartz with which is associated small plates, microcrystalline clusters, and schistose laminae of pale-green non-pleochroic chlorite, and clusters of green stilpnomelane. Pale-reddish cataclastic porphyroblasts of garnet are locally abundant in a great range of development. Locally, garnet porphyroblasts are strewn along a crush zone. Some thin beds have abundant green stilpnomelane and, rarely, biotite. Thin stringers of saccharoidal vein quartz transect all structures in the rock.

This rock type is abundant in the eastern part of the mapped area where it occurs next north of the martitic quartzite beds. It may grade imperceptibly into other rock types, and hence rock of this description is usually found in small amounts associated with either martitic quartzite or stilpnomelane-garnet slate of the next unit to be described.

Stilpnomelane-garnet slate

Stilpnomelane-garnet slate, a heterogeneous unit characterized by a lack of clastic quartz, consists mainly of dark-green to black ferrostilpnomelane slate with abundant anhedral pale-red garnet in granules and lenses. Locally it becomes noticeably graphitic and in places contains pods or beds of chert near which is developed fibrous yellow amphibole. The rock has a distinct banding, with layers usually about 1/2 to 1 inch in thickness. On weathering it becomes very soft and friable, yellow-brown to black, and often has a noticeable iridescent coating, presumably due to manganese minerals.

In thin section a variety of mineral associations and textures are commonplace. The more coarsely porphyroblastic greenish-black slate is composed almost entirely of platy green ferrostilpnomelane, with which is associated red-brown garnet, mainly in aggregates. In some specimens chlorite and ferrostilpnomelane are closely intergrown, together with minor amounts of biotite. Locally, brown ferristilpnomelane is developed as a feathery reaction rim near chert fragments. (See figures 15, 16, 17, pages 78,79, 81.) Graphite is locally abundant, and where present the grain size of the slates is considerably finer and porphyroblasts are nearly absent.

Rocks of the above type are most abundant in the eastern part of the mapped area north of the main road and drill holes, but a thin belt of related dark slate extends westward some 700 feet, interbedded with, and grading into martitic quartzite. Rocks of the westward extension are less graphitic, and the dominant mineralogy here consists of well-developed ferristilpnomelane and chlorite with some grunerite and chert. It is megascopically a red-brown fibrous slate.

Gray siliceous slate

Unconformably overlying the vitreous quartzite and associated ferruginous rocks is a heterogeneous sequence of black slate and graywacke. The formation consists of graphitic slate, porphyroblastic chloritic slate, coarse- to fine-grained black graywacke, and very locally, cherty gruneritic slate. A conglomerate has been recognized at the base of this formation and appears to be irregular in lateral distribution and in size of the clasts. The black slate sequence has been mapped next southwest of the quartzite for its entire exposed length. All of the phases of this unit are distinctive and readily recognized; however, the greater part of the area underlain by this unit is covered, and presence has been confirmed generally by inspection of old test pits. In areas of adequate exposure, as along the southern part of the Little Commonwealth mapped area, the various rock types were observed to grade abruptly into one another with no great structural deformity in evidence. As a result, the sequence of rocks is considered to constitute one formation. Further mapping and specimen study to the northwest of Little Commonwealth will probably produce representative specimens of all gradations between these units.

The black fine-grained slate of this unit grades imperceptibly from graphitic slate, through gray siliceous slate with a decidedly white streak, to dark-green or black porphyroblastic chloritic slate. In places the more siliceous phases have a well-developed slaty cleavage. The basal conglomerate of this unit consists of large and small angular clasts of red-stained saccharoidal quartzite in a matrix of slaty material of the indigeneous local composition, i.e., the clasts are everywhere quartzitic, but the matrix may be graphitic, chloritic, or a more poorly sorted rock where graywacke occurs. Within the Little Commonwealth area, this conglomerate is not well exposed but has been observed in two places. Just south of a large outcrop of quartzite is a test pit and crumbled ledge containing a dark-green soft chloritic slate that locally contains small fragments and pebbles of pinkish or brownish quartzite. This locality is about 550 feet north and 450 feet west of the southeast corner of sec. 31, at the head of a small gully. The conglomerate also occurs at the east end of the exploration area as revealed in a test pit that lies 410 feet north and 670 feet east of the southeast corner of sec. 31. Here the conglomerate consists of highly deformed clasts of quartzite, about 5 to 8 cm in longest dimension, in a highly sheared black graphitic matrix. The dark-gray to black siliceous slate is often observed to part along graphitic surfaces.

Most exposures of this sequence are badly weathered and generally not suitable for preparation of thin sections. One successful section of a thinly laminated, well-cleaved, lustrous medium-grained semi-schist showed a delicate banding of finely crystalline mosaic quartz and darker somewhat graphitic layers. The individual layers range in thickness from 0.5 mm to about 2 mm. A few flakes of pleochroic brown biotite are scattered in the quartzose bands, and stout prisms of blue-green tourmaline are abundant and randomly oriented in the graphitic bands. A cross-crenulation, or false cleavage (Harker, 1939, p. 157), is quite apparent in the hand specimen. In thin sections the trace of this false cleavage is outlined by wavy cross structures composed of medium-grained sericite or muscovite.

In close association with the dark fine-grained slate there locally occurs deeply weathered fibrous limonitic material associated with porous brown to white thinly laminated chert. Usually the rock is weathered to an extent that makes impossible the identification of the mineral constituents; however, some fresher material of the same character and distribution from sec. 25, T. 40 N., R. 17 E., has the acicular mineral well developed in rosette pattern typical of grunerite. This chert-grunerite phase occurs in small lenses, commonly not more than 200 feet long and 30 feet thick. A small area of chert-grunerite occurs at Little Commonwealth, along the south slope, at about 500 feet north and 700 feet west of the southeast corner of sec. 31.

Locally, as in the extensive outcrop 950 feet north and 1,650 feet west of the southeast corner of sec. 31, there occurs a moderately massive, well-bedded, blocky, coarse- to medium-grained black graywacke, which is commonly magnetic. This same rock unit, also found in the NW$\frac{1}{4}$ sec. 31, shows in thin section numerous grains of clastic feldspar within a matrix composed of coarsely recrystalline mosaic quartz and scattered numerous flakes of brown biotite, with minor amounts of chlorite and white mica. Magnetite occurs as dusty opaque particles in the matrix.

The thickness of this stratigraphic unit is difficult to measure, owing to poor exposure and structural thickening through folding, but it is probably not more than about 200 feet and is locally much thinner.

Green graywacke

Conformably above the heterogeneous rock sequence last discussed occurs an unknown thickness of interbedded massive to laminated dull green, coarse- and medium-grained, poorly sorted quartzite or graywacke and light-gray lustrous phyllitic slate. Both rock types weather red or reddish-brown. The more massive rock usually breaks with a conchoidal or hackly fracture and locally has irregular blebs and stringers of white, sugary quartz. It contains evenly distributed rounded glassy quartz grains in a light gray green fine-grained matrix.

The more fine-grained slaty phase of this rock is light to dark gray and is noticeably heavy.

This formation is the youngest of the exposed strata in the Little Commonwealth area and is found only in test pits and scattered crumbled ledge. As a result, little is known in this area concerning the character of the unit. Mapping farther to the northwest, however, has indicated that comparable rocks occur in great thickness and include not only the types here described but also a variety of buff and light-green slates. No estimate for thickness of this unit in the Little Commonwealth area is possible.

Stratigraphic interpretation of the rocks at Little Commonwealth

The interpretation of the stratigraphy of the rocks which occur within the Little Commonwealth area has been impeded by their heterogeneity and close juxtaposition. The physical characteristics of many of the rocks are comparable to rocks of other areas which are widely different, both geographically and stratigraphically. For instance, the vitreous quartzite closely resembles the Sturgeon formation of lower Animikie age. The martitic quartzite, in best development and where exposed in polished outcrops, is not unlike parts of either Negaunee iron-formation or Vulcan iron-formation. The graphitic and chloritic slates, occurring on both north and south sides of the quartzite (both martitic and vitreous) at the east end of Little Commonwealth, are in general aspect not greatly different from rocks of the Paint River group of upper Animikie series mapped elsewhere in the Florence syncline. Recognition of these similarities has appeared in every report concerning this exploration, and most of the previous interpretations of the area have postulated profound faulting or unconformity, or both.

Detailed field work, and petrographic study of selected critical specimens, have contributed to reduction in complexity of concept. The most helpful concept in the establishment of the stratigraphic relationships in the area is the continuity of the vitreous quartzite and related rocks between through-going stratigraphic units above and below.

The sericitic phyllite, which persistently occurs at the base of the quartzite throughout its exposed length, has been mapped along the north side of Little Commonwealth. It has been intercepted, at intervals commonly less than 300 feet along strike, in all test pits and trenches alONG the base of the north slope. It is apparent that this essentially non-ferruginous rock was the northern limit for exploration efforts.

The rocks that occur stratigraphically above the quartzite are less easily identified as a unit, mainly because of similarity of some lithologies that occur stratigraphically lower in the area. The relationships between the various phases of this overlying stratigraphic unit have been revealed through detailed mapping, both in the Little Commonwealth area and all along the southwest side of the quartzite. Phases of this formation, including graphitic slate, chloritic slate, cherty grunerite, and locally, graywacke, have been observed throughout the area of occurrence as gradational one into the others, and mixed rocks showing features of any of the phases are not uncommon. This formation contains a discontinuous basal conglomerate, which varies in composition according to local condition of its associated slate. Although the conglomerate is poorly exposed and possibly quite discontinuous, its occurrence along the stratigraphic top of the quartzite and associated rocks may indicate an erosional unconformity.

In the western part of the mapped area the sericitic phyllite and heterogeneous black slate form, respectively, the footwall and hanging-wall rocks of the vitreous quartzite. As the quartzite is traced southeastward into the central part of the mapped area, argillaceous material is observed to be intimately interbedded with massive to thinly laminated quartzite beds. Breccias, composed of angular fragments of quartzitic material in an argillaceous matrix, are locally outstanding but in no instance can be proven to transgress the expected direction of bedding. These have many features of intraformational conglomerate or autobreccia. The more quartzose rocks grade into highly ferruginous clastic rocks of medium to very fine grain. In the very fine grained black ferruginous slate, fragments and lenses most closely resemble the bedded chert of oxide or carbonate iron-formation. At no place in the area have actual contacts been found between the various units stratigraphically equivalent to the vitreous quartzite, and in the drill core these rocks are observed to pass gradationally one into another.

It appears that the distribution of the rocks stratigraphically equivalent to the quartzite results from an exceptionally abrupt facies change; the vitreous quartzite passing eastward, gradationally, into a sequence of slaty rocks that are in part highly ferruginous. These relationships are shown diagrammatically in figure 6. One of

Figure 6. Generalized stratigraphic diagram showing inferred original distribution of Animikie rocks in the Little Commonwealth area.

the great difficulties in the interpretation of the stratigraphy is the obscurity due to glacial cover at the east end of the exploration. If this facies change concept applies, reappearance of Little Commonwealth rocks to the east beyond the covered interval would be nearly impossible to recognize, since they are observed within the mapped area to include slates not uncommon to either Paint River strata of the Florence and Iron River-Crystal Falls districts, or to the underlying Michigamme formation.

Explanation of details of depositional environment that gave rise to this group of rocks is a more difficult problem, because of the limited exposures, areal isolation, and rise in metamorphic grade. Other details supporting the concept of facies change are mainly concerned with structure of the area and metamorphic transformations within the rocks.

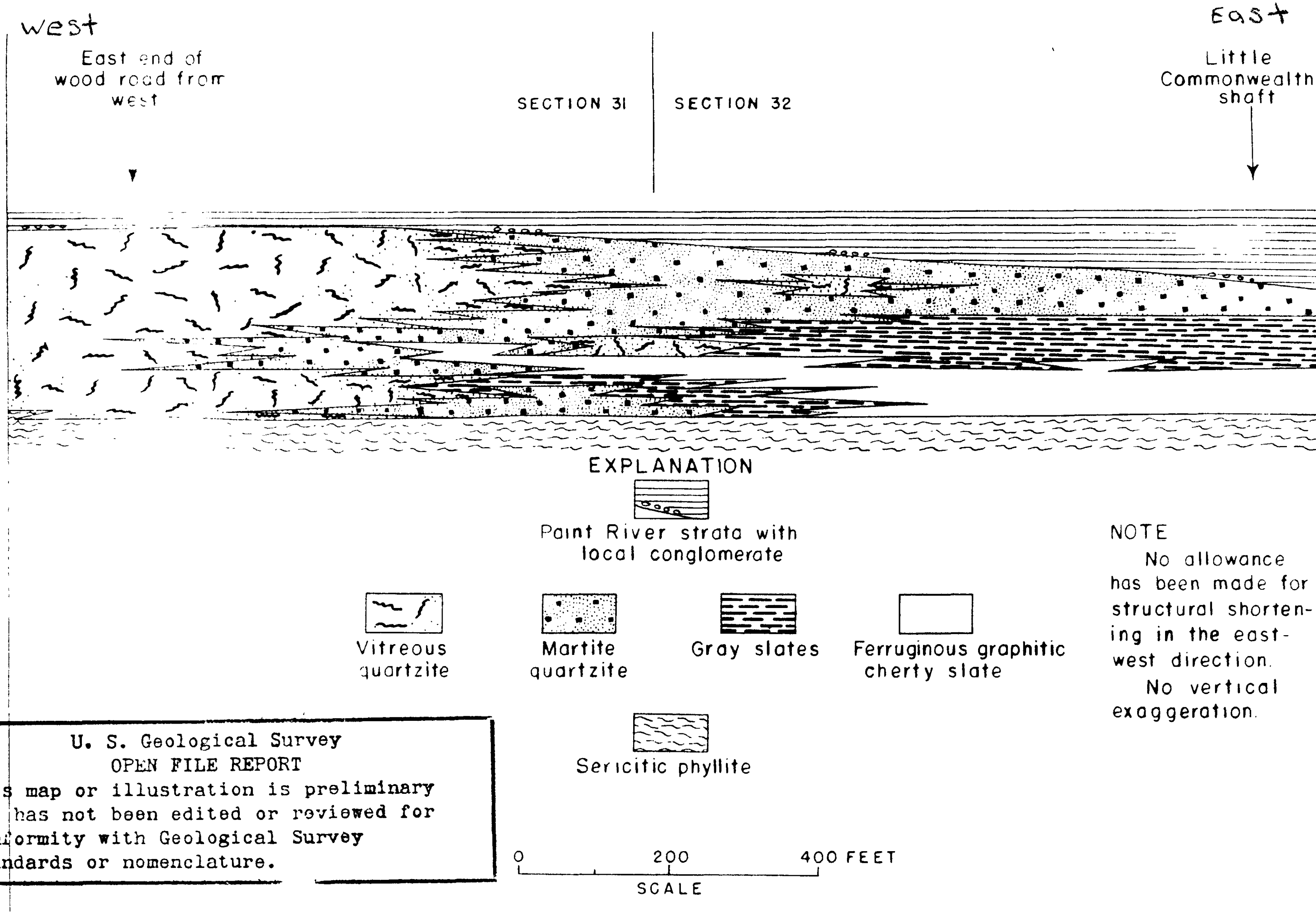

Figure 6 Generalized stratigraphic diagram showing inferred original distribution of Animikie rocks in the Little Commonwealth area

STRUCTURE

Detailed mapping of the quartzite northwest of Little Commonwealth confirms the few measurements of attitude of bedding and minor structure within the exploration area. All significant structural data concern the vitreous quartzite and martitic quartzite. Other rocks in the area are less well exposed and, where seen in outcrop, are generally highly contorted or are so badly weathered that adequate measurements are questionable because of the obscurity of bedding or possible creep or slump.

The attitude of bedding in the quartzite is nearly vertical and in the eastern part of the area is locally overturned to the north. Tops of beds are consistently to the southwest. Drag folding is probably developed in the quartzite, but folds are obscure because of more massive bedding and extensive fracturing and recrystallization in the expected position of the noses of folds. Small drag folds and chevron plications indigeneous to the martitic quartzite have been mapped in the eastern part of the area. In these minor folds the axial planes are nearly vertical and the axial line plunges very steeply (70°-80°) to the west. They indicate an anticlinal structure to the north and a syncline to the south, both plunging westward. The inferred larger structures have not been observed; however, from the general study of the Florence district, it is thought that the anticline to the north of Little Commonwealth is a real feature and is probably broken by a high angle fault--one of the major structural features of the district. There is, at present, no knowledge of the structure to the south of the Little Commonwealth area.

Well-developed isoclinal folding on a small scale has been observed within the area at a locality 640 feet north and 100 feet west of the southeast corner of sec. 31. Here the folding is developed in a rhythmically laminated argillite and quartzite in which there is a large amount of martite. The physical appearance resembles oxide iron-formation, and all previous descriptions of the area have called this outcrop "iron-formation." Close petrographic examination of this rock shows that it is not different from the martitic quartzite of this report, and subsequent examination of hand specimens revealed the presence of isolated rounded clastic quartz grains. Since it shows clastic features, it cannot, by definition (James, 1954, p. 239-240), be called "iron-formation."

The areal distribution of the rock types within the Little Commonwealth area suggests that transverse faulting is not important. The uninterrupted contact of the sericitic phyllite to the north supports this. The exposures are poor, however, and the possibility of significant strike-slip faults making a low angle with bedding cannot be discounted, though none have been recognized. In many localities where martitic quartzite is exposed, deformation has taken place along many small closely spaced slip planes. Martite is usually abundant along these slips (fig. 7). The restricted exposure of bedrock precludes estimation

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Figure 7. Banded martitic quartzite. Light band at top of photograph is vitreous quartzite. Dark alternating laminations below are argillite with probable interlaminations of chert. Note abundance of martite (mt.) parallel to bedding and along small slip planes (fracture cleavage). At left center, bands of chert are partly bleached.

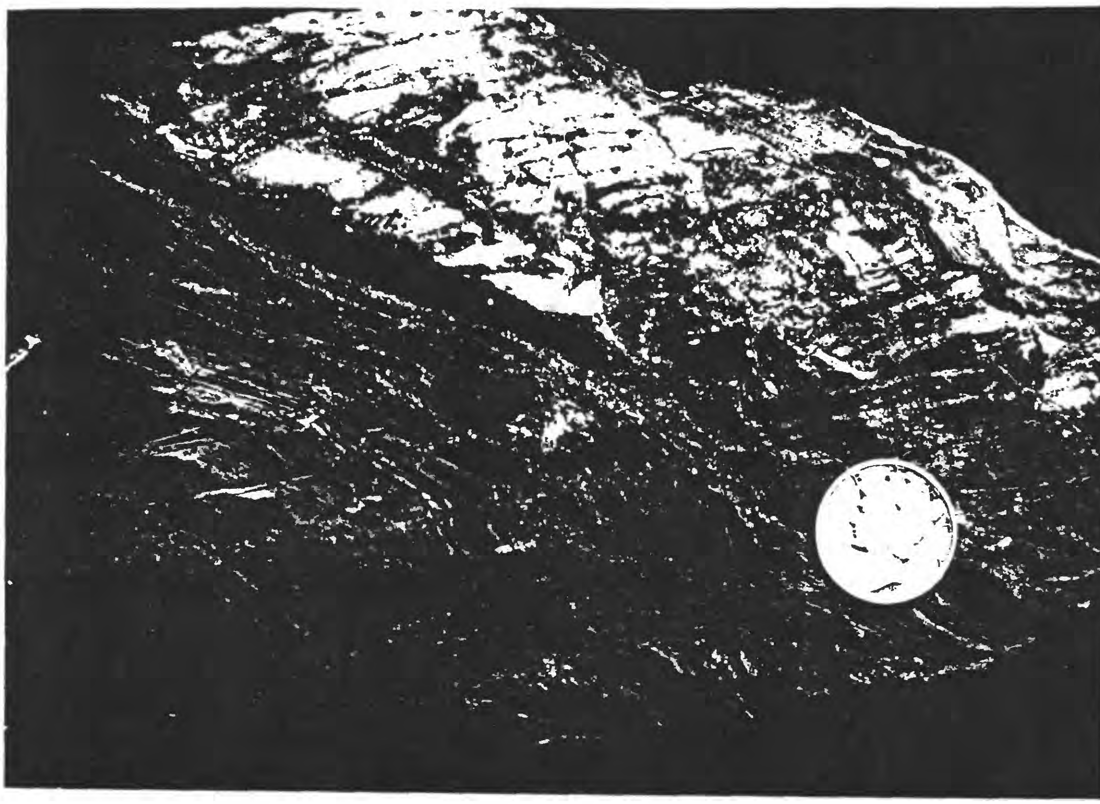

Figure 7. Banded martitic quartzite. Light band at top of photograph is vitreous quartzite. Dark alternating laminations below are argillite with probable inter-laminations of chert. Note abundance of martite (mt.) parallel to bedding and along small slip planes (fracture cleavage). At left center, bands of chert are partly bleached.

of the relative amount of movement that has been taken up along slip planes; however, it does not appear to be of great magnitude.

Minor structures in the Little Commonwealth area are difficult to trace or to relate to larger structures. In general, crenulation, isoclinal folding, and chevron plication are more common in the delicately laminated rocks, whereas brecciation is characteristic of the more massively bedded types. This may be due in part to the condition that folds of the kind present in the laminated rocks, if present in the massive ones, would be of larger size and more difficult to recognize in small scattered outcrop areas.

Zones of breccia are well developed in the area and are comprised of angular tabular fragments of quartzite in a matrix of argillite and martite. The structure of the breccia appears at first to be chaotic, but on close inspection usually is distinctly lineated (fig. 8).

Figure 8. Martite quartzite breccia. Dark areas are argillite with abundant ($\pm$ 40%) martite. Note lineation of breccia fragments.

Breccia fragments range in size from several millimeters to 20 or 30 centimeters in the long dimension. They are generally stained with iron oxide. The proportion of argillite to martite in the breccia matrix ranges widely. Where martite is nearly absent the color is reddish-brown in outcrop and dark gray green in fresh specimens from drill core. The martite can occur in the matrix in such amounts as to completely obscure argillitic material and partly replace quartzite fragments. This condition is especially in evidence in the vicinity of the two exploratory shafts.

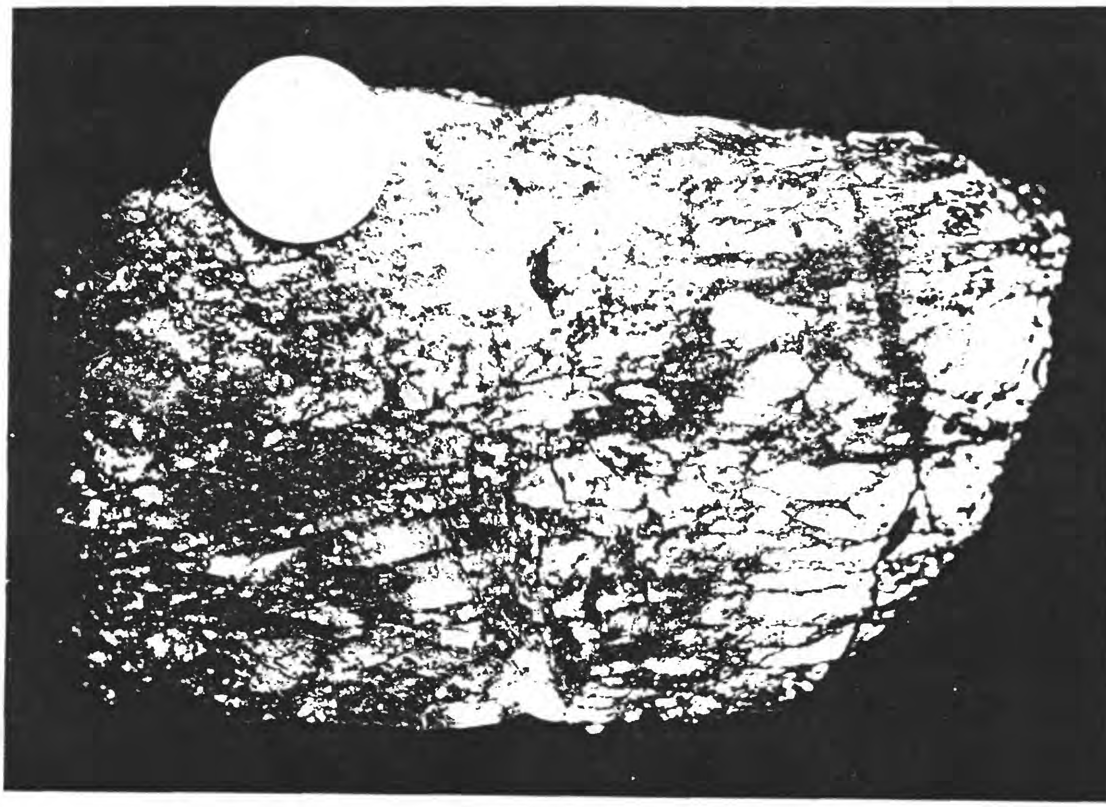

Figure 8. Martite quartzite breccia. Dark areas are argillite with abundant ($\pm$ 40%) martite. Note lineation of breccia fragments.

The vertical attitude of all rocks in the area, as well as in much of the Florence district, is indicative of the amount of deformation to which they have been subjected. Drag folds have been mapped within vitreous quartzite to the northwest. The nature and extent of most of the Little Commonwealth structure cannot be adequately appraised from present exposures, but it is possible that both crenulation and brecciation have developed in response to frictional forces in the more plastic parts of the rock arising from differential movement between confining competent strata. Relation of the breccia areas to faulting is not clear. As previously mentioned, the continuous contact to the north, between the quartzite and associated facies, and sericitic phyllite precludes displacement of importance, except possibly in the direction of dip of the beds. Recognition of the abrupt facies relationships between quartzite and associated rocks has permitted mapping of a reasonable distribution of gradational rock types. This distribution does not seem to be affected by faulting transverse to bedding and is only moderately modified by folding.

The rocks of the area are metamorphosed, and all textures observed in thin section suggest transformation under conditions of deficient stress. Hence, the present metamorphic condition of the rocks was probably developed subsequent to folding, and in this case features of preceding structural deformation may have been obscured through recrystallization. Poor exposures produce little evidence, but in general schists or crosscutting crush zones are of minor occurrence. Most of the post-metamorphic relief of stress is believed to have occurred along small slip planes in the competent rock or has developed incipient fracture cleavage in some of the post-quartzite slaty rocks.

The irregular distribution of the zones of breccia and the distinct lineation of the breccia fragments in all observed instances are not characteristic of tectonic breccias. In some large breccia zones, as at the western exploratory shaft, the angular fragments in a highly martitic matrix are nearly all rectangular, of the same size (roughly 8 cm long and 5 cm wide), and show no evidence of rotational movement or attrition due to friction. In the trench just west of the eastern shaft there is exposed a well developed breccia of small tabular fragments aligned in the direction of bedding in a matrix of metallic blue martite. Along the sides of this trench, and particularly at the west end, the martite quartzite is exposed in well-bedded, laminated rock. An isoclinal fold is exposed in the west wall of the shaft. These features are found within a distance of 50 feet along the strike of the beds. No displacement along strike of the beds can be demonstrated. Elsewhere, isoclinally folded, thin-bedded strata are apparently confined between through-going unfolded beds. In places characterized by conspicuous brecciation it is often possible to trace undisturbed thin quartzose laminae for distances of 20 or 30 feet through a mass of lineated breccia (fig. 9). The absence of evidence other than the breccia for

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Figure 9. Brecciated and banded martitic quartzite. Lighter laminae in places contain recognizable quartz grains. Dark part of matrix is brown argillite. Lighter colored spots and masses are martite. Polished surface.

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faulting, and the irregular distribution of the breccia, indicate

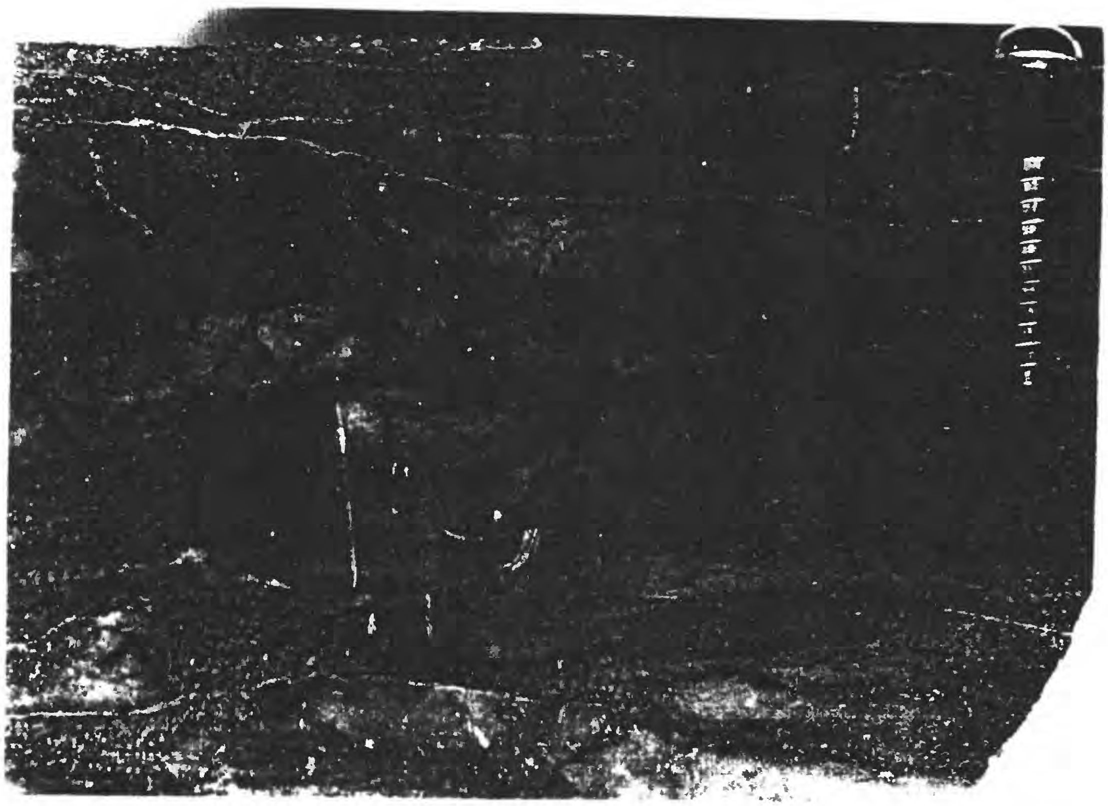

Figure 9. Brecciated and banded martitic quartzite. Lighter laminae in places contain recognizable quartz grains. Dark part of matrix is brown argillite. Lighter colored spots and masses are martite. Polished surface. Screw is 1/2 inch long.

that it may not be related to tectonic deformation but possibly represents relict structures developed prior to lithification of the rocks or during subsequent diagenesis.

The several facies are of such character that it may have been possible for them to develop small pre-lithification structures, possibly through differential load compaction and downslope slump. In the original conditions of deposition, the distribution of material from west to east would have been relatively uncompactible sand grading to highly compactible ferruginous, carbonaceous mud. Although evidence is lacking, the original slope (or dip) of the laminae of sediments was probably not horizontal and may have been as much as 20° or 30° (Nevin, 1931, p. 35) but probably was somewhat less than this. Compaction of the sands and muds would probably have sharply increased the initial dip because the compactibility of average sand is negligible, but that of average shale is an inverse exponential function of burial depth. According to Pettijohn (1949, p. 479), compaction of shale can amount to a 20 percent reduction of original volume for 1,000 feet burial, and 40 percent at 3,000 feet. This laminated mass would have dipped more steeply at greater distances from the quartzite, until the initial dip was lessened on approach to a more homogeneous mass of mud or shale. The short distance between nearly pure quartzite and its stratigraphic equivalent made up almost entirely of muds supports the possibility of a rather steep initial dip for the sediments after compaction.

Association of chert-siderite (chert-grunerite) and carbonaceous (graphitic) muds or shale indicates that the waters of the basin of deposition were at times precipitating iron carbonate and colloidal silica in a nearly stagnant environment. Metamorphism has almost obscured the differences between this chert and fine-grained quartzite, so that an estimate of the amount of chert in the clastic rocks is impracticable. Thin lenses of chert have been found in some of the argillitic (see p. 71) portions of the rock, and it is not impossible that chert or siderite could have been present as a cement for some if not all of the thin quartzose laminae or could have been laid down in thin beds.

The now-argillitic rock was, during compaction, not unlike a ferruginous shale or siltstone. The sequence of sediments at several hundred feet from the quartzite would have been chert and sand interlaminated with wet compacting ferruginous muds. Within the mass of sand and mud, differential lithification would be expectable. The porosity of the sand would allow free percolation of cementing solutions while the much more fine grained mud would retain much of the original water content (Yoder, 1955, p. 506, and references) and would permit less circulation. Cementation of the sand would produce relatively brittle layers, while the muds, even after compaction, would be much more plastic in nature. This mass of sand and mud resting in a relatively high angle of initial dip would be unstable, and disturbances of any sort (Shrock, 1948, p. 69, 275-77) could cause either slumping and stretching of the mass down slope or dislodgement of parts of the mass which would slide down slope. By either of these movements the more brittle cemented sandstone layers would be brecciated or segmented and dilatent areas within would be filled by plastic mud or silt. The plastic readjustment of the laminated muds would probably result in contortion of the laminations into folds and other flow structures. Such structural development has been described by Crowell (1957) in mudstones of northern California.

Inasmuch as the rocks are standing vertically and have therefore been subjected to post-lithification deforming forces, much of the minor structure could have resulted from this deformation. In these rocks it is, of course, impossible to separate the prefolding structures from those developed subsequently.

METAMORPHISM

District setting

The regional distribution of the effects of metamorphism in northern Michigan and adjacent parts of Wisconsin has been discussed by H. L. James (1955). The metamorphic zones are shown to be related to four nodes of increasing grade. The Florence district lies mainly between the Peavy node and the Florence County node. In the extreme northern part of the district, along the Brule and Menominee Rivers, the rocks are in the biotite grade of metamorphism, and the grade rises rapidly northward, with sillimanite occurring in the Michigamme slate at Peavy dam, a distance of about 4 miles. The north limb and east termination of the Florence syncline are not greatly metamorphosed. The only recognizable feature of the rock attributable to transformation is a distinct slaty cleavage developed in the more argillaceous rocks. These rocks are metamorphically equivalent to those in the Iron River-Crystal Falls district which James (1951, p. 253) mentions as being of very low grade (probably low chlorite grade). In such rocks it is nearly impossible to distinguish between original features of bedding and grain size and modifications of these features through incipient metamorphism.

In the SW¼ sec. 34 and in sec. 33, T. 40 N., R. 17 E., along the south limb of the Florence syncline, there occurs near the base of the iron-formation a green to brown fine-grained ferruginous slate that contains conspicuous porphyroblasts of chlorite. This incipiently porphyroblastic rock is the first indication of a change in metamorphic grade in the district. The significance of the change is not known at present, because the thin slaty bed has not been recognized along the north limb of the syncline. It probabily represents a rock more sensitive to metamorphism.

In the southern and southwestern parts of the district a gradient of the metamorphic zones rises towards the area underlain by granite. James (1955, p. 462-63) notes: "An area of high-rank metamorphic rocks lies south of the town of Florence, but it has not been studied in sufficient detail to warrant delineation of isograde above that of garnet. The garnet isograd has been established by reference to iron-formation." Prinz,_/ mapping in the extreme southeast corner of

_/ Prinz, W. C., 1956, personal communication.

Florence County (T. 38 N., R. 19 E.) finds that the metamorphism of this area increases westward. The westernmost rocks which he studied are metagabbro and are in the epidote-amphibolite (biotite or garnet) facies.

Concerning the nature of the metamorphism in northern Michigan, James (1955, p. 1461) states: "The metamorphism is unusual in that it was not synchronous with deformation; in Harker's terminology, it would be classed as metamorphism under deficient shearing stress." The textural products of metamorphism in this area are mainly slates. Schists are rare, except in the highest grades. In the present investigation of the Florence district, no schists have been found. Details of the relationships between deformation and metamorphism are discussed by James (1955, p. 1482-83); in general, there is no correlation between the two, and metamorphic isograds are generally found to transect structural units. The origin of the heat energy necessary for the transformations is thought to have been "derived from subjacent bodies of magma, by means of which heat acquired at greater depth was transferred by mass movement to higher levels in the crust." (James, 1955, p. 1485.)

Limitations to the study of metamorphism

In general the area north and northeast of the quartzite ridge is of low metamorphic grade, whereas to the south and southwest of the quartzite the rocks are thought to be in the garnet grade or higher. Direct comparison of the Little Commonwealth area with most of its geologic setting is not possible because information is not available which would allow an estimate of rate of rise of metamorphism to the south and southwest. It is suspected that the rocks at Little Commonwealth are structurally separated from those to the north in the Florence syncline.

The isolated nature of the Little Commonwealth area presents further problems. The stratigraphic position of the rocks is in question, and the extensive glacial cover prevents tracing these rocks to the east where the metamorphic grade is lower. To the west and northwest the exposed stratigraphic sequence which is recognized at Little Commonwealth is in part represented by the vitreous quartzite. The massive character and lack of sensitive minerals in much of this unit render it a poor indicator of metamorphic grade. The underlying sericitic phyllite is poorly exposed, and the rocks which overlie the quartzite have not been studied over an area great enough to establish their relation to metamorphic grade.

Within the Little Commonwealth area both quartzite and slaty units are uniformly fine grained, and except for selected specimens the petrologic study of the rocks is difficult. The rapid changes in original distribution of the rock units and intergradation between them combine to make appraisal of characteristic minerals, and hence metamorphism, tenuous. These rocks are somewhat unusual because several of the units have no recognizable district counterparts with which they may be compared. In addition, the spotty occurrence of tourmaline within the rocks and its relation to other minerals suggests that there may be some unknown amount of metasomatism. Chemical analyses are not available for rocks of the area.

Descriptive metamorphism

The rocks at Little Commonwealth have been thermally metamorphosed with stress seemingly playing a very minor role in the mineral reconstitution. Decussate texture resulting from random distribution of the platy and acicular minerals is common. The minerals are thought to have crystallized in place, and in some instances primary features of the rocks, such as quartz grains in the quartzite, are recognizable. The inferred original composition of the rock units ranges widely from nearly monomineralic, as in the vitreous quartzite, to a quite heterogeneous mineralogy as shown by the ferruginous, graphitic slates. Other than the quartzite, the rocks are of two broad categories, both characterized by an abundance of iron. One group comprises the quartzitic ferruginous rocks; the other comprises the graphitic and argillitic ferruginous rocks. Each group appears to be completely gradational into adjacent facies.

In the petrographic study of the rocks, mineral identification was made by conventional optical methods, except in cases where the minerals were too fine grained or of complex intergrowth. In these instances identification was made by X-ray techniques, on specimens picked from the thin sections.

Sericitic phyllite

Metamorphic effects in the sericitic phyllite cannot be adequately appraised because of limited exposure.

Vitreous quartzite

The effects of metamorphism in the vitreous quartzite are poorly shown in hand specimen. Throughout most of the rock, the accessory minerals are scarce. Many thin sections of this rock show only recrystallized mosaic quartz. Others have, in addition to the quartz, a few scattered small plates of white mica--mainly sericite, but larger flakes have the optical properties of muscovite (birefringence = 0.04; $2V = 44^{\circ}$). The few scattered clastic grains of zircon show no visible effects of the metamorphism. In the darker varieties of quartzite, which grade into the martitic quartzite, chlorite is more abundant but yet constitutes a minor accessory. It occurs in dull-green microcrystalline aggregates of fine flakes and, rarely, in thin stringers of the aggregate flakes. Hotchkiss (1920) mentions "calcareous material, garnets, and specks of pyrite," and hematite, both finely divided and as specular hematite veinlets. Of the garnets, Hotchkiss says: "In one place, 100 paces north and 100 paces east of the center of section 31 (40 N, 18 E), garnets are found in fairly pure quartzite immediately at the contact with more slaty gradation phases. These garnets are well formed salmon colored dodecahedra. They occur in tiny, flat ellipsoidal cavities about 1/2 to 3/4 of an inch long ..." No garnets were observed in the vitreous quartzite during the present study, nor were slaty phases of the quartzite observed at the locality mentioned by Hotchkiss. Covered areas present could be underlain by argillitic rocks as are described by both Hotchkiss and by Brooks (1888). Throughout most of the exposed length of the quartzite there is extensive recrystallization of the rock with resulting vein quartz. No criteria were found in this study for distinguishing the origin or method of mobilization of the silica. It may be due to metamorphism, or equally as plausibly, deposited in fractured parts of the quartzite resulting from folding prior to the onset of metamorphism. Otherwise stated, evidence is lacking within the quartzite which would indicate if metamorphism was contemporaneous with deformation or was imposed at a later time. From a study of the present mineral constitution and distribution within the vitreous quartzite, it seems that this unit was originally a very clean sand deposit throughout the main exposed body of the rock. Slaty horizons may be present within this mass, but are now obscured by cover.

Martitic quartzite

The vitreous quartzite grades abruptly but imperceptibly eastward into the martitic quartzite. This latter is a rock of varied composition but typically consists of interbedded thin layers of quartzite, graywacke and argillite. The thicker beds of quartzite have remained relatively monomineralic during the metamorphism; however, there is noticeably less sericite or muscovite in these beds, except for very local areas. Within the beds of mixed composition there is developed a suite of metamorphic minerals which are characteristic for the rock. This suite includes chlorite, garnet, stilpnomelane, martite, an unidentified fibrous to platy silicate mineral, and alteration products of these. Throughout most of the argillaceous portion of the rock, the dominant silicate mineral is chlorite, though it occurs in microcrystalline aggregates and does not stand out in thin section. It is typically gray-green, and where well developed the larger plates are usually bent or contorted. Intimately associated with the chlorite, but a minor accessory in the rock are small anhedral garnets, pink to red and highly fractured. In some instances these garnet grains are smashed and cataclastically strewn through a laminae of the rock. Stilpnomelane is well developed but minor in amount. The characteristics of this mineral will be discussed with a following group of rocks in which it is better developed and more abundant. Typical of the martitic quartzite is an unidentified silicate mineral which appears optically to be gradational between chlorite and stilpnomelane. It is olive-green, has parallel extinction, moderate birefringence (ca.0.013), and usually occurs in imperfect semi-radial growths. The crystals tend to be acicular, or possibly elongate plates, but it can also occur in very fine plates closely associated with chlorite. It can be distinguished from chlorite, however, by its higher birefringence and, where in radial development, by crystal habit. Difficulty has been encountered in isolating a reasonable sample for X-ray analysis, but present results now being confirmed indicate that this mineral is structurally neither chlorite nor stilpnomelane. _/

_/ S. W. Bailey (1958) personal communication

The dominant mineral in this rock unit, other than quartz, is martite that is very unevenly distributed but universally present (figs. 10 and 11). It differs in quantity and occurs as dusty dis-

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Figure 10. Photomicrograph of martitic quartzite showing relict quartz grains in matrix of chlorite and opaque martite. Crossed nicols.

Figure 11. Photomicrograph of martitic quartzite, showing distribution of martite and iron silicates. Light areas are quartz. Opaque areas are martite. Platy minerals are chlorite, stilpnomelane, and unidentified silicate. Note tendency of martite (circled area) to crystallize pseudomorphically after silicate. Plane light.

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seminations of very fine grains in the argillitic phase of the rock, or at the other extreme, locally comprises more than 80 percent of a given specimen or bed and appears in hand specimen to constitute the entire rock. Where best developed it has a metallic blue luster, gives a red streak, and, by aggregation of crystals of various sizes, can obliterate all other textural features of the rock. Because of the opaque nature of the mineral and a strong tendency to crystallize, the relationships between martite and the silicate minerals is not well demonstrated. Martite is nearly always accompanied by chlorite and, in numerous observed instances, has grown pseudomorphically after stilpnomelane and the unidentified silicate mineral (fig. 11). The most common distribution of martite in the quartzitic phases of the rock is in stringers and clots along dilatent areas--cracks, joints, or small shatter zones (see fig. 7). The two areas of strongest concentration of martite

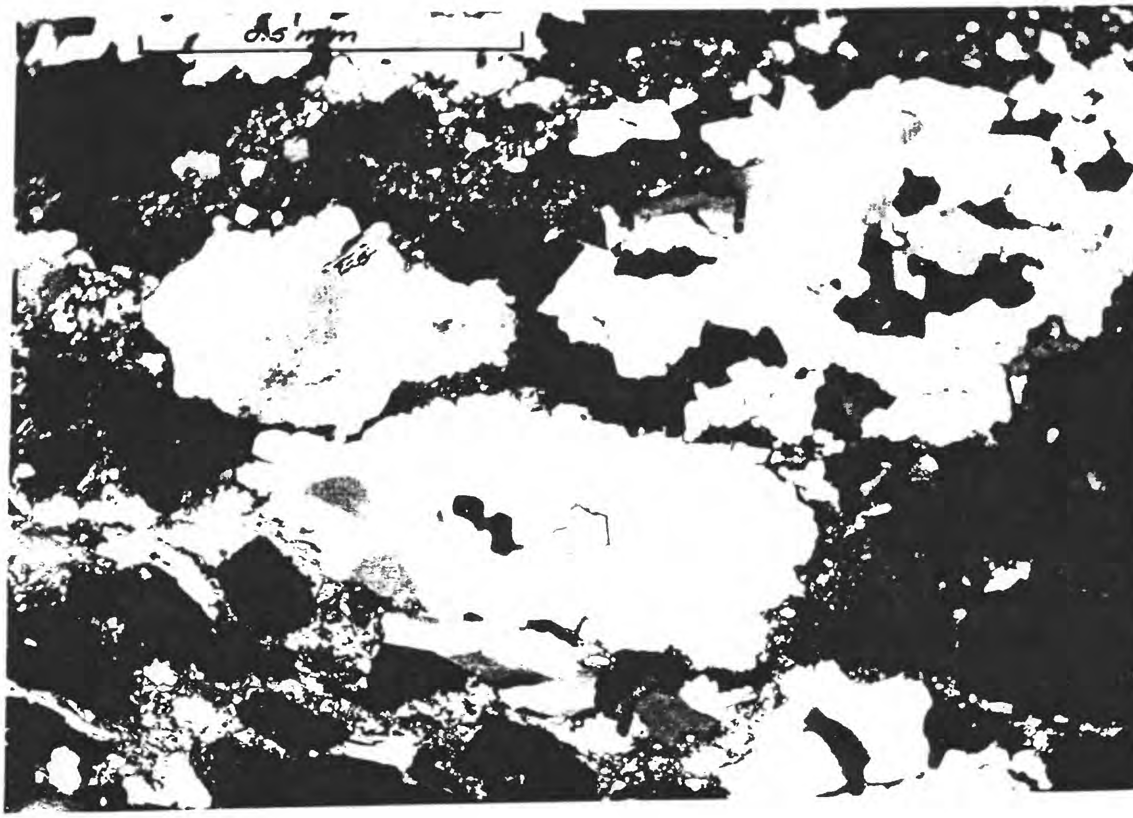

Figure 10. Photomicrograph of martitic quartzite showing relict quartz grains in matrix of chlorite and opaque martite. Crossed nicols.

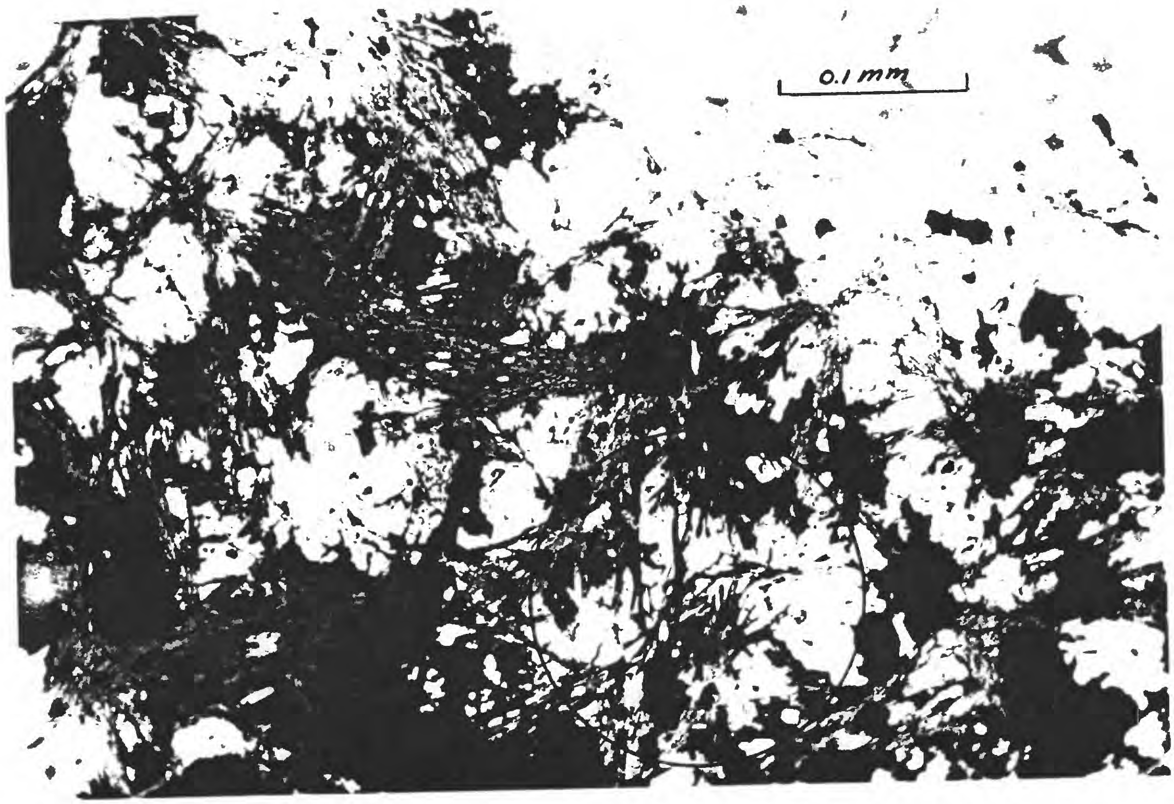

Figure 11. Photomicrograph of martitic quartzite, showing distribution of martite and iron silicates. Light areas are quartz. Opaque areas are martite. Platy minerals are chlorite, stilpnomelane, and unidentified silicate. Note tendency of martite (circled area) to crystallize pseudomorphically after silicate. Plane light.

are found at the two deep exploration shafts. Nothing is known concerning distribution with depth in the western shaft, but Brooks (1880) gives a detailed account of the "sec. 32 shaft" as the east shaft was then known. He states, in part:

"Near the southwest corner of sec. 32, T. 40 N., R. 18 E., is a shaft 63 feet deep, which began with one foot of specular ore at the top, increased to 8 feet, then narrowed up to less than one foot at a depth of 20 feet, and had at the bottom a thickness of ten feet, according to Mr. James Tobin. Apparently about two thirds of the material from the shaft is a rich, merchantable, granular, specular ore (martite), not slaty, but in places showing a dull banding. The upper portion contained the greatest admixture of rock ...

"Both walls of the ore mass are banded quartz schist holding laminae of magnetic and specular ore and martite. The quartz is of saccharoidal character which characterizes this range, and in places contains flattened, pebble-like pieces ..."

Observations of the bedrock surface indicate that this varied distribution is not entirely related to bedding irregularities but more probably is controlled by the amount of argillaceous material and by zones of autobrecciation within the unit. The strong tendency of the martite to crystallize into xenoblastic or idioblastic crystals and crystal aggregates indicates a relatively high degree of mobility of the iron oxides at some stage of the metamorphic transformation. Its occurrence as pseudomorphic after well crystallized silicate minerals suggests greatest mobility at some time late in the metamorphic history. Martite is often well crystallized along small fractures and minor parallel shear zones in the containing rock. Fractures occur not only in the quartzite rocks but also disjoin garnet crystals and aggregates of stilpnomelane and unidentified iron silicate. This is taken as further evidence for a late placement of part or all of the martite.

Impure quartzose clastic rock with abundant martite-magnetite and iron silicates is not a common type within this part of the Lake Superior region. It is not comparable with the chert-hematite iron-formation of southern Dickinson County, Michigan, nor with chert-siderite iron-formation of southern Iron County, Michigan. Similarity in clastic character and distribution of magnetite exists between the Little Commonwealth martite-quartzite and the Goodrich quartzite described in the Kiernan quadrangle (Gair and Wier, 1956), some 20 miles north of Little Commonwealth, in south central Iron County, Michigan. Descriptions of this rock, however, contain no mention of associated silicates, and reference is made to abundant chert. Other published descriptions of magnetite-rich sedimentary rocks make no mention of clastic material in the amount found at Little Commonwealth.

No published description of ferruginous clastic rocks in the Lake Superior region are comparable in detail with those at Little Commonwealth; however, rocks very similar to the martite quartzite are found in a stilpnomelaniferous series of metamorphic rocks in the Lake Wakatipu region of New Zealand (Hutton, 1940). The rocks described are in four subzones of chlorite grade metamorphism and are characterized, especially in the two higher subzones, by widespread occurrence of stilpnomelane. The fundamental difference between the corresponding types is that feldspar is a nearly constant constituent in the Lake Wakatipu rocks but has not been observed within the area of the Little Commonwealth exploration. Of particular interest, however, is a group of rock which Hutton calls "magnetite-garnet-amphibole" schists. Concerning these rocks, he states: (p. 37-38)

"This group of schists is characterized by the development of magnetite, spessartite-garnet, and usually a bluish-green amphibole, although failure by one or more of the constituents, or by the incoming of others, the rocks grade towards quartz-schists on the one hand, and pure magnetite-schists on the other.

"Magnetite, the most plentiful constituent, occurs in xenoblastic, less commonly idioblastic, grains up to 5.0 mm in diameter. In the very ferruginous schists iron ore may also occur as clouds of minute grains throughout the rock."

Quartz-garnet-stilpnomelane schists occur in close association with these rocks in the two higher subzones of chlorite grade metamorphism. Accepting the gradation at Little Commonwealth between martitic quartzite and garnet-quartzite, these two rock units considered together would almost exactly correspond to descriptions of comparable Lake Wakatipu rocks. The only constituent found in the latter rocks which has not been confirmed at Little Commonwealth is the bluish-green amphibole. This mineral has not been recognized within the area, but a similar amphibole is described by James (1955, p. 1470-1477) as a constituent in Animikie rocks in metamorphism of biotite grade and higher.

Appraisal of the original deposited constituency of the martitic quartzite is more difficult than for other rocks in the area. If the present amount of magnetite is representative of original amount of deposited iron, the environment of deposition may have been that of clean quartz sand and minor amounts of clay minerals carried into a highly ferruginous shallow water bog. The iron, precipitated as a hydrous oxide, formed a cement for the clastic grains. Hutton (1940, p. 45-46) discusses such an origin for comparable rocks in the Lake Wakatipu region. Instability of conditions of deposition in the Little Commonwealth area is indicated by the more or less rhythmic banding of thin quartzite beds and more ferruginous, argillaceous beds. Farther distant from the main deposition of quartz sand, the dominant clastic constituency would expectably be fine-grained silts and mud, also quite quartzose, and deposited in a similar environment. The behavior of these rocks under conditions of metamorphism will be discussed with the next rock type.

Quartzose phyllite and garnet quartzite

The rocks at Little Commonwealth demonstrate a complete gradation between the martitic quartzite and the green to brown garnet quartzite with associated fine-grained, slightly less ferruginous slate. These latter rock types, volume for volume, are probably not much less ferruginous than the martitic quartzite but are of different physical appearance because of the greater abundance of argillitic constituents, resulting in a different distribution of the iron present. Chemical analyses are not available for comparison, however, and the "less-ferruginous" nomenclature is the outgrowth of hand specimen study. Basically, these two units are quite quartzose but have an abundance of silicates in the matrix and greater development of garnet. All thin sections of the rock show a large amount of gray-green chlorite in aggregate clusters of small flakes, and in platy, almost schistose, stringers. The chlorite is seen to grade into the unidentified iron silicate, noticeable in thin section by a change in color from gray-green to yellow-green or yellow, and a rise in birefringence. The material is too finely crystalline to obtain diagnostic optical data on the mineral. Stilpnomelane, in bright green plates, is a nearly constant constituent but varied in amount present (fig. 12). X-ray

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Figure 12. Photomicrograph of garnet-stilpnomelane quartzite showing tendency of platy green ferrostilpnomelane to develop radial aggregates. Opaque mineral is martite. Small fibrous to platy crystals are brown stilpnomelane. Calcite (c) replacing quartz (q) occurs throughout the thin section. Crossed nicols.

Figure 12. Photomicrograph of garnet-stilpnomelane quartzite showing tendency of platy green ferrostilpnomelane to develop radial aggregates. Opaque mineral is martite. Small fibrous to platy crystals are brown stilpnomelane. Calcite (c) replacing quartz (q) occurs throughout the thin section. Crossed nicols.

studies of fine-grained matrix aggregate show intimately intergrown chlorite, ferrostilpnomelane, and minor amounts of biotite. Several thin sections show bands in which the dominant silicate mineral is biotite (brown, pleochroic, small 2V, birefringence = 0.003±). Red garnet occurs as scattered anhedral grains, clots, and globular layers. The latter occurrence seems to be volumetrically more important. Locally within these rocks are scattered "floating" quartz grains, most of which are recrystallized, strained, and embayed at the borders. The presence of chert in these rocks is difficult to ascertain. Observation of recrystallized quartz grains in the vitreous quartzite has demonstrated that the metamorphism has operated to reduce and homogenize the granularity of the clastic quartz. The resulting apparent grain size in the mosaic is about 0.05-0.10 mm. James (1955, table 2) shows that, in response to metamorphism, the grain size of chert is increased, and at biotite or garnet grade is about .10 mm. Thus, it would appear that fine-grained clastic quartz pods would be indistinguishable from pods, or stringers, or even beds of chert in the rocks at Little Commonwealth. Extended treatment with HCl of specimens of garnet-stilpnomelane-chlorite quartzite showed in the remaining residue both frosted quartz grains and irregular 2 cm square areas of grayish white very irregular siliceous plates which closely resemble blebs of chert. No clastic grains are identifiable within these plates. It seems not unlikely that gel silica could have been a constituent in the original composition of these rocks, and also in the martite quartzite, and possibly locally in the vitreous quartzite.

The environment for the deposition of these rocks seems to have been one of facies change associated with, but at a greater distance from, the source of the vitreous quartzite. Fine siliceous and argillaceous clastic material was carried towards a basin in which the waters were of nearly proper character to produce carbonate, or possibly oxide iron-formation (James, 1954, p. 256-263). It appears from inspection of the metamorphic minerals developed, that these originally deposited muds were characteristically deficient in soda, lime, and potash, suggesting that the source of the sediments may have been the weathering of an earlier terrane made up dominantly of sedimentary rocks, rather than that of an emergent igneous land-mass.

In response to metamorphism these rocks, low in alkalic constituents but with abundant or representative amounts of iron, magnesia, and manganese developed their characteristic mineralogy under the restrictions of bulk chemical composition. Chlorite was probably formed first, grading with increasing metamorphism into stilpnomelane. Layers which had much manganese present gave rise to the bands of garnet clusters. Locally, where small amounts of alkali were present, biotite developed at the expense of stilpnomelane. The abundant quartz in the rock was not noticeably depleted during these processes.

Stilpnomelane-garnet slate

The gradation between the units described above and the graphitic stilpnomelane-garnet slate is more sharply defined in the field than is evident in close inspection of drill core and thin sections. This is due to the very dark green to black color of these rocks, and to the appearance of identifiable chert in pods and bands with associated grunerite. Association of graphitic slate with carbonate iron-formation (chert-grunerite) is common in the Lake Superior region; however, close study has demonstrated that interbedded with these rocks of the inferred carbonate iron-formation-association, are beds identical in character to the argillitic stilpnomelane-garnet quartzite described previously, and the unit is thought to be a mixed assemblage of both types of rock, with iron-formation type rocks being volumetrically less important.

This unit of rocks is less well known than the foregoing types, mainly because of their deeply weathered character and changeable constituency. Locally the rock is highly stilpnomelaniferous with bold bands of unaltered red garnet (fig. 13). In this condition it

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Figure 13. Garnet-ferrostilpnomelane slate, showing irregular contact between garnet band and slaty rock. Note nematoblastic texture of stilpnomelane slate. White area to right of screw is quartz. Screw is 1/2 inch long.

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is noticeably nematoblastic in hand specimen, presenting a glistening, dark green appearance. Sections of drill core demonstrate that this

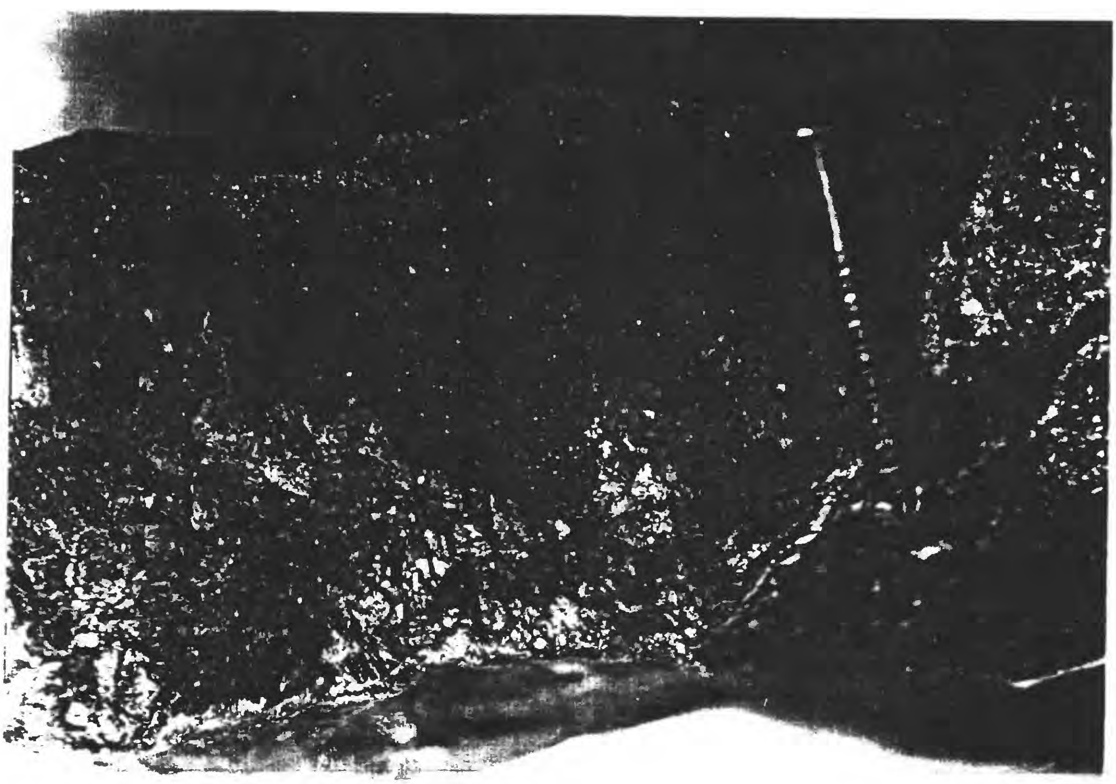

Figure 13. Garnet-ferrostilpnomelane slate, showing irregular contact between garnet band and slaty rock. Note nematoblastic texture of stilpnomelane slate. White area to right of screw is quartz. Screw is 1/2 inch long.

dark green variety of the rock is intimately interbedded with more quartzose garnetiferous rock in which there are locally discontinuous pods of siliceous material, presumably chert. The individual plates of vivid green, strongly pleochroic ferrostilpnomelane are 0.5 to 1.0 mm in diameter and are developed in a striking decussate texture (fig. 14). These chert pods are enclosed in a reaction rim of

Figure 14. Photomicrograph of garnet-ferrostilpnomelane slate showing coarse decussate texture of green ferrostilpnomelane, and contact with garnet (g)(upper right). Quartz (q) in dilatent area between lobes of garnet crystals. Plane light.

yellow-brown finely acicular grunerite (brown, pleochroic, amphibole cleavage; $Z \wedge C = 11^{\circ}-15^{\circ}$, biref. = 0.022). The chert-grunerite components increase somewhat towards the lower part of the unit, as shown in drill core. Locally, there is abundant graphite, and in these places the development of metamorphic minerals appears to have been arrested, resulting in a very fine grained rock in which the minerals are unidentifiable by optical methods.

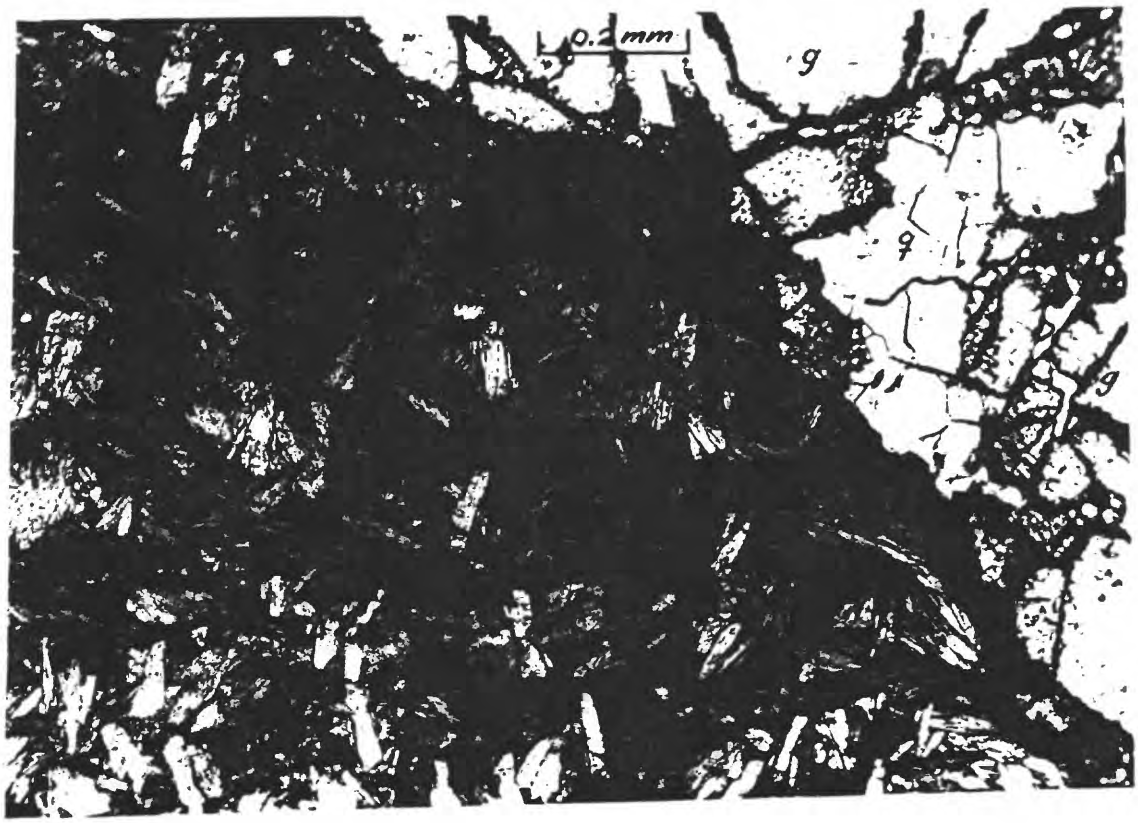

Figure 14. Photomicrograph of garnet-ferrostilpnomelane slate showing coarse decussate texture of green ferrostilpnomelane, and contact with garnet (g) (upper right). Quartz (q) in dilatent area between lobes of garnet crystals. Plane light.

In a large test pit just north of the road midway between drill holes FC 101 and FC 103, a peculiar phase of this rock has caused some interest, and probably has proved troublesome in earlier interpretations of the area. The rock is very dense, heavy, mashed and contorted, and locally contains abundant fragments of chert. Some of the material on the dump around this test pit is in part graphitic, hematitic, and pyritic. The chert fragments are noticeably corroded, and all show a rim of a dark feathery mineral which is in turn enclosed by a dense purplish band (figs. 15 and 16). Thin sections of this rock show an

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Fig. 15. Segmented chert with reaction rim of stilpnomelane. ch = chert, py - pyrite, s - stilpnomelane, q+h - quartz and hematite, m - matrix of graphitic slate and hematite. Most specimens suggest lateral separation of chert bands. Screw is one-half inch long.

Figure 16. Polished specimen, etched with HF, showing alteration of chert fragment. ch = chert, s = stilpnomelane, q+h = quartz and hematite, m = matrix breccia, graphitic and hematitic. Specimen from test pit 25 feet N., and 200 feet E. of drill hole FC 101. Screw is 1/2 inch long.

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unusual mineralogic sequence. At the interface between chert and the silicate there is usually noticeable pyrite in anhedral grains and stringers. Behind the thin belt of pyrite is a delicate intergrowth

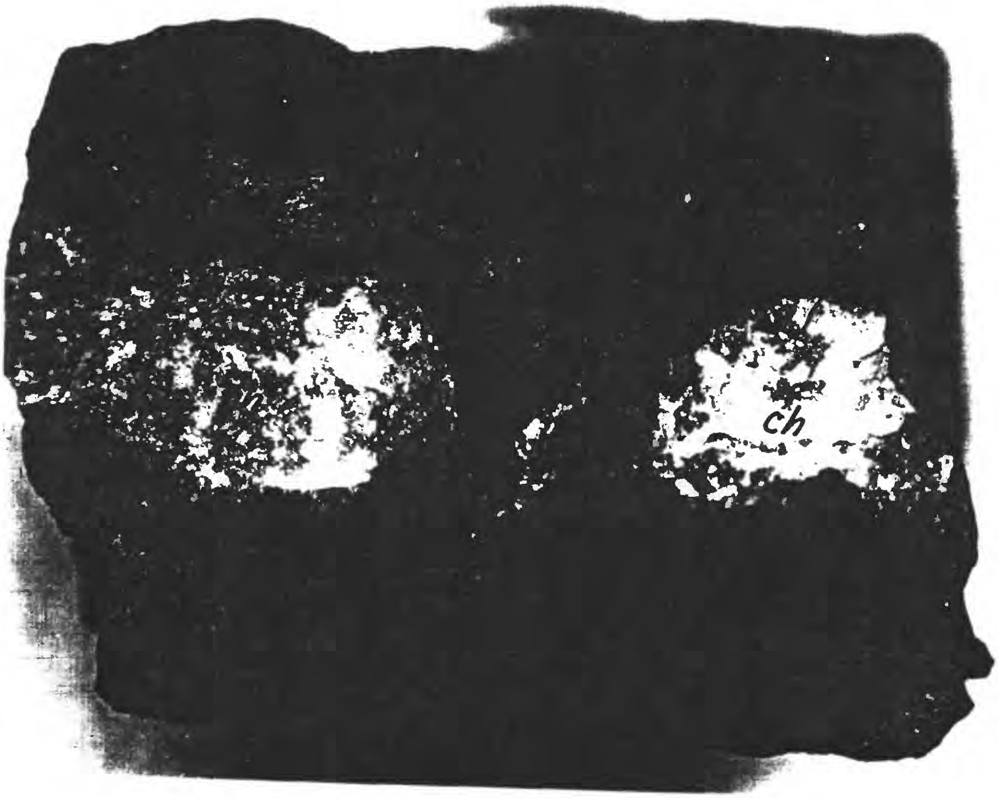
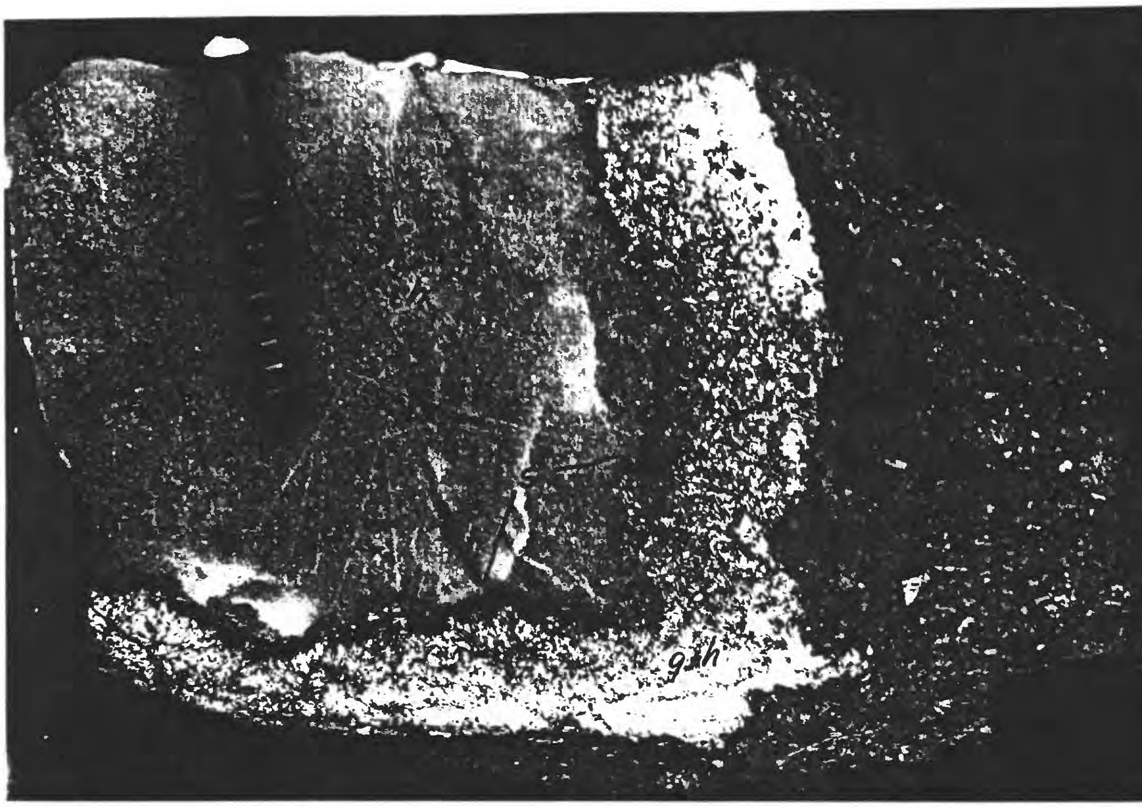


Figure 15. Segmented chert with reaction rim of stilpnomelane. ch = chert, py = pyrite, s = stilpnomelane, q+h = quartz and hematite, m = matrix of graphitic slate and hematite. Most specimens suggest lateral separation of chert bands. Screw is one-half inch long.



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of feathery brown stilpnomelane, the texture of which indicates growth towards the chert (fig. 17). Next behind this brown band is a wider

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Figure 17. Photomicrograph of reaction rim of stilpnomelane on chert fragment. ch = chert, s = stilpnomelane, q+h - quartz and hematite, py = pyrite. Note pseudomorphism of quartz and hematite after stilpnomelane. Crossed nicols.

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belt of quartz and hematite. The quartz is entirely pseudomorphous after the stilpnomelane crystal form, while hematite forms interstitial fillings and imparts a purple or dark red color to the slide in reflected light.

The reaction rim has been observed in all stages of destruction of the chert. Where it has gone to completion, there is a central thin lenticular mass of pyrite followed by broader bands of both brown stilpnomelane and quartz-hematite. The matrix which encloses these stilpnomelane-chert fragments is very fine grained, dull black in color, and more or less siliceous (fig. 16). The graphitic nature of this material was not disclosed until specimens of the rock were subjected to extended treatment with HCl. The residue, constituting a large part of the matrix of the specimens studied, was highly graphitic, though in the original state it may have contained a considerable amount of hematite.

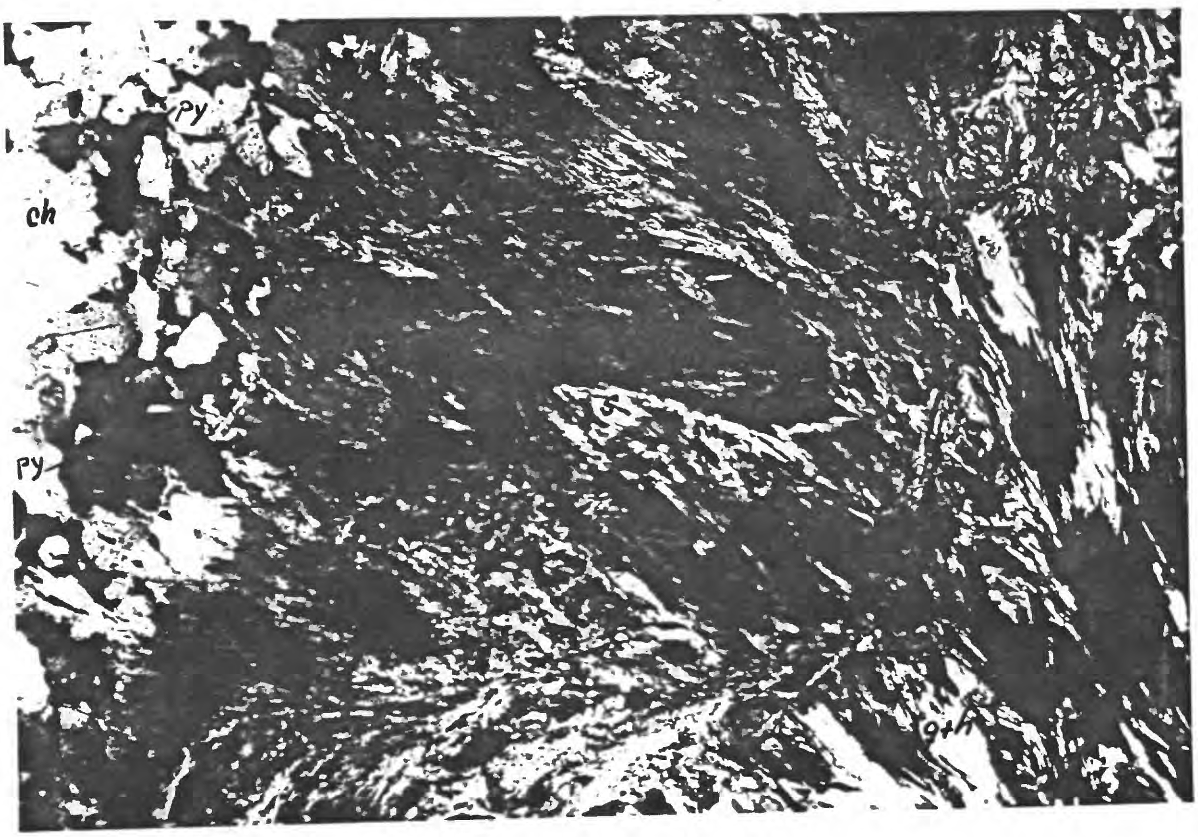

Figure 17. Photomicrograph of reaction rim of stilpnomelane on chert fragment. ch = chert, s = stilpnomelane, q+h = quartz and hematite, py = pyrite. Note pseudomorphism of quartz and hematite after stilpnomelane. Crossed nicols.

Within this facies of the Little Commonwealth rocks is observed considerable variation in the mineralogic occurrence of stilpnomelane. In the portions of the rock characterized by the association of graphite with chert-grunerite, the dominant form of the mineral is deep green ferrostilpnomelane, whereas in more clastic parts of this facies the mineral is found in ragged brown plates and slender platy brown prisms characteristic of the ferric form--stilpnomelane. Hutton (1938) discusses in great detail the chemical, optical, and structural character of the stilpnomelane group of minerals. Rock types discussed in his study closely resemble those of the Little Commonwealth area. The transition from ferro- to ferristilpnomelane is one involving oxidation; and within Little Commonwealth, this oxidation has in some cases possibly proceeded further and has dissociated the stilpnomelane into hematite and quartz. Hutton considers the manganese mineral parsettensite a member of the stilpnomelane group, but this mineral has not been observed during this study of the area, in spite of the apparent abundance of manganese in some places.

Rocks stratigraphically above the vitreous quartzite

Exposures of rocks that overlie the quartzite and associated facies are not extensive in the Little Commonwealth area. Outcrops, where present, are deeply weathered, and relation of these rocks to metamorphism is not clear. The outstanding difference is found in absence of martite and garnet. Fine-grained slates uncommonly have minor porphyroblast development. Tourmaline occurs in some rocks. A small area is underlain by chert-limonite rock in which the limonitic portion suggests the fibrous growth common to grunerite, but unaltered grunerite has not been identified. The apparent arrested development of metamorphic minerals in these rocks could be due to either original compositional differences, or to local variations in metamorphic parameters or agents or conditions.

Metasomatism

In many thin sections and hand specimens of rocks from the Little Commonwealth area there are considerable amounts of tourmaline. In some rocks this mineral is nearly absent whereas in others it can constitute the bulk of a specimen. Close study has demonstrated no obvious relation to bedding or restriction of the mineral to a particular rock type. Tourmaline usually occurs in randomly oriented, segmented, prismatic crystals whose direction of strongest absorption is in the transmission direction of the ordinary ray (figs. 18 and 19). Rarely

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Figure 18. Phtomicrograph of quartzite with abundant tourmaline and muscovite. This rock is associated with martite quartzite facies although martite is nearly absent. Matrix consists of equal amounts of quartz and muscovite. All dark crystals are tourmaline. Plane light.

Figure 19. Photomicrograph of garnet-stilpnomelane quartzite showing development of grunerite (g)(see p. 90) after radial aggregates of ferristilpnomelane (s). White areas are quartzite, opaque mineral is martite. Note tendency of martite to form imperfect pseudomorphs after silicate minerals. Clusters of chlorite in upper right corner. Garnet grains in lower left corner. Plane light.

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it forms incomplete rosettes of crystals, and on one or two slides very long, thin crystals are observed, which nearly span the thin section. Tourmaline is distinctly developed later than all the other silicate minerals, but relation to the martite is obscure. Poor exposures have prevented delineation of areas of abundant tourmaline, but the apparent erratic distribution of this mineral strongly suggests the possibility of metasomatism.

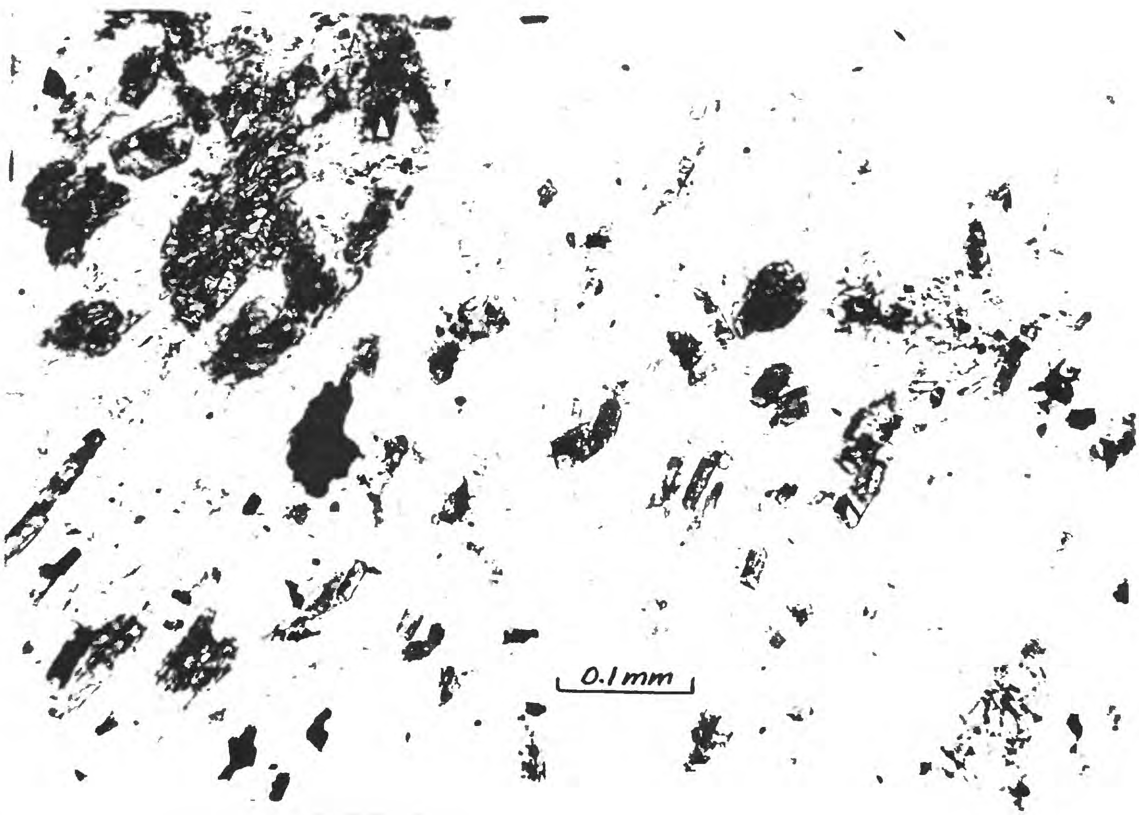


Figure 18. Photomicrograph of quartzite with abundant tourmaline and muscovite. This rock is associated with martite quartzite facies although martite is nearly absent. Matrix consists of equal amounts of quartz and muscovite. All dark crystals are tourmaline. Plane light.

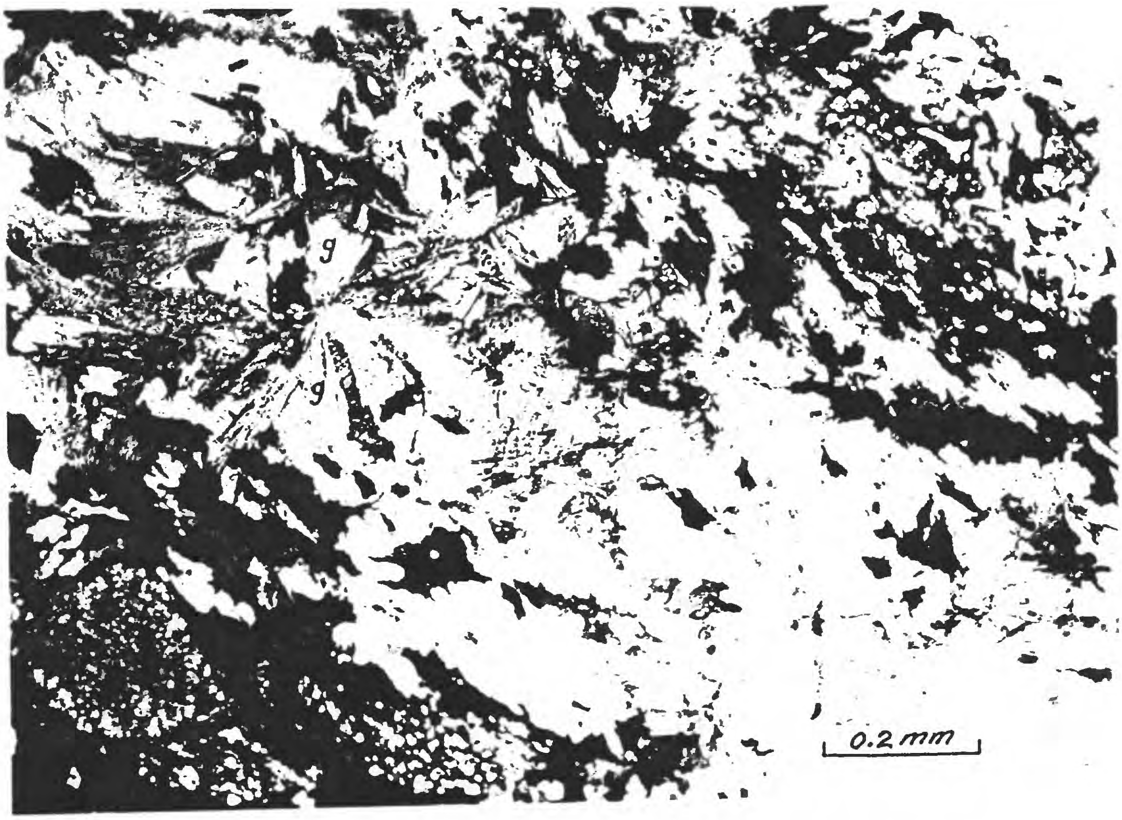


Figure 19. Photomicrograph of garnet-stilpnomelane quartzite showing development of grunerite (g)(see p. 90) after radial aggregates of ferristilpnomelane (s). White areas are quartzite, opaque mineral is martite. Note tendency of martite to form imperfect pseudomorphs after silicate minerals. Clusters of chlorite in upper right corner. Garnet grains in lower left corner. Plane light.

Further support for hydrothermal solutions postdating metamorphism in the area is found in the occurrence in minor amounts of chalcopyrite, aresnopyrite (reported in the drill core), and the leaching of stilpnomelane in the development of quartz and hematite in pseudomorphs after the former mineral. The possibility was considered that much of the present ubiquitous concentration of magnetite-martite may have been caused by late solutions, but evidence in the area is inconclusive. The fact remains, however, that in the apparent paragenesis of the minerals at Little Commonwealth, those that show late crystallization are tourmaline, ~~martite~~magnetite, and some of the sulfides.

Metamorphic grade

The rocks at Little Commonwealth are of unusual composition and distribution, and so far as is known, are not comparable with any other exposures in the Florence district or neighboring districts. Chemical analyses are not available, and even though this information were obtained, comparisons with rocks elsewhere would be tenuous, because of the isolated position of the exploration area.

The mineral constituency of the rocks allows the following generalizations concerning chemical composition. The rocks associated with the vitreous quartzite are low in soda, potash, and lime, but are highly ferruginous, with accessory amounts of magnesia and manganese. Quartz of both clastic and chemical origin (chert) is the dominant constituent, except in one facies which tends towards the composition of a chert-siderite iron-formation with some fine clastic material. This latter rock is locally quite carbonaceous, resulting in development of graphite. All the rocks may have appreciable amounts of alumina; the vitreous quartzite having the least of the group.

Garnet is abundantly developed in all the aluminous rocks and is probably the most conspicuous metamorphic mineral. The occurrence of garnet in this environment may be misleading, however. Ramberg (1952, p. 60 and fig. 30) considers that highly ferruginous chlorite with accessory iron oxide could react to form garnet at a considerably lower grade of metamorphism than that which would achieve a comparable reaction if high-magnesian chlorite were involved. He also considers (p. 144) that the crystallization of garnet is greatly favored by the availability of manganese. At Little Commonwealth the best development of garnet is in layers, or stringers, presumably parallel to bedding, indicating an original distribution of manganese-rich layers.

The restricted development of muscovite and biotite reflects the deficiency of soda and potash in much of the area. Sericite and muscovite are characteristic in the footwall sericite phyllite, and very locally in the vitreous quartzite, but are nearly absent in the argillitic and ferruginous rocks of the quartzite association. Only locally in these latter rocks is biotite identifiable by X-ray methods and is there inseparable from stilpnomelane by optical methods.

Stilpnomelane is a mineral of questionable value as an indicator of metamorphic grade. In the Little Commonwealth rocks both ferrostilpnomelane and stilpnomelane (the ferric end-member) are present, and transition of the ferrous member into the ferric member can be seen in thin section. The mineral is very well developed and, with quartz and chlorite, constitutes the bulk of many of the rocks. Hutton (1938, p. 201) discusses the development of stilpnomelane in schists of the chlorite zone, and states:

"A study of higher grade rocks than the chlorite zone by Turner (1933) has not shown stilpnomelane to be represented among the mineral assemblages."

James (1954, p. 1474) considers the development of stilpnomelane to be in part primary, during diagenesis, and partly in response to metamorphic conditions. He considers it to be largely restricted to metamorphic grades below garnet, but mentions the occurrence of a dark ferric variety of stilpnomelane in the garnet zone. He notes:

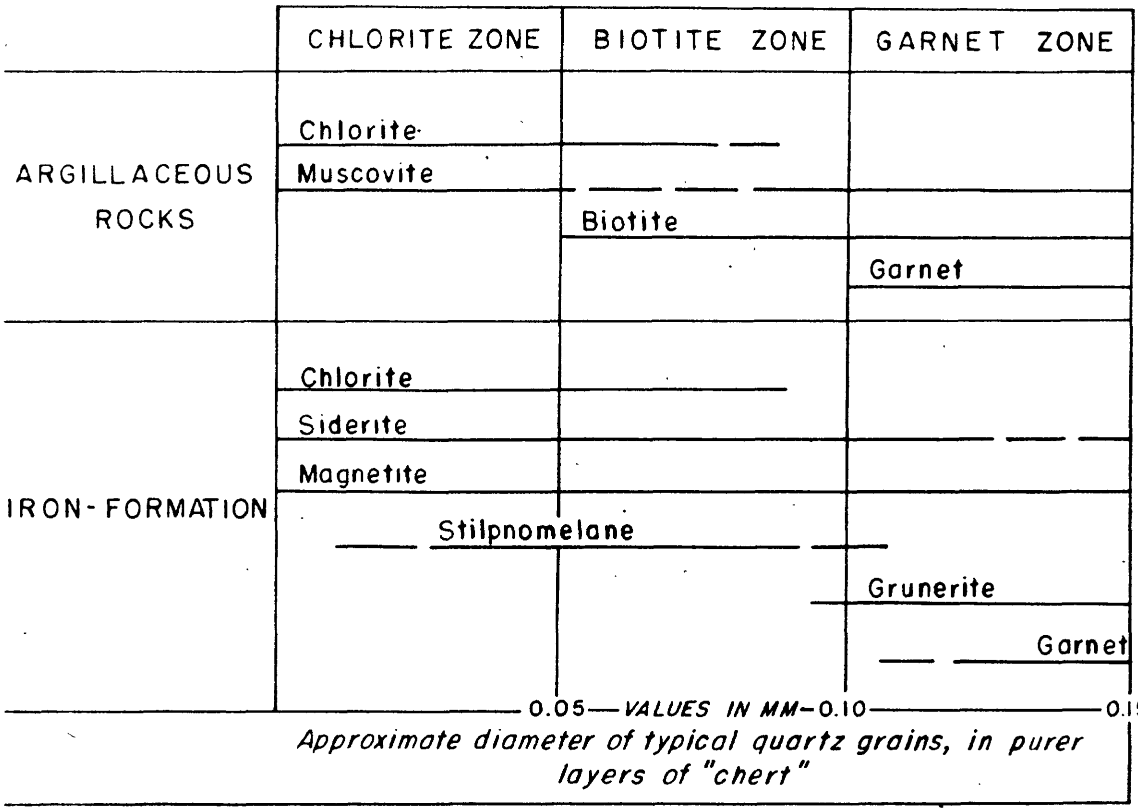
"The local presence of stilpnomelane in the garnet zone is taken to indicate that its field of stability extends slightly beyond the biotite level, though the mineral may be retrograde in this association."

There is scant development of grunerite in some of the rocks at Little Commonwealth, but in general it is a minor constituent. It is most easily recognizable in the drill core which penetrates graphitic stilpnomelane garnet slate. In typical development the grunerite occurs as yellow-brown fibrous rims and patches adjacent to lenses of chert. In outcrop the rocks are so highly weathered that only limonite remains in which the relict structure of grunerite is preserved. The appraisal of relative amount of grunerite is further complicated by relations observed in thin section. In several instances the transition from ferric stilpnomelane, which also has a strong tendency towards development of radial crystal aggregates, to grunerite is noticeable only by increase in birefringence and change in extinction angle ($Z \wedge c$) from 0° in the stilpnomelane to 12° for grunerite (see figure 19). Hence, it may be impossible to distinguish between stilpnomelane and grunerite in hand specimen. The relationships of the grunerite to stilpnomelane and to the chert pods indicate that this mineral is in an incipient stage of development.

Concerning the relation of grunerite to metamorphism, James (1955, p. 1477) says: "In general, the key mineral of intermediate-intensity metamorphism of the iron-formation rocks is grunerite. The appearance of this mineral probably slightly precedes that of garnet in the argillaceous rocks."

The poor development of grunerite may be due to one or more of several factors. (1) No siderite has been identified at Little Commonwealth and, accordingly, is thought to have been of minor importance as a distinct phase in the original rock composition(s). The grunerite rims on chert suggest that siderite may have been very locally abundant adjacent to the chert. (2) Siderite may have been present in minor amounts in the argillitic ferruginous rocks. If the system were open during metamorphism, with resulting escape of CO_2, the remaining iron could have been incorporated into the stilpnomelane. (3) The development of grunerite from stilpnomelane involves an excess of alumina, and if there is no migration of this component, the growth of grunerite could be arrested, and the better crystallization of stilpnomelane would probably follow.

In the mineral relationships at Little Commonwealth there is noticeable incompatibility. Table 2, taken from James (1955, table 2), shows the expectable distribution of minerals of the various metamorphic zones for northern Michigan. Comparison of the metamorphic petrology of Little Commonwealth with rock-type divisions shown in the table is difficult because the argillaceous rocks associated with the vitreous quartzite are completely gradational with those which approach the mineralogical composition of a chert-siderite iron-formation. These latter rocks, in turn, gradationally become more graphitic. The overall mineralogical composition of these rocks may be characterized as follows: (1) Chlorite is probably the dominant silicate mineral. (2) Stilpnomelane is very well developed and apparently completely



Dashed lines indicate uncertainty as to classification.

After James, H. L. (1955)
Table 2

Table 2. Mineral assemblages of some common rocks in the metamorphic zones of northern Michigan.

gradational from the ferrous to the ferric varieties. (3) Biotite is present but is not significant either in quantity or in crystal growth. (4) Garnet is present in almost all the sedimentary facies, in a well advanced stage of development. (5) Grunerite appears to be in a stage of incipient growth. (6) Martite and magnetite appear to be crystallized in present distribution later than many, if not all, of the silicates.

This mineral assemblage and the relative crystallographic development of the individual minerals indicate that these rocks are now in some grade of metamorphism within the biotite zone. The extensive development of garnet is thought to have been accelerated by concentrations of manganese minerals in the original composition of the rocks. The abundance and poor crystallization of chlorite are indicative of the lower part of the biotite zone. In terms of regional metamorphic zones, the rocks at Little Commonwealth appear to be in the lower or middle part of the biotite zone.

The unique character and rapid gradation of these rocks have contributed towards a more complex bulk chemical composition and this is reflected in the complexity of the metamorphic mineral assemblage. Yoder (1955) points out that for a metamorphic isograd to have a precise meaning, the reaction must be specified. The final appraisal of the metamorphic grade at Little Commonwealth cannot be made until mapping in the vicinity, mainly to the south and southwest, establishes a more meaningful frame of reference.

There is some evidence in thin section that the mineral relations at Little Commonwealth are in part due to retrograde metamorphism. Almost all the garnet crystals and grains observed are highly fractured, and many are cataclastically distributed through the surrounding rock. Locally, these fragments are completely chloritized. Elsewhere chlorite is seen as an alteration rim in which is preserved features of the remaining garnet, while still others show alteration to chlorite commencing at small centers throughout the garnet grain.

Related to this late alteration of metamorphic minerals, but of unknown extent is the evidence for hydrothermal activity within the area. Thin sections from scattered localities show the alteration of stilpnomelane to quartz and hematite. The quartz is pseudomorphous after the stilpnomelane structure, while hematite fills the local interstices. In parts of the area, where this condition is most prevalent, there is also the most abundant tourmaline. Pyrite, chalcopyrite, and arsenopyrite all occur in the argillaceous rocks at Little Commonwealth, but details of their distribution are not known. The distribution of martite-magnetite in dilatent parts of the rock as well as in coarse granular aggregates which apparently replace all other minerals suggests that it was, at some late stage, quite mobile. This mobility may have been imparted by the hydrothermal solutions.

CONCLUSIONS

Detailed study of the Little Commonwealth area has led to a number of conclusions; however, these are partly based on observations for several miles to the northwest of the immediate vicinity of the exploration. The following points seem to be valid for the area of this report:

1. The complexity of rock types and distribution of these rocks is not due primarily to folding or faulting but is rather the result of a very abrupt eastward facies change from vitreous quartzite to highly ferruginous clastic rocks, some of which bear resemblance to chert-siderite iron-formation. Stratigraphic equivalents of these rocks farther to the east in the Florence district have not been recognized.
2. The absence of detrital feldspar or ferromgnesian minerals in rocks of the vitreous quartzite stratigraphic position indicates that the sediments were probably derived from erosion of a pre-existing land-mass made up dominantly of sedimentary rocks, rather than from an igneous terrane.

3. Rocks overlying the vitreous quartzite and its stratigraphic equivalents have been mapped for more than 3 miles to the northwest. Reconnaissance study of the succeeding rocks indicates that these post-quartzite units at Little Commonwealth and northwestward may be basal Paint River (upper Animikie) in age. The lowermost unit contains a basal conglomerate locally developed. It is thought that the quartzite and stratigraphically equivalent rocks are of pre-Paint River age.

4. Accepting the distribution of rock types as due to facies change, structural deformation beyond elevation of the beds into a vertical position is not outstanding within the area. Minor structures could have developed in response to tectonic forces, but it is believed that a significant part of this structure may be of pre-lithification or diagenetic origin.

5. The unique assemblage of rock types has led to the development of metamorphic minerals that are difficult to classify in terms of regional metamorphic zones. The abundance of garnet and incipient development of grunerite are accompanied by well formed ferrostilpnomelane. It is believed that these rocks are in the biotite zone of metamorphism. Diaphthoresis is probably present in the metamorphic mineralogy, but evaluation of relative importance must await study of a larger area than that of this report.

References

Aldrich, H. R., 1932, Relationship of the Keyes Lake Quartzite to the Little Commonwealth iron formation (unpublished report in files of Wisconsin Geol. and Nat. History Survey.

Bayley, R. W., 1958, Geology of the Menominee iron-bearing district (abst.): Institute on Lake Superior Geology, p. 8, Duluth, Minn.

Brooks, T. B., 1880, Part IV, The Menominee iron range, Oconto County, Wis., in Geology of Wisconsin, 1873-79, v. 3: [Wisconsin Geol. Survey] p. 481-492, 679-687, 690-717, and maps and figs.

Crowell, J. C., 1957, Origin of pebbly mudstones: Geol. Soc. America Bull. v. 68, p. 993-1010.

Dutton, C. E., 1950, Progress of geologic work in Iron and Dickinson Counties, Michigan: U. S. Geol. Survey Circ. 84.

Gair, J. E., and Wier, K. L., 1956, Geology of the Kiernan quadrangle, Iron County, Mich.: U. S. Geol. Survey Bull. 1044, p. 35-38 and figs.

Harker, A., 1939, Metamorphism, 2nd ed. 358 p., London, Methuen.

Hotchkiss, W. O., 1920: Geology of the Florence district, Wisconsin: Unpublished report in files of Wisconsin Geol. and Nat. History Survey.

Hutton, C. O., 1938, The stilpnomelane group of minerals: Geol. Mag. v. 25, p. 172-206.

Hutton, C. O., 1940, Metamorphism in the Lake Wakatipu region, western Otago, New Zealand: New Zealand Dept. Sci. and Ind. Research, Geol. Mem. 5.

James, H. L., 1954, Sedimentary facies of iron-formation: Econ. Geology, v. 49, p. 235-293.

James, H. L., 1955, Zones of regional metamorphism in the Precambrian of northern Michigan: Geol. Soc. America Bull. v. 66, p. 1455-1488.

James. H. L., 1958, Stratigraphy of pre-Keweenawan rocks in parts of northern Michigan: U. S. Geol. Survey, Prof. Paper 314-C, p. 37-39.

Nevin, C. M., 1931, Principles of structural geology, 410 p., New York, John Wiley and Sons.

Pettijohn, F. J., 1949, Sedimentary rocks, 526 p., New York, Harpers.

Shrock, R. R., 1948, Sequence in layered rocks, p. 64-70, New York, McGraw Hill Book Co.

Van Hise, C. R., and Leith, C. K., 1911, Geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, p. 321-327.

Yoder, H. S., 1955, Role of water in metamorphism: Geol. Soc. America Special Paper 62, p. 513.

Yoder, H. S., 1957, Isograd problems in metamorphosed iron-rich sediments; in Annual report of the Director, Geophysical Laboratory, Carnegie Inst. of Washington (yearbook 56), Paper no. 1277.