AN ARCHEAN MYLONITE FROM NORTHWESTERN ONTARIO.

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ABSTRACT. A sill of micropegmatitic granite porphyry of Archean age in northwestern Ontario, as a result of tectonic deformation, was mylonitized through a thickness averaging one-fourth mile along at least one border.

INTRODUCTION.

THE term mylonite was first applied by Lapworth (1)* in 1885 to rocks in the North-West Highlands of Scotland that were the product of extremely fine cataclastic granulation of the mineral constituents. Lapworth defined a mylonite as a "microscopic pressure-breccia with fluxion structure" and, although it was referred to purely mechanical deformation, he recognized that there was some neomineralization associated with the granulated mineral particles. In general, rocks formed by mylonitization are compact and chert-like in appearance, but contain a fine layering that, in many cases, resembles flow structure in rhyolites. Such rocks can be recognized in the field, particularly if they are found to grade into the undeformed equivalent. The incomplete stages of mylonitization can be recognized by the presence of augen porphyroclasts or unreduced residuals. The aphanitic ultimate product in which there has been complete cataclastic reduction of all minerals is known as ultramylonite.

Mylonite zones have been reported not only from the Scottish Highlands, but from localities in the United States, Scandinavia, the Alps, and many other places, where for the most part they are associated with great thrust faults. They may occur in zones up to 600 or even 1,200 feet thick, but are generally much narrower. Such rocks occur mostly in the soles of overriding thrust blocks and have been formed under considerable pressures by the differential movement. Although the powerful metamorphism that many parts of the Canadian Shield have undergone has often been emphasized, descriptions of mylonite zones in these areas are rare or wanting in the literature. One notable exception is the description of the granulated anorthosites north of Montreal by F. D. Adams (2). Although Adams did not use the term mylonite, his

* Numbers in parentheses refer to bibliography at end of paper.

excellent descriptions leave no doubt as to the nature of these comminuted rocks.

The present paper describes a mylonitized granitic intrusive from Confederation Lake in the northwestern portion of the Uchi-Slate Lakes map-area, which is situated in northwestern Ontario 75 miles north-northwest of Hudson or Sioux Lookout on the Canadian National railway. The field studies were undertaken during an examination of the area on behalf of the Ontario Department of Mines,* the following descriptions being the substance of one chapter of a dissertation, presented for the degree of Doctor of Philosophy in Yale University. The writer is indebted to Mrs. Adolph Knopf for discussions of mylonitization and to Professor Adolph Knopf for constructive criticism of the manuscript.

SUMMARY OF GEOLOGY.

The oldest rock formations in the district comprise a number of metasedimentary groups collectively known as the Slate Lake series. The rocks consist for the most part of impure quartzites and arkosic quartzites that are altered to broad zones of mica schists and paragneisses in the vicinity of younger intrusive granites, and to sericite and carbonate schists along zones of strong shearing. The series includes a great lenticular conglomerate member, an horizon of magnetic iron formation and some narrow intercalated belts of pillowed greenstones. The formations of the Slate Lake series strike easterly, with dips about vertical. To the north the series is overlain with angular unconformity by a dominantly igneous group consisting, for the most part, of interbedded volcanics of different characters. This group has been named the Uchi series. Basic volcanics termed greenstones comprise the greater part of the series and consist mostly of hornblende schist and amphibolite. They are interbedded with beds of volcanic breccia and tuff of porphyritic andesite, together with rhyolite flows, and fine-grained silicic tuffs. All the beds stand nearly vertical, the strikes swinging from south to west-southwest, this feature producing a marked unconformity with the underlying Slate Lake series, which was formerly referred to Timiskaming age (3), but which, in fact, is older than the Uchi volcanics—the so-called Keewatin equivalents.

An older granitic intrusive, known as the Confederation gran-

* Ann. Rept., Ont. Dept. Mines for 1939, Vol. XLVIII.

ite porphyry, extends through the main body of Confederation Lake, as a long, thick, vertical sill located entirely within the Uchi series. This sill has been involved in the folding of the older rocks, so that, whereas it is massive in the central core, it is sheathed in its sheared equivalent and, along part of the eastern border, a broad zone of mylonite and ultramylonite has been developed from it. Following the intrusion of the Confederation granite porphyry, there were injected basic intrusives that occur as long, sill-like, vertical masses between the flows of the Uchi series and which, also, have been involved in the regional folding (4). Younger post-folding intrusions of batholithic dimensions marked the close of Archean igneous activity in the district.

PETROLOGY OF THE CONFEDERATION GRANITE PORPHYRY

The intrusive occurs as an elongate mass, at least 12 miles long and one to two miles wide. The enclosing rocks form a thick, vertical, homoclinal section, towards the synclinal end of which the Confederation intrusive lies. This igneous mass was first described in 1925 by Greig (5:p.100), who considered it to be a sill and noted that the rock—

" . . . is characterized by a coarse intergrowth of quartz and feldspar. Microcline and plagioclase near albite are the feldspars present, and the rock is almost entirely composed of these minerals. There are a few alteration products and little carbonate. In thin sections from other parts of the mass, carbonate replaces the feldspar, and the structure tends towards a graphic intergrowth of quartz and carbonate. Chlorite is also present in small amounts."

The following year Bruce (6:p.16) examined the Confederation granite porphyry, which he called the "older granite" but, because of a local intrusive relationship, considered the mass to be a dike rather than a sill. Bruce noted brecciation of the rock in some thin sections, and similarly described a graphic intergrowth of quartz and orthoclase. Both Bruce and Greig mapped the body as essentially conformable with the enclosing flows, so that, although locally transgressive, it is principally a concordant mass. Both workers recognized the deformation, and Bruce's map contains a note that the intrusive may be equivalent in age to the granite that is called Laurentian in the Lake of the Woods district. The massive portions of the intrusive that were examined by the writer are porphyritic, but over a considerable area the rock is pseudo-porphyritic (porphyroclastic) owing to partial cataclastic reduction of all the minerals except the quartz. The texture described as graphic is recognized as a micrographic intergrowth of quartz with microcline, microperthite, and albite—a texture similar to that of many granophyres and micropegmatites.

Petrographic Descriptions.

The more massive phases of the intrusive weather like a normal granite, but contain many narrow shear zones, some of which are silicified. To the south and east, towards the border of the intrusive, the rock passes into a sheared "quartz porphyry" which resembles the material in the narrow shear zones within the massive phase of the body. The unsheared massive rock is gray on the freshly-broken surface and is composed essentially of phenocrysts of gray feldspars and quartz. Under the microscope (Plate I, Figs. 1 and 2), it is seen to consist of intergrowths of quartz, potash feldspar, and albite in a ratio of 4:3:2, which minerals comprise from 90 to 95 per cent. of the rock, accessory minerals being green biotite altering to chlorite, muscovite, sericite, and sphene altering to leucoxene.

The sheared equivalent consists of abundant "blue eyes" of quartz and phenocrysts of gray feldspar in a schistose matrix. The mineral content estimated from thin sections is as follows: 40 per cent. quartz; 24 per cent. albite; 15 per cent. sericite; 13 per cent. potassium feldspar, and five per cent. green biotite, the remaining minerals being zircon, chlorite, and leucoxene. The texture is cataclastic and the feldspars appear to have been reduced to a greater extent than the quartz. This is contrary to the general rule that quartz is the first mineral to become pulverized by deformation. Most of the sericite is developed from the more finely comminuted potassium feldspar (Plate I, Fig. 3).

The marked foliation planes of the rock are vertical. The milky-blue quartz phenocrysts are up to 6 mm. in diameter, but average about 3 mm. These quartz grains, in many places, have been deformed into slightly lenticular shapes and are set in a schistose matrix so that the rock consists essentially of quartz phenocrysts in a microgranular matrix of quartz, feldspar, sericite, chlorite, and biotite. (Plate II, Fig. 1.) All gradations between this "quartz porphyry" and the massive granite porphyry have been observed in the field. In localities where the extent of shearing has been moderate, fine microperthite constitutes half the area of thin sections, the remainder consisting essentially of quartz and a little albite.

Mylonite.

Towards the eastern border of the granite porphyry sill, the massive rock and its sheared equivalent passes, in a direction transverse to the strike, into an aphanitic rock that has the appearance of a slightly sheared rhyolite, presenting such a contrast that its relation to the main granitic mass can only be recognized in the field by the gradation between the two. This zone, which passes on the west into granite porphyry and, on the east, is bounded by volcanics of the Uchi series, has a maximum width of 1,500 feet and an average width of approximately one-quarter of a mile, and a total length of at least three or four miles.

The rock weathers light pea-green to pale buff in color, and is light grayish-green on the fresh surface. The texture is extremely fine and, in outcrop, the appearance of the rock is massive, although on closer examination a fine, almost imperceptible, layering or foliation is evident, having a vertical position and striking parallel to the border and long axis of the sill.

Thin-section studies (Plate II, Fig. 2 and 3), show that the rock is composed of finely-divided granulated quartz, potassium feldspar, and albite that have undergone some replacement by chlorite, sericite, and carbonate. Upon insertion of the gypsum plate in the 45° position, the majority of the quartz grains turn yellow, indicating that most of these grains are in directions parallel to ω, thus possessing an optical alignment. In some instances, contorted microveinlets of quartz trend parallel to the folia. The microveinlets may be the result of segregation of quartz at a time when the rock was under intense stresses, but as the folia are displaced by a number of microfaults that do not intersect the quartz microveinlets, it is possible that the quartz has been introduced later; although this possibility is not supported by the chemical evidence, nor by the fact that the alignment of the optical directions of the quartz grains suggests that the microveinlets were involved in the tectonic deformation of the rock. Both field evidence and microscopic examination indicate that this rock represents a mylonite zone along part of the eastern border of the Confederation granite porphyry sill, where it is in contact with the Uchi volcanics.

Chemical Constitution.

A chemical analysis of the fresh granite porphyry is compared with one from the mylonitic equivalent.

	I	II
SiO_2	77.93	71.01
Al_2O_3	11.47	14.14
Fe_2O_3	1.34	1.43
FeO	0.84	1.99
MgO	1.65	1.39
CaO	tr.	0.76
Na_2O	2.80	3.87
K_2O	2.44	3.03
TiO_2	0.52	0.17
P_2O_5	tr.	0.04
S	tr.	0.04
CO_2	0.34	1.06
H_2O	0.96	1.14
	100.29	100.07
		Sp. Gr = 2.674

Norm of II	
Quartz	31.50
Orthoclase	17.79
Albite	32.49
Anorthite	3.06
Corundum	3.37
Hypersthene	5.74
Magnetite	2.09
Ilmenite	0.30
Apatite	0.34
Unused	2.24
	98.92

Symbol: I.4.2(I).4

Minerals estimated in thin section of 1	
Quartz	45
K-feldspar	13
Albite	24
Sericite	10
Biotite	5
Chlorite	2
Sphene	1
	100

I Granite porphyry.
II Mylonite.
W. F. Green, analyst.

Specimen No. I of the granite porphyry was unfortunately chosen from material having an unusual concentration of quartz phenocrysts, as is indicated in the estimated mineral content obtained from thin section studies. Mylonitization appears to have taken place without any marked change in bulk chemical composition, excepting for a loss of silica.

Textures.

A characteristic feature of the massive granite porphyry constituting the central core of the sill is the intergrowth of quartz with potassium and plagioclase feldspars on a microscopic scale. The quartz, in addition, occurs as phenocrysts. The dominant potassium feldspar is microcline, although some microperthite is present, and the plagioclase is highly sodic with a composition between Ab_{96} An_4 and Ab_{92} An_8 in different localities. In dealing with somewhat similar textures in albite granite near Sparta, Oregon, Gilluly (7:p.73) reported a correlation between the quartz and albite content with cataclastic phenomena, and presented evidence to show that the albite granite was derived from a sheared quartz diorite by late magmatic or deuteric alteration. In the Sparta granite myrmekite as well as micrographic intergrowths between quartz and albite were found. In the Confederation granite porphyry myrmekite was not seen, and the micrographic intergrowth for the most part is between quartz and the potassium feldspar, although some albite is involved. This texture, in contrast to the Sparta granite, is primary and has been destroyed by shearing and mylonitization over an extended part of the intrusive. The rock, therefore, could properly be termed micropegmatitic granite porphyry (graphophyre).

There is some chess-board structure in the plagioclase, which may indicate that this plagioclase is a replacement albite and which would account, therefore, for the very small proportion of calcic plagioclase molecule present. No saussuritic feldspar was seen in thin section, and there is more than sufficient carbonate to account for the lime content shown in the analyses, which is remarkably low. These features suggest albitization of original plagioclase as well as some of the potassium feldspar, but it is not known if there is any relation between the shearing and development of albite.

MYLONITIZATION.

The extreme microbrecciation of a thoroughly mylonitized rock results in an interstitial paste that is partly pseudoisotropic, as is evident from the amount of light excluded when the rock is examined in thin section under crossed nicols. E. B. Knopf (8) has pointed out that mylonites are not synonymous with fault breccias or fault gouges, as these are constituted of incoherent particles, whereas a mylonite has been crushed

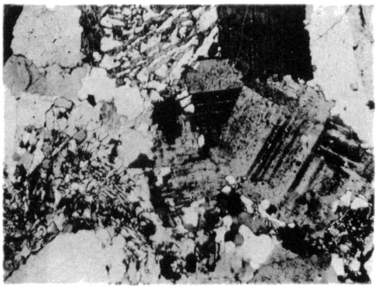

FIG. 1

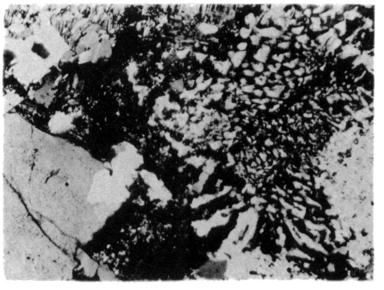

FIG. 2

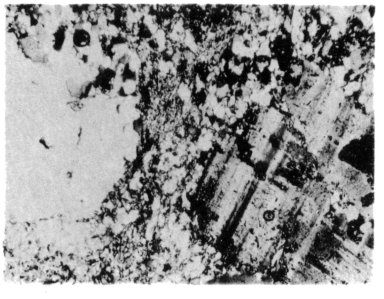

FIG. 3

FIG. 1. Photomicrograph of thin section of massive granite porphyry showing phenocrysts of quartz and feldspar with interstitial micropegmatite. Crossed nicols; X 20.

FIG. 2. Photomicrograph of thin section of massive granite porphyry showing characteristic intergrowths of quartz and feldspar. Crossed nicols; X 20.

FIG. 3. Photomicrograph of thin section of partially mylonitized granite porphyry in which the interstitial micropegmatite has been granulated, but the phenocrysts have survived. Crossed nicols; X 20.

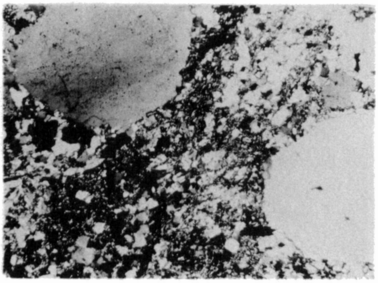

Fig. 1

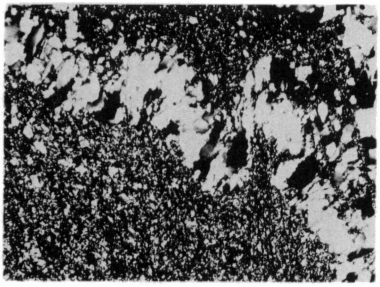

Fig. 2

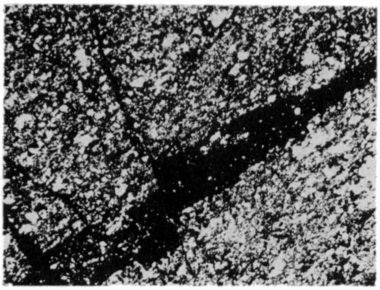

Fig. 3

Fig. 1. Photomicrograph of thin section of "quartz porphyry" resulting from cataclastic reduction of all the minerals present in the granite porphyry, excepting the quartz phenocrysts. Crossed nicols; X 20.

Fig. 2. Photomicrograph of thin section of mylonitized granite porphyry showing contorted microveinlet of quartz interpreted as a probable segregation. Crossed nicols; X 20.

Fig. 3. Photomicrograph of thin section of the ultramylonite. Dark areas that indicate displacement by microfaults are composed mostly of chlorite. Crossed nicols; X 20.

under conditions where it cannot lose its coherence. The most common reported occurrence of mylonites is adjacent to faults, particularly those of the thrust type, along which there has been considerable movement involving a great superincumbent load. No evidence of faulting was observed in the course of geologic mapping of the southeastern part of the Confederation Lake district, and it is suggested that the microbrecciation was developed by a localized concentration of pressure near the borders of the sill at the time of regional folding of the rock formations.

In the case of granulation of the Morin anorthosite, Adams (2) noted that the most extensive granulation occurs near the borders of the intrusion, which he attributed to movement in the consolidated rock while deeply buried and at relatively high temperatures. Adams furthermore noted the lack of development of saussurite and uralite and the absence of widespread foliation. In contrast to the Morin anorthosite, the feldspars in the Confederation granite porphyry underwent granulation prior to the quartz.

Most of the ancient granites that have been tectonically deformed in the Archean areas of the Canadian Shield are characterized by a gneissic structure. Such a structure may be induced in abyssal intrusives buried at considerable depths and under sufficient pressure that the minerals segregated into layers. The Confederation granite porphyry is interpreted as a hypabyssal concordant intrusive that was involved in folding at moderate depths where a combination of confining and shearing stresses were operative, the latter being dominant.

In an area undergoing tectonic deformation the larger intrusive masses tend to act as buttresses to stresses, and the location of the fold axes is, therefore, dependent on the position of the intrusive masses with respect to the stratified rocks. The Uchi series consists of roughly 20,000 feet of volcanics which, in the map-area, all occur on the southeastern limb of a syncline. The basic sills intruded into the volcanics add an additional 10,000± feet to the section and the Confederation granite porphyry occurs at the top of the section near the synclinal axis. The fact that this thick section has not been complexly folded with numerous repetitions of the flows is believed due to the resistance offered by the massive intrusive sills to minor folding.

In the case of a very thick, flat-lying sill overlain and underlain by thin flows in an area that is undergoing tectonic deformation, any fold axis tending to pass through the sill is likely to be shifted to the border of the intrusive because the mass would act as a buttress. The sill, therefore, may be turned on edge as a result of folding, but the writer questions whether thick sills not having great areal dimensions can be folded under ordinary circumstances. This may be illustrated by the analogy that a thick deck of playing cards may be bent with the hands, but if one or more thin plaques of less pliable material, such as wood, are inserted at intervals between the cards, the deck cannot be bent. The field support for this concept is that no major fold axes passes through the section in which the sills occur, whereas in adjoining areas underlain by thin flows and stratified rocks the folding is much more complex.

On this basis, the absence of minor folding in the section occupied by the sills is thought to be the result of the shifting of the fold axes to the weaker borders of the sill areas, which would result in a considerable localization of stresses at these points, particularly in the case of the thickest of the intrusive bodies, the Confederation granite porphyry. It is suggested that the mylonitized zone was formed under these conditions, during the time the sill was being turned on edge, when a tremendous concentration of pressures was produced at the borders of the mass.

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