flakes of pale green muscovite which replace both feldspars and fine-grained calcite pseudomorphous after euhedral sphene. The order of crystallization apparently is: (1) sphene, (2) microcline, (3) quartz, (fracturing), (4) albite, (5) muscovite, (6) calcite. The results of an analysis of this microcline have been presented by Allen (1920).

It seems probable that the fracturing of the microcline and the consequent formation of the curved platey structure took place during the later stages of pegmatite consolidation and probably resulted from the final intrusive forces that brought about pegmatite emplacement. Thus the late stage albite, which stems from residual pegmatitic solutions, was precipitated along these readily accessible fractures. The quartz of the core, most of which crystallized after the microcline of the intermediate zone, as is shown by its apophyses (Fig. 1), is not granulated nor deformed. Therefore the deformation of the microcline is an intrapegmatitic, not a post-pegmatitic phenomenon.

Thus this pegmatite is of special interest for two reasons: 1) It offers clear-cut evidence for the late-stage development of the core (Fig. 1) and 2) It offers evidence that prior to core formation the wall zone had crystallized sufficiently to support fracturing.

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EXOMORPHISM AROUND AN APLITE—PEGMATITE DIKE, FELCH, MICHIGAN[1]

E. Wm. Heinrich, *Department of Geology and Mineralogy, The University of Michigan, Ann Arbor, Michigan.*

The Metronite quarry is 2½ miles east-northeast of Felch in Dickinson County, Michigan. The workings have been developed in the Randville dolomitic marble (Lower Huronian) which overlies the Sturgeon quartzite, the basal Huronian in this area. The Randville, which is 500–1500 feet thick, has been intruded by the Republic granite and its dikes of post-Keweenawan age (Killarney).

The occurrence of unusual minerals in this area was recorded by Dana

[1] Contribution No. 248, The Mineralogical Laboratory, Department of Geology and Mineralogy, The University of Michigan, Ann Arbor, Michigan.

(1892) who reported large crystals of tremolite and diopside in altered dolomite. Lamey (1934) recognized that the Randville dolomite was intruded by the Republic granite and trasnformed through contact metamorphism. He states (p. 257) "Some parts of the formation consist almost entirely of interlocking masses of these silicates"—tremolite, actinolite, anthophyllite, pigeonite, diopside, phlogopite and antigorite. The latter he found to be especially abundant near granitic dikes. Other minerals present locally are pyrrhotite, pyrite, chalcopyrite and quartz.

The Metronite quarry has been operated for tremolite, whose white color and chemical inertness make it desirable as a paper filler. The quarry, which is about 150×80 feet in plan and 50–60 feet deep at the

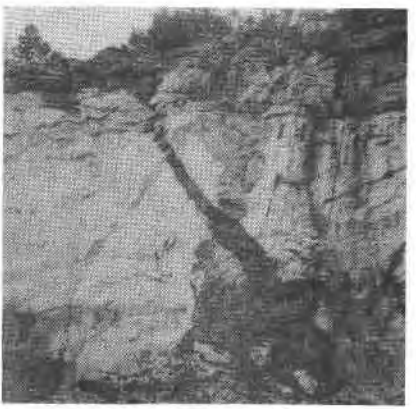

FIG. 1. South wall of Metronite quarry, near Felch, Michigan, showing aplite-pegmatite dike cutting tremolite marble.

face, exposes chiefly pink and white marble without distinct foliation. Most of the faces show predominantly white silky tremolite in white, granular dolomite, but locally they are masses of coarser grained, pale green amphibole needles, commonly arranged in radial fashion, with interstitial orange calcite.

Extending diagonally across the quarry is a sharply defined aplite-pegmatite dike, which strikes N. 42° E., dips 62° NW. and ranges from one to two feet in thickness. Along its margins there has been developed a contact metamorphic zone, two inches to one foot wide, whose chief constituent, a coarsely bladed, dark green serpentine, contrasts sharply with the light colored marble and aplite (Fig. 1). Also present in the exomorphic zone are coarse-grained masses of a dark gray felted mineral not identified megascopically, very coarse blades of pale green amphibole and several sulfides. The altered zone was formed mainly at the expense of the marble, but locally it replaces marginal parts of the dike itself.

Much serpentine occurs within the dike along its margins. Sulfides also are found within the dike but are concentrated chiefly in the marble particularly along the hanging-wall side of the intrusive.

Thin sections of the wall rock reveal that it varies from a relatively pure dolomitic marble to a nearly pure tremolite rock. The carbonate-rich marble has a minutely sutured and complexly interlocking texture, with scattered groups of tremolite euhedra. Stained hand specimens were found to consist almost entirely of dolomite; calcite is very subordinate and appears only locally. The marble also contains a few widely scattered crystals of apatite and graphite.

At the other end of the series is a rock containing chiefly tremolite. The white silky fibers and the pale green coarser needles (formerly identified as actinolite) have identical optical properties that place them well within the tremolite part of the series: $\gamma = 1.630$, $\gamma \wedge c = 19°$, colorless and nonpleochroic in thin section. The tremolite rock has a felted texture; tremolite occurs both as fine needles and larger crystals, not uncommonly in radial groups. Veinlets of carbonate transect the crystals and corrode them marginally.

The dike, which is mainly aplitic to fine-grained granitic in texture and composition, contains pegmatitic masses locally. These consist chiefly of ovoid single crystals of pink microcline, as much as 1×2 inches, set in a mesh of finer-grained gray quartz and aplite. Enveloping each of the microcline crystals is a thin dark red film. The pegmatitic parts crystallized early and are veined by the younger finer grained phase.

In thin section the equigranular aplite shows a poorly foliated texture due chiefly to parallel common biotite flakes. The other constituents, microcline, oligoclase and quartz, also are somewhat aligned. All are anhedral, except the biotite. The plagioclase shows zoning, with cores selectively sericitized. Small amounts of chlorite replace biotite. Accessories are muscovite, zircon, magnetite and chalcopyrite.

The most conspicuous mineral in the contact zone is light to very dark green antigorite, which occurs both as minute flakes and fibers and as coarse blades two inches long. It replaces chiefly minerals of the marble but locally also replaces mineral grains in the outer parts of the aplite. The masses of the gray, finely felted mineral not identified megascopically, were found by the immersion method to consist chiefly of scapolite, which makes up 80% of this rock. This is, as far as the writer could ascertain, the first recorded occurrence of scapolite in Michigan. The indices of refraction are: $\epsilon = 1.551$, $\omega = 1.573$. From these values the composition is estimated to be $SMa_{10}Ma_{29}KMe_{61}$ (Larsen and Berman, 1934, p. 245).

Other constituents of this rock are zoisite, phlogopite, tremolite,

antigorite and very minor talc and magnetite. Tremolite and zoisite were apparently the earliest minerals to crystallize. Most of the tremolite was then replaced by scapolite, which forms an equigranular mosaic. Both tremolite and zoisite occur as corroded remnants, the former within scapolite and the latter chiefly within phlogopite. A zoned euhedral crystal of zoisite has parts of the inner zone selectively replaced by phlogopite (Fig. 2). Some of the phlogopite has been altered to serpentine, and some of the tremolite has been changed to a mixture of serpentine and talc. A few very thin talc seams cut across the entire aggregate of minerals.

FIG. 2. Zoned zoisite crystal (z) selectively replaced by phlogopite (p). From scapolite rock at margins of aplite dike, Metronite quarry. 50x.

Locally within the aplite and more commonly in the altered zone along the hanging-wall side are small concentrations of sulfides (chiefly pyrite) and ilmenite. Chalcopyrite is a minor constituent, and pyrrhotite has been reported. Polished sections show that the pyrite, which is in equigranular, subhedral masses, is probably slightly older than the ilmenite, which is interstitial and irregularly intergrown with the non-metallic constituents.

The deposit is an unusual example of the exomorphic effects by a granitic dike on an already metamorphosed Ca-Mg silicate marble. The main mineral resulting from the intrusion of the Republic granite was tremolite. The alteration to scapolite required the addition of potassium and sulfur from the dike. Calcium, silicon and carbon dioxide, the other scapolite constituents, were available from the tremolite and dolomite

of the wall rock. In this alteration of tremolite, magnesium and hydroxyl were liberated and converted either to phlogopite or to serpentine. The formation of scapolite appears to represent a localized type of metasomatism by the dike, for in general tremolite was altered directly to serpentine.

The laboratory phases of the study were supported by Michigan Memorial Phoenix Project 204.

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QUANTITATIVE DETERMINATION OF KAOLINITE BY *X*-RAY DIFFRACTION. A REPLY TO G. W. BRINDLEY AND S. S. KURTOSSY *AM. MINERAL.* **46** (1962), 1205–1215

H. W. van der Marel, *Institute for Soil Survey, Wageningen, Netherlands.*

In the above manuscript the authors came to the conclusion that the large spreading found in my experiments (1960) for the (001) reflections of various kaolinites was caused by preferential orientation.

The <2 mu separates dried 2 hours at 110° C. of 14 samples from pure well-known deposits of 6 different countries were investigated. They contained after *x*-ray and chemical analyses impurities to a maximum of 15% and their main particle size ranged after electron microscopy from 0.5–1.5 μ (Gabon) to 0.1–0.3 μ (Brokopondo). For the integrated intensities I (001,K)/I (020,B) was found = 1.9 to 0.85 = 200:100.

In the earlier experiments of Von Engelhardt (1955) 4 American kaolinites and 1 kaolinite from Provence (France) were investigated, which samples also occurred in my collection. The original kaolinites were in this case previously mixed with cork meal 100:100 volume %, and gave a spreading of 19.03:13.58 = 140:100 (American samples) and 19.03:11.31 = 177:100 (all samples). The finest kaolinite used in this investigation was after electron microscopy mainly of 0.05–0.30 μ and the coarsest of 0.08–1.34 mu size.

Both experiments, the variation in particle size of the samples being in the first experiment somewhat larger than in the second one, clearly