JOINTS IN THE RIB MOUNTAIN AREA, WAUSAU, WISCONSIN

by

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ABSTRACT

Four distinct joint sets have been identified in the large quartzite xenoliths of the Wausau pluton, southwest of Wausau, Wisconsin. Planes parallel to three of these joint sets have a common line of intersection, while the fourth set is perpendicular to this line of intersection. These four joint sets with the same relative angular relationships have been found in the quartzite of Rib Mountain, Hardwood Hill and Mosinee Hill. However, the attitude of the joints is different in each of these locations. This difference in attitude may be accounted for by simple rotations of the xenoliths. It is proposed that these xenoliths formed during magma emplacement as a result of monoclinal bending and faulting of an overlying quartzite unit. In this model rotation of the xenoliths occurs as they break away from the roof of the magma chamber and settle into the melt.

INTRODUCTION

The Wausau pluton is located in Marathon County, Wisconsin, southwest of the city of Wausau (fig. 1). This pluton has a reported age of 1,520 Ma (Van Schmus, 1980) and consists of two parts separated by the Rib River. The rock of this pluton exhibits many interesting and often subtle variations which are reported by Sood, and others (1980) and by LaBerge and Myers (1983). The present study has concentrated on the southern section of the Wausau pluton which is made up of two intrusions. The first intrusion is syenitic in composition and forms a crescent shaped outcrop. The second, referred to as the Ninemile pluton, is granitic in composition and has intruded the syenite forming an elliptical outcrop measuring roughly 15 x 19 km, elongated northeasterly (LaBerge and Myers, 1983). Rib Mountain, one of the highest points in Wisconsin, as well as Hardwood Hill and Mosinee Hill, are formed by erosionally resistant quartzite xenoliths within the syenite. These hills form a ring rising as much as 200 m above the Ninemile Swamp, which has formed in the center of the pluton over the more easily weathered Ninemile granite (fig. 2).

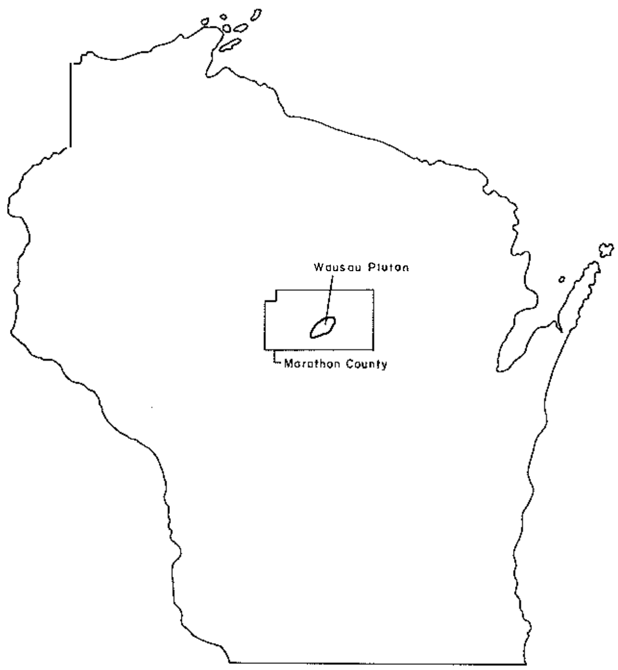

Figure 1.--Map of Wisconsin showing location of Marathon County and the Wausau pluton.

Outcrop surrounding the Wausau pluton is early Proterozoic metavolcanic country rock. Xenoliths of this country rock, as well as quartzite xenoliths, are abundant in the syenitic intrusion, although no outcrop of quartzite is found in place (LaBerge and Myers, 1983). Xenoliths range in size from small (cm) up to the large (km) hill-forming blocks. The large quartzite xenoliths are quite uniform in both texture and composition, suggesting that they formed during a regional event rather than from contact metamorphism in the pluton. All xenoliths are angular in shape and display sharp contacts with the syenite. This evidence clearly indicates brittle behavior of the country rock during the intrusion process and suggests shallow emplacement with rapid cooling. A precise determination of overburden thickness from this mechanical evidence is impossible, but a thickness from 1 to 3 km is indicated.

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QUARTZITE XENOLITHS

The quartzite xenoliths consist of a hard, white quartzite. Hand specimens from Rib Mountain consist of well-rounded, well-sorted, coarse sand-sized quartz grains which account for 90 to 95 percent of the rock volume. Mica and iron oxide appear to make up most of the remainder. LaBerge and Myers (1983) report the presence of K-feldspar, which they attribute to granitization, near contacts with the syenite. Dark bands (concentrstions of interstitial mica and iron oxide) suggestive of bedding are found in the quartzite of Rib Mountain, but were not observed in other quartzite xenoliths. Ripple marks are found in the Queen's Chair area of Rib Mountain (fig. 2) but were not found in other outcrops on Rib Mountain, nor in outcrops of other xenoliths. In the Queen's Chair area several quartzite blocks contain clear exposures of ripple marks. The surfaces exposed are quite smooth showing showing ripple marks with rounded crests and troughs and a wavelength of 4 to 5 cm. However, no blocks with these clear exposures were found in place. A park information sign calls attention to ripple marks in one large block which does seem to be in place. The indicated markings are on a vertical face which strikes east to west. This face parallels the dark bands in the block and the markings have the same periodicity, 4 cm, as the smooth ripple marks observed. However, unlike the smooth, rounded markings mentioned above, these markings are sharp, jagged fracture surfaces. Thus, while the exposed surface apparently parallels bedding in the quartzite and the periodic markings seem to correspond to ripples, the actual outcrop surface is the result of brittle fracture and does not correspond to the original ripple surface. This modification of the ripple surface prevents reliable determination of younging in the quartzite from asymmetry in the surface markings.

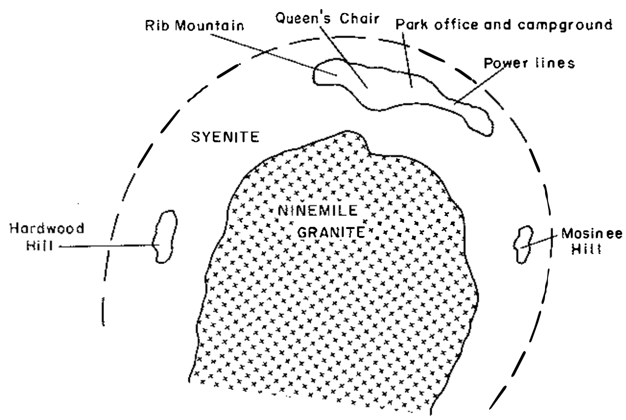

Figure 2.--Generalized geologic map of the Wausau pluton (southern part).

Several joint sets are clearly evident in the quartzite xenoliths. Measurement of joint attitudes in the three largest xenoliths was undertaken with the idea of correlating patterns in the different xenoliths and thus determining relative rotations. Preliminary results of this effort have been reported by the author (Dockstader, 1980).

Four joint sets were readily apparent in the state park area of Rib Mountain. Orientation of these joint sets was initially determined by simply measuring the attitude of a few prominent joints from each set. As a check on the reliability of this procedure and to give the results greater statistical validity, fifteen students in the University of Louisville summer field camp were assigned to measure 20 joint attitudes each, both in the Queens Chair area and just north of the state park office. These results are summarized in the contoured pole diagrams of figure 3. Although the relative frequency distributions for these two locations differ somewhat, the same four concen-trations do show up in each diagram. These concentrations correspond to the same attitudes identified initially for the four readily apparent joint sets. Centers of concentrations are shown in figure 4. To facilitate discussion, these pole concentrations are labeled a, b, c, and d. Pole a is a horizontal joint set. Pole b corresponds to joints in the vertical plane identified above as the bedding plane. Joint surfaces corresponding to poles c and d are also nearly vertical in these outcrops. To return this Rib Mountain quartzite to a position with horizontal bedding requires a rotation of 180 degrees about an east-west horizontal axis. Following this rotation, planes corresponding to poles b, c, and d will intersect along a horizontal north-south line, and pole a now corresponds to a vertical plane with an east-west strike. Since the direction of younging in the quartzite is not clearly discernable in outcrop, the direction of rotation required to return the quartzite to an upright position is also uncertain. For illustrative purposes figure 5 shows the results of a rotation which brings south-facing surfaces into an upward facing position. In situ positions are shown with lower case letters, whereas upper case is used for positions after rotation.

Four joint sets are readily apparent in outcrops along the length of the Rib Mountain Ridge. Attitude measurements of prominent joints from the west end of Rib Mountain to the power line crossing (fig. 2) show the same orientation found in the Queen's Chair and park office areas. This evidence suggests that this block of quartzite, roughly 3 km in length, rotated as a single unit. Along the 1.2 km section of Rib Mountain from the power line to the east end of the ridge, four joint sets are again apparent; however, they are found in a new orientation. Poles to these

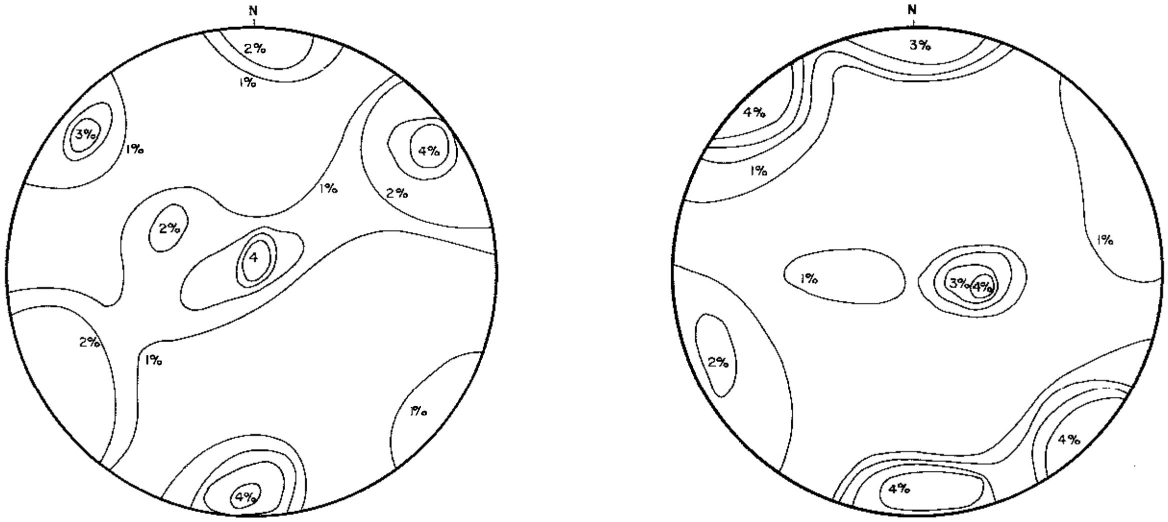

Figure 3.--A. Poles to joints planes near the Queens Chair, Rib Mountain. Countours show 1, 2, 3, and 4% concentration per 1% area. B. Poles to joint planes north park office, Rib Mountain.

joint planes are indicated by lower case letters in figure 6. Although the orientation of these poles differ from those of figure 4, the joints show the same pattern relative to each other as those represented in figure 4. The new joint orientation seems to be simply the result of a rotation of the whole outcrop. Using relative positions to identify corresponding poles, figure 6 has been labeled so that poles are identified with the same letter as corresponding poles in figures 4 and 5. Note that the near symmetry of joint sets c and d about the bedding (b) makes it impossible to distinguish these sets without an indicator of younging. The procedure followed in marking corresponding joints was to assume that although different blocks of quartzite may have rotated independently, they probably rotated in the same sense relative to the center of the pluton. This assumption is discussed further below. The identification of bedding (pole b) agrees with orientation of dark bands occasionally observed on this part of the ridge. However, on this part of the ridge the dark bands were much more difficult to find than on the western section, and no ripple marks were apparent. Bedding on the east section has an attitude of N. 60° W., 65° SW so that a rotation of 65 degrees about a horizontal axis trending N. 60° W. will return the beds to a horizontal position. The results of this rotation are illustrated with upper case letters in figure 6. A 105-degree rotation would also return the beds to a horizontal position. Because sym-

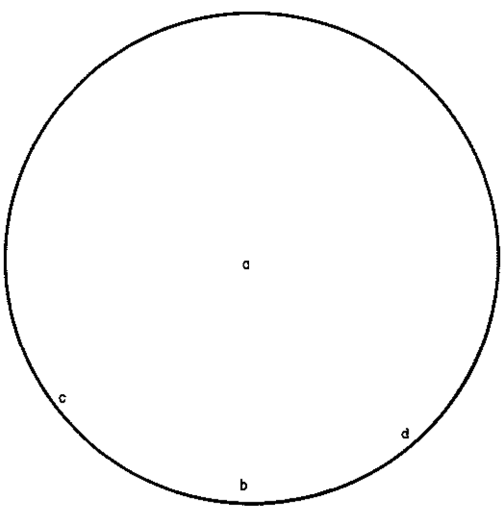

Figure 4.--Poles to prominent joints in Rib Mountain determined from centers of concentration in figure 3A, and figure 3B.

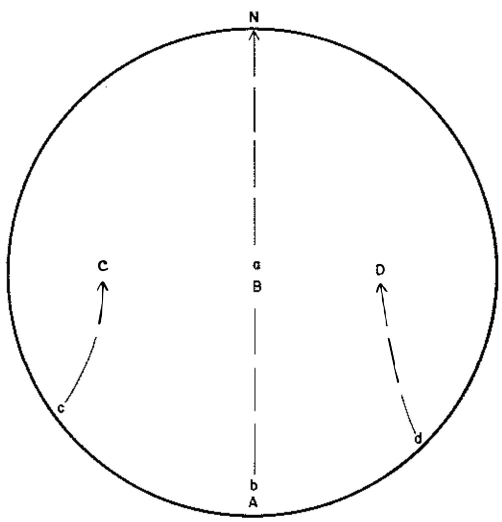

Figure 5.--Poles to prominent joints in Rib Mountain. Lower case represents joint in situ and upper case represents joints after a rotation which brings bedding represented by pole b into a horizontal position represented by pole B.

metry in the joint set geometry either rotation would yield very similar joint attitudes. Note also that once the beds on the eastern part of the ridge are returned to a horizontal position an additional rotation in the counterclockwise direction about a vertical axis is required to return the joints to the same attitudes illustrated by the upperase letters in figure 5.

The difference between joint attitudes in the two parts of Rib Mountain indicates the presence of two separate xenoliths, which rotated independently in the magma. In both cases the major component of rotation is about an axis tangential to the pluton margin. This observation suggests that the xenoliths were not tumbled about in the magma, but were simply turned up or down in a single rotation and provides the basis for the assumption mentioned above in identifying relative orientations of joint sets c and d in different outcrops.

Outcrops on Hardwood Hill and Mosinee Hill show neither color bands nor ripple marks to indicate bedding. However, a comparison of joint orientation with Rib Mountain makes a determination of bedding possible. In determining joint attitudes on Hardwood Hill and Mosinee Hill the procedure was simply to take a few measurements of the visually prominent joint sets. On Hardwood Hill four joint sets were found in the same relative position as on Rib Mountain. Corresponding joints are labeled with the same letters as in earlier diagrams (fig. 7). As before, lower-case letters indicate <u>in situ</u> orientations, whereas upper case indicates positions after rotation of bedding into a horizontal position. Note that a fifth joint set was also observed on Hardwood Hill and is labeled x. A few joints in this relative position show up in the measurements taken on Rib Mountain (fig. 3). Hardwood Hill is thickly vegetated, limiting good outcrops. Not enough information was gathered to prepare a frequency diagram, so no significance is attached to the fifth joint set. What is judged significant is that the bedding is nearly vertical with a strike parallel to the local margin of the Wausau pluton, suggesting the simple rotation of the xenoliths mentioned above. Results from Mosinee Hill (fig. 8) also show four joint sets in the same position relative to each other as in the xenoliths discussed above. Bedding is vertical with a strike parallel to the local margin of the pluton. In addition to the rotation observed for the other xenoliths, an additional rotation of 90 degrees about an axis perpendicular to the bedding is also apparent. This rotation is analogous to the 17 degree rotation observed for the eastern section of Rib Mountain.

In summary the large quartzite xenoliths ring the southern section of the Wausau pluton. Relative joint orientation in conjunction with primary structures indicate that bedding in the xenoliths is roughly vertical and faces either into or away from the center of the pluton.

IGNEOUS INTRUSION

Two, vertical, orthogonal joint sets, striking north-south and east-west, pervade the igneous rock in the southern part of the Wausau pluton. It is my observation that such orthogonal joint sets occur in tabular intrusions (thickness substantially less than diameter) whereas more complex jointing occurs when the thickness is roughly the same or greater than the intrusion diameter. Figure 9, an aerial photograph taken over the Shonkin Sag laccolith, illustrates orthogonal

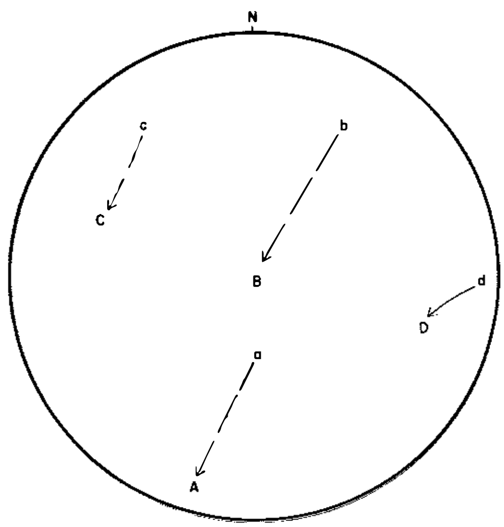

Figure 6.--Poles to prominent joints on the east end of Rib Mountain.

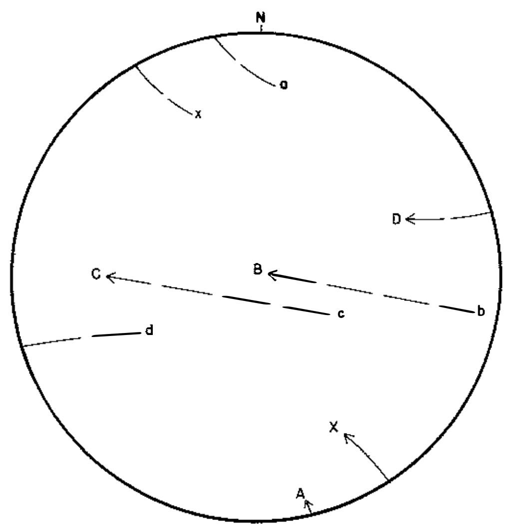

Figure 7.--Poles to prominent joints on Hardwood Hill.

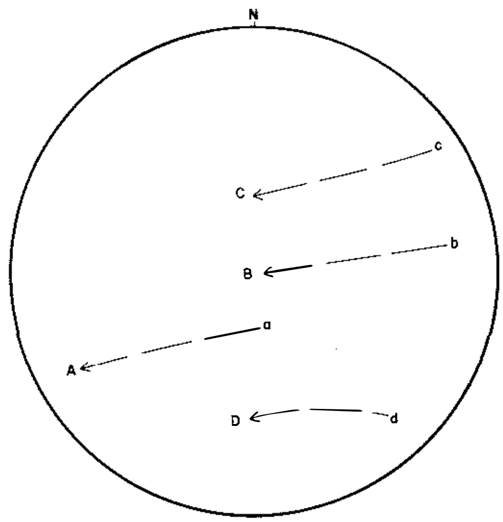

Figure 8.--Poles to prominent joints on Mosinee Hill.

jointing over a tabular intrusion. Devils Tower, Wyoming, is a well known intrusion with more complex jointing. The joint pattern, as well as the roughly circular plan view (LaBerge and Myers, 1983) are evidence to the author of a tabular or laccolithic form for the Wausau pluton. The Grizzly Peak cauldron, Sawatch Range, Colorado (Fridrich and Mahood, 1984), is an example of multiple intrusions in a laccolithic form, which seems in many ways to be analogous to the Wausau pluton. This laccolithic model predicts a thickness of roughly 1 to 2 km for the Wausau pluton.

FORMATION OF XENOLITHS

Host-rock deformation during emplacement of a laccolith creates a mechanism for the formation of both large and small xenoliths. This is the mechanism proposed for the formation of the xenoliths found in the Wausau pluton. A laccolith begins as a sill which spreads until enough upward force is produced from the magma pressure to lift the overburden. Once this critical area is reached the intrusion will thicken. The roof of the intrusion will be nearly flat, and monoclinal bending of the overlying strata will accommodate the additional thickness of the magma (Koch and others, 1981). As the intrusion continues to thicken, bending of the overburden progresses into fracturing and faulting. At this point the overburden is pushed up by magma pressure, in a process which operates much like a hydraulic piston. Piston faults develop around the intrusion periphery allowing the piston of overburden to be pushed up relative to the surrounding country rock. During this entire process, the floor of the laccolith remains virtually undeformed (Johnson, 1970; Pollard and Johnson, 1973; Dockstader, 1982).

Large xenoliths may be easily formed from the roof of a laccolith during the transition from monoclinal bending to faulting. This process is illustrated in figure 10. As uplift progresses, fractures will develop in those areas where the overburden is most sharply bent. In the case of a competent overburden like quartzite, a large intact block of roof rock may be detached from the adjacent host by these fractures. As the block falls into the magma, the angle of the fractures allows the end of the block closest to the intrusion center to fall freely, while the opposite end will catch. The end which is caught will then act as a pivot as the xenolith swings down into the magma. After the block has swung part way into the magma, the hinge end will come free and the xenolith will rotate about its center of mass, causing this end to kick in toward the center of the laccolith. The final result of this process is to place the xenolith some distance in from the intrusion margin with formerly horizontal surfaces now vertical, and the former top of the xenolith facing the intrusion center. Small xenoliths of country rock will be produced during the fracture process and will surround the large xenoliths. If the hinge end of the large xenolith breaks free unevenly, an additional component of rotation may be introduced. This is the mechanism proposed for formation of the xenoliths in the Wausau pluton.

Just as folding roof rock down into the magma provides a plausible mechanism for the formation and orientation of a xenolith, folding floor rock up might possibly provide similar results. Two observations argue against this mechanism. In areas where floor rock has been observed--near the Highwood Mountains, Montana, and Cascade, Montana (personal observations by the author) and in the Henry Mountains, Utah (Johnson and Pollard, 1973)--no deformation of the floor rock has been observed; whereas folding and fracturing of roof rock, as described above, has been observed. Second, where inclusions of floor rock have been identified in an intrusion, the inclusions were concentrated toward the intrusion core (Fridrich and Mahood, 1984).

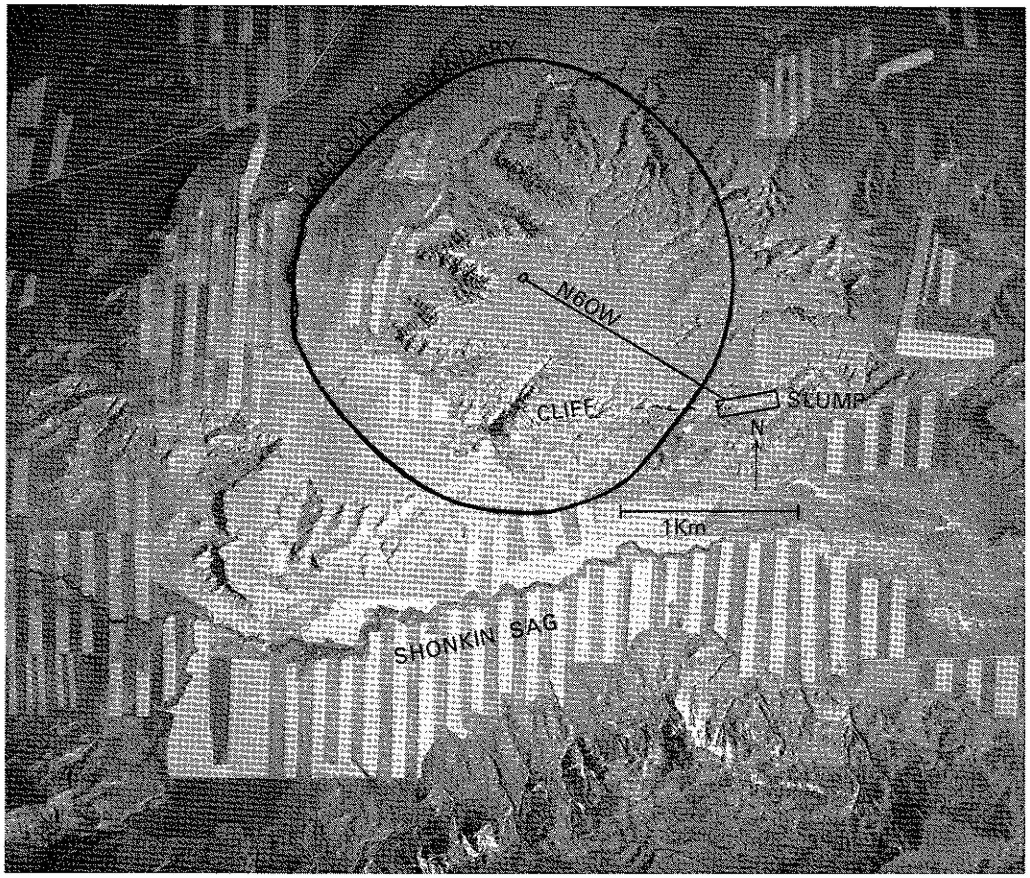

Figure 9.--Aerial photograph of Shonkin Sag laccolith, Montana. The orthogonal joints in the igneous rock are visible where gulleying has exposed the rock.

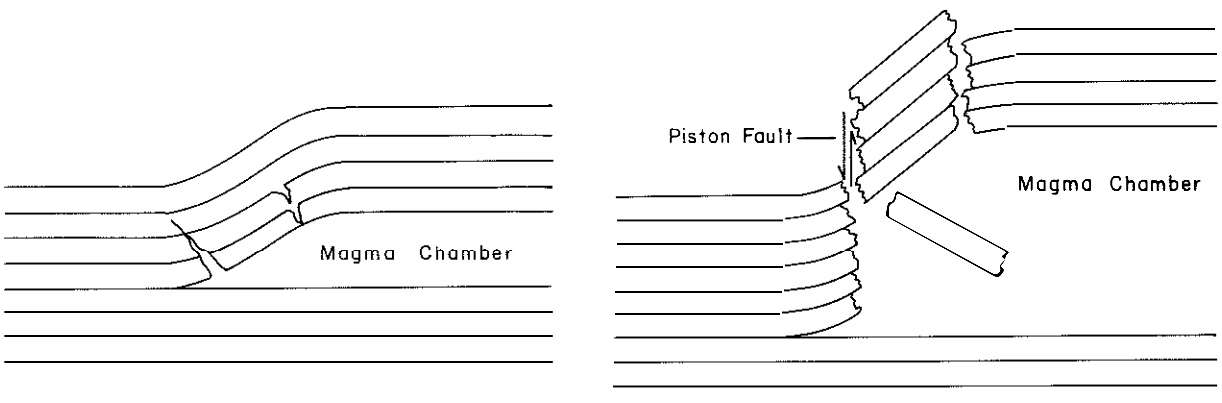

Figure 10.--The formation of xenoliths during bending and fracturing of the roof rock. A. Early stage of fracture formation. B. Advanced stage of fracture with xenolith settling into the magma chamber.

CONCLUSIONS

Emplacement of the Wausau pluton took place through metavolcanic rock and overlying metasedimentary rock. A quartzite layer at least 0.8 km thick (the north-south dimension of Rib Mountain) was near the bottom of the metasedientary sequence. Magma rising through the metavolcanic sequence spread beneath the quartzite and pushed up the overburden bending and then faulting the roof margins. During this process, blocks of roof rock from the fractured roof margins fell into the magma. The largest blocks (km in size) fell into a position where surfaces which had faced upward now faced into the center of the intrusion. This initial intrusion, syenitic in composition, was followed by a second granitic intrusion.

ACKNOWLEDGMENTS

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