

SEQUENCE OF INTRUSIVE EVENTS IN THE GRAY LAKE REGION OF THE WAWA SUBPROVINCE, QUETICO PROVINCIAL PARK, ONTARIO, CANADA

Anita Ho, Carleton College, Northfield, MN 55075
Eric Small, Williams College, Williamstown, MA 01267

Introduction

A sequence of intrusive events is represented in the Archean rocks of the Wawa Subprovince of the Superior Province. This study examines the sequence in the Grey Lake region of the Quetico Provincial Park, Ontario, Canada. The sequence includes (from oldest to youngest) ultramafic volcanics, tonalites, trondhjemites, potassium feldspar pegmatites and quartz veins. The dikes are emplaced along zones of weakness in the host rock such as faults, shear zones, and preexisting dikes. These veins, dikes, and bosses vary compositionally and texturally and were emplaced by different igneous processes. These processes include volcanism, the junction of suspect terranes, and the emplacement of the Vermillion Batholith in the adjacent Quetico belt. A late trondhjemitic stage could be related to the Vermillion Batholith and provides evidence that this batholith acted as a stitching pluton between the volcanic-plutonic Wawa subprovince and the adjacent Quetico subprovince, which abuts the Wawa to the northwest (Card and Ciesielski, 1986).

The Quetico belt consists of metasedimentary rocks, metavolcanics, and some igneous intrusions. Percival and Williams (1989) suggest that the Quetico belt represents an accretionary prism of sediments between the Wawa terrane and the Wabigon, another metavolcanic subprovince which bounds the Quetico belt farther to the northwest. Anatexis of these sedimentary rocks resulted in granite/pegmatite intrusions in the Quetico belt (Card and Ciesielski, 1986).

The Wawa belt consists of an amphibolite-rich, greenschist to lower amphibolite facies metavolcanics and a hornblende tonalite unit with biotite schist rafts. Field observations indicate the hornblende tonalite unit consists of quartz, plagioclase feldspar and hornblende, with about 10% mafics. This strongly deformed unit has a foliation which parallels the Wawa-Quetico junction and several regional lineaments, trending N50E to N70E and dipping steeply to the north.

The junction between the Wawa and the Quetico belts trends N40E and has been traced for over 40km. The Burnside Lake Fault trends subparallel (about N30E) to the Wawa-Quetico junction and crosses it near Nest Lake to the south of the study area (Woodard and Weaver, 1990).

The Vermilion Batholith was emplaced in the Quetico belt after the host rocks were foliated and prior to the appearance of the Burnside Lake Fault (Gerber, 1990). Emplacement of the batholith resulted in the introduction of potassium in both the Quetico and Wawa rocks (Mariano and Woodard, 1984). Intrusion of batholithic material into both belts suggests that the Vermilion Batholith may have acted as a stitching pluton (Gardner et al., 1988) along the Wawa-Quetico junction.

Methods and Observations

The intrusive sequence in the Wawa belt was determined by observing the orientations, cross-cutting relationships, and compositions of dikes. The presence, distribution, and relative age of crystallization of potassium feldspars was determined by staining specimens in a saturated solution of sodium cobaltinitrate at Beloit College and examining the resulting textures. The observed sequence of intrusions into the metavolcanic and tonalite units of the Wawa belt is summarized as follows:

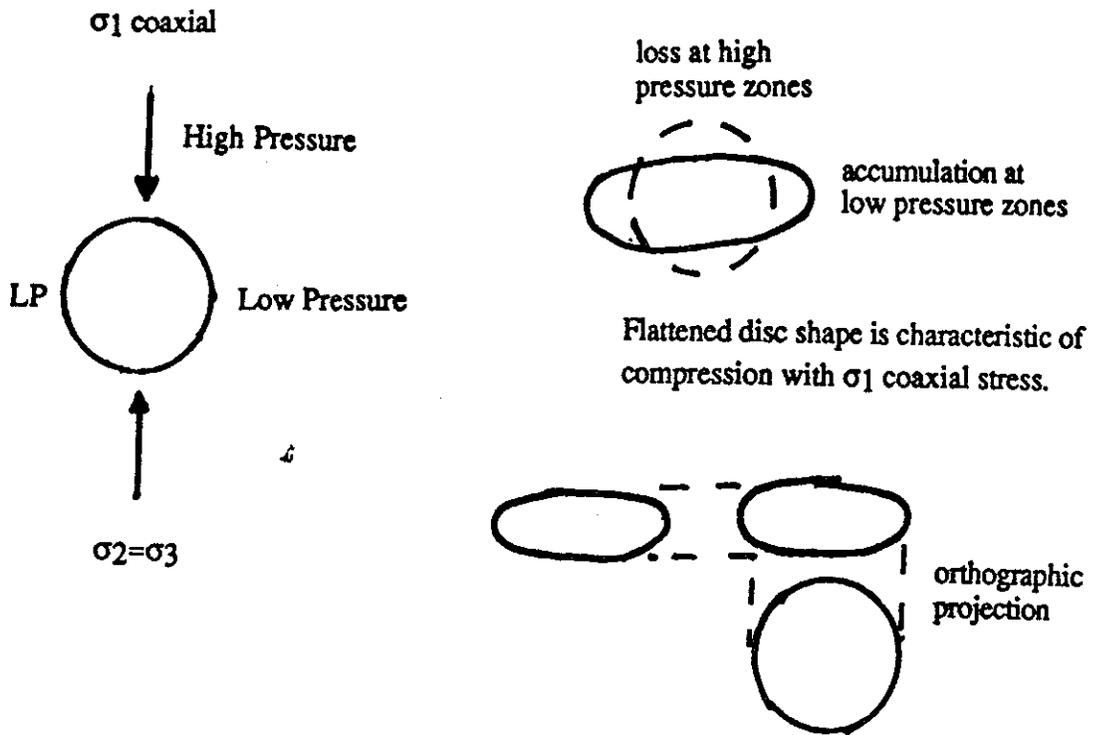
Ultramafic feeder dikes cut through volcanic breccia within the tonalite. The crosscutting relationships between these units are not clear. These dikes have chill zones and are deformed.

Tonalite dikes are found in the metavolcanic unit and in the tonalite unit itself. These dikes are <5cm wide and continuous laterally for <2m.

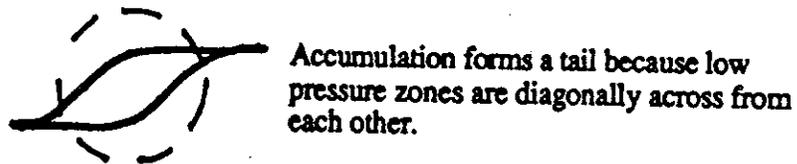
Leucocratic stringers cut across the tonalite and metavolcanic units as well as the ultramafic feeder dikes. They are <1cm wide, not continuous, with no clear orientation. They crosscut each other and show compressional deformation.

Trondhjemite dikes cut across all the above, and consist of quartz, plagioclase, <5% mafics, and 15-25% potassium feldspar shown by staining to be mostly secondary. Some contain unoriented mafic clasts. They are foliated with the regional foliation at about N50E, and show a general increase in size over time. The three "generations" were determined by their groupings when plotted on a stereonet. (See Figure 1.) The first-generation dikes are <5cm wide, continuous for <2m. They are folded, sheared and offset 1-100cm. They trend variably with

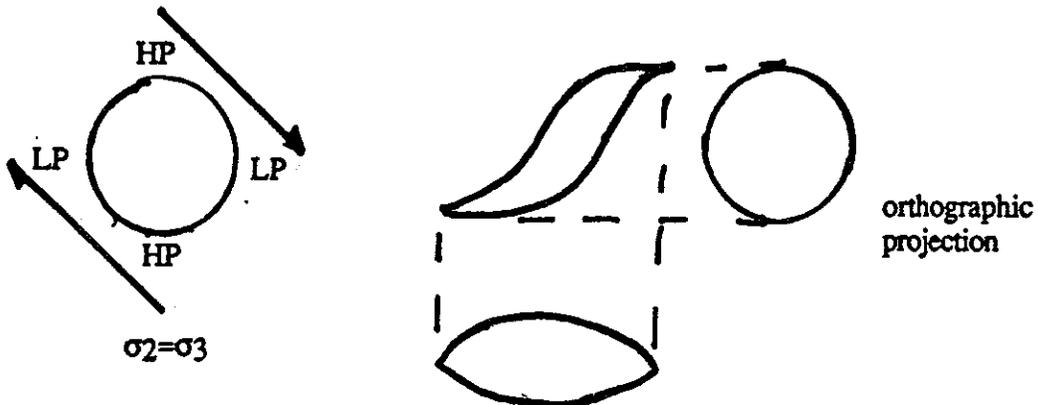
Figure 1. Formation of augen structures.



σ_1 non-coaxial



Sigmoid shape is characteristic of shearing in which σ_1 stress is non-coaxial.



the regional foliation, and plot a partial girdle on the stereonet which indicates variations in their orientations. The second-generation dikes are 5-25cm wide, continuous for <5m, and intrude along planes offsetting the first-generation dike, but are not disturbed by the offset. The third-generation dikes are sometimes >1m wide, and are more continuous and less deformed than the other generations. They are often aligned along shear or offset planes of the earlier trondhjemites, and show more variation in grain size and composition.

Large trondhjemite dikes up to 20cm wide and bosses >30m wide and >100m in length are found along Wawa-Quetico junction. Their foliation is variable, and they are continuous (not folded or faulted). Their composition differs slightly from the earlier trondhjemites, and they also contain <2% unoriented mafic fragments. Textural analysis shows most potassium feldspars to be secondary.

Potassium feldspar pegmatite dikes parallel the earlier trondhjemite dikes for up to 10m and sometimes crosscut them. These pegmatites also crosscut the large trondhjemite intrusives and intrude into the metavolcanics and tonalites. They consist of quartz, plagioclase, and perthite, and are 2cm-2.5m wide and up to 10m in length. Grains are mostly 1-4cm across but may be as large as 10cm. These dikes are not deformed as much as previous dikes, and soak the surrounding rock with potassium.

Finally, quartz veins 2-5cm wide and <2m in length cut across the pegmatite dikes. They often fill up joints and faults.

Discussion

Differences in composition, texture, and the structural relationships of dikes indicate a sequence of intrusive events in the Wawa belt. This sequence represents changing processes and geologic controls. It can show how the changes are related to large-scale events like the junction of the Wawa and Quetico belts and the emplacement of the Vermilion Batholith.

The ultramafic volcanic feeder dikes represent volcanism related to the metavolcanic unit, or a later post-tonalite rebirth of volcanic activity. The age relationships between the tonalite, ultramafic feeder dikes, and enclosing breccia are not clear enough to determine whether the feeder dikes cut through the tonalite (indicating a second stage of volcanism), or whether the tonalite was emplaced around the dikes and the enclosing volcanic breccia. The ultramafic dikes would have to be significantly younger than the tonalite to allow enough time for them to cool and produce the observed chill zones.

Ultramafic rafts in the tonalite unit indicate that the tonalite was injected as a sill or dike after the metavolcanics were already in place, and this intrusion involved some process that resulted in fragments of the older metavolcanics being ripped up and incorporated into the tonalite. The orientation of the ultramafic rafts with the foliation of the host rock and the concordance of the host rock foliation with the regional foliation indicates that the tonalite was emplaced prior to the regional deformational event. (Field evidence does not indicate whether the tonalite dikes in the metavolcanics are related to the major tonalite emplacement or to the later tonalite dikes in the tonalite unit.)

The leucocratic stringers could represent a pre-first generation trondhjemite stage of trondhjemites, since they are similar in color and texture. If the stringers represent the earliest intrusion of trondhjemite, a clear increase through time of the size of trondhjemite dikes would exist, from the <1cm stringers to third generation dikes >1m wide. Even if the stringers are not part of the trondhjemite sequence, there is still a clear increase in size of the dikes. This increase through time indicates that the trondhjemite-producing processes intensify throughout the sequence, and may be related to the convergence of the Wawa and Quetico belts.

Although the three generations of trondhjemite intrusion are similar in compositional and texture, it is still possible to differentiate between them because of their relationships to a sequence of deformational features found in the tonalite and metavolcanic units. The first stage of trondhjemites is not aligned with the regional foliation. Instead, the strike is variable and often perpendicular to the foliation in the host rock; the later stages of dikes are aligned with the regional foliation. This suggests that the first stage of trondhjemites was emplaced prior to the deformational event that created the foliation and structural control in the host rocks that would guide the emplacement of future dikes. The shearing event that creates the offset in the first stage of trondhjemites began prior to the emplacement of the second generation of trondhjemites. Dikes in the second stage were emplaced along zones of weakness in the host rock which included the planes of shear offsetting the first-stage dikes. This explains their preferential location along the first stage's offsets and along the foliation direction in the rock. Because the second generation dikes are aligned with the foliation in the host rock, the regional foliation event must have begun prior to the second stage intrusion. This deformational event continued to fold and offset these dikes after the emplacement of the second stage. Like the second stage, the emplacement of the third generation of trondhjemites also were controlled by the shear zones and foliation in the host rock. The intensity of shearing diminished soon after the intrusion of the third stage dikes, so they are only slightly disturbed. The foliation process must have continued

throughout most of the three stages of trondhjemite emplacement because all stages exhibit foliations trending N50-70E. The unoriented mafic fragments within the dikes suggest that the dikes were emplaced as a fluid magma rather than by replacement.

The large, late trondhjemite intrusive stage was mapped by Godfrey and Jennings (1991) as semi-aplitic granite. The weak or absent foliation, post-deformational characteristics, and assumed field composition (including potassium feldspar) led to the hypothesis that these dikes are granites and related to the Vermilion Batholith. However, staining with sodium cobaltinitrate proved the potassium feldspar to be secondary, so the rock was originally a trondhjemite. The unfolded, continuous character and discordant foliation of these dikes indicates that they were not subjected to the regional deformation. Even though these large dikes and bosses are compositionally different from the plutonic rocks in the Quetico belt, they still might be intrusives branching off from the Vermilion Batholith. These low-potassium rocks could represent an early stage of plutonic activity in which only plagioclase and quartz were abundant. Changing temperatures and pressures or sub-crustal source areas, or differentiation of magma, magma mixing, or anatexis might result in an increase in potassium in the pluton. Potassium-bearing fluids could then alter the dikes emplaced earlier by the batholith, along with most of the other rocks in the region.

If the Vermilion Batholith is the source for the late trondhjemite intrusives, then the geographical distribution of these dikes and bosses provides evidence that the Vermilion Batholith in the Quetico belt acted as a stitching pluton, joining the Wawa and Quetico belts. Batholithic dikes in the Wawa belt would indicate that these intrusives are crossing the Wawa-Quetico junction--acting in a similar fashion as the stitching pluton described by Gardner et al. (1988). If the stitching pluton hypothesis is correct, the age of the batholith would provide a date representing the last phase of the junction of the Wawa and Quetico belts.

The potassium feldspar pegmatite dikes were preferentially emplaced along and through all the older trondhjemites, shear zones and faults, and within the foliation of the host rocks. These pegmatites soaked the surrounding trondhjemitic dikes with potassium. The method of emplacement of the pegmatite dikes is not clear from their relationship with the trondhjemites. Perhaps the dikes intruded as fluid magmas, and through replacement processes the surrounding rock was altered to include secondary potassium feldspar. These pegmatites appear to be closely related in time and space to the latest trondhjemites. Their undeformed, continuous nature coincides with their emplacement towards the end of the intrusive sequence when deformational processes were no longer active. They could represent the younger phase of batholithic activity that supplied the potassium responsible for regional alteration. This stage of intrusion had an extremely significant effect throughout the Gray Lake region, causing secondary potassium alteration in most of the rocks.

The quartz veins represent the last gasp of the intrusive sequence. Their emplacement along joints or faults, and frequently perpendicular to the major regional lineaments, suggests that while the earlier dikes were fluid magma intrusions, the quartz was deposited out of solution--a process less dependent upon exploiting zones of weakness in the host rock.

Conclusions

1. There is a similar sequence of intrusive events found in the metavolcanic and tonalite units. This sequence is closely correlated with regional deformational events, probably related to the joining of the Wawa and Quetico belts, and the emplacement of the Vermilion Batholith.

2. The emplacement of dikes is structurally controlled by preexisting characteristics of the host rocks. These controls include shear zones, foliation direction, and older intrusive bodies. Older dikes provide possibly the easiest route for the emplacement of younger intrusions.

3. The size of trondhjemite intrusives increases throughout the sequence. This intensification of the trondhjemite forming process could be related to the collision of the Wawa and Quetico belts.

4. Secondary introduction of potassium, probably related to the Vermilion Batholith, altered the original composition of many rock types. This potassium was introduced through dikes within older rock.

5. Semi-aplitic granite dikes and bosses were trondhjemitic in composition prior to potassium alteration. If these dikes and bosses were emplaced by an early, low-potassium concentration stage of plutonism, then the Vermilion Batholith may have acted as a stitching pluton joining the Wawa and Quetico belts.

References Cited

- Card, K.D. and Ciesielski, Andre, 1986. Subdivisions of the Superior Province of the Canadian Shield: *Geoscience Canada*, v. 13, p. 5-13.
- Gardner, M. C. et al., 1988. Pennsylvanian pluton stitching of Wrangellia and the Alexander terrane, Wrangell Mountains, Alaska. *Geology* 16: 967-971.
- Gerber, Miquette, 1990. Petrographic and chemical comparison of granitic-rich migmatite with the leucogranite of Vermilion Batholith, Quetico Provincial Park, Ontario. *Third Keck Research Symposium in Geology*, Northhampton, Massachusetts, p. 90-93.
- Mariano, Anthony and Woodard, H. H., 1984. Potassium metasomatism of trondhjemite migmatite wallrock, Vermilion Complex, northern Minnesota: *Institute on Lake Superior Geology, 30th Annual Meeting, Wausau, Wisconsin, Proceedings and Abstracts*, p. 32-33.
- Percival, J.A. and Williams, H.R., 1989. Late Archean Quetico accretionary complex, Superior province, Canada, *Geology*, v. 17, p. 23-25.
- Woodard, H. H. and Weaver, S. G., 1990. The nature of the boundary between the Wawa and Quetico belts, Basswood Lake area, Minnesota-Ontario. *Third Keck Research Symposium in Geology*, Northhampton, Massachusetts, p. 82-85.

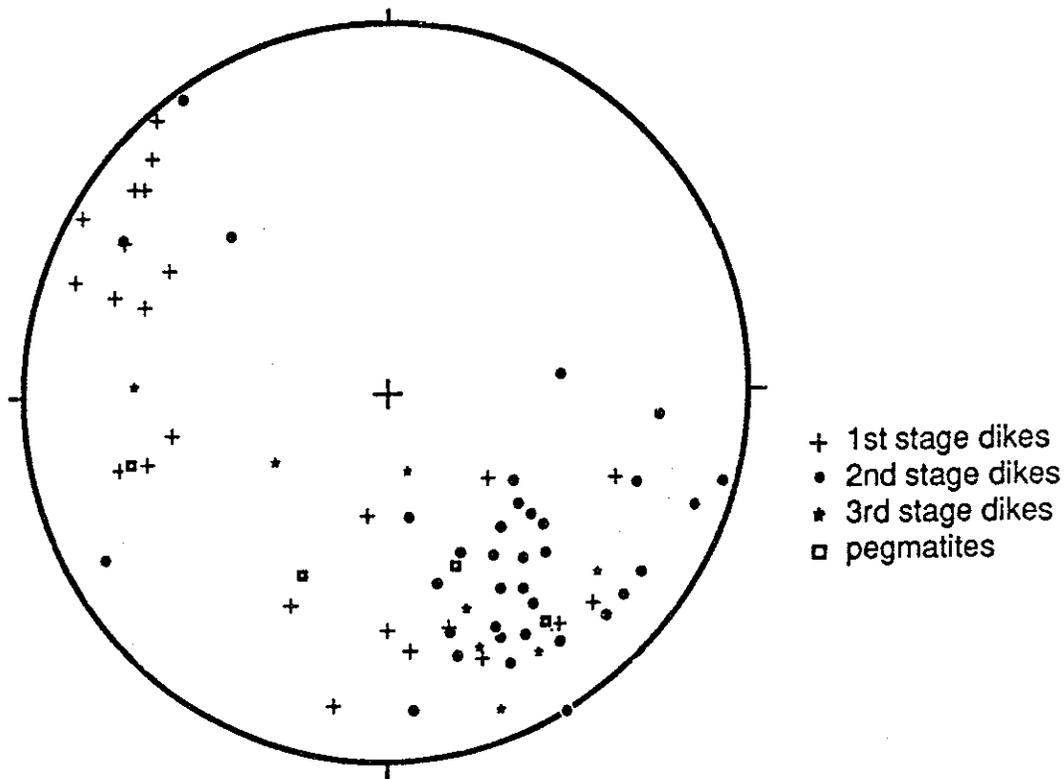


Figure 1. Stereonet showing the equal area lower hemisphere projections of the poles to planes of the trondhjemite dikes and pegmatites. Different generation of dikes were determined by observed cross-cutting relationships, composition, and groupings on this stereonet.

Joint Analysis Along the Junction of the Quetico and Wawa Structural Belts, Quetico Provincial Park, Canada

Josh Ishimatsu Pomona College (1993)
Elise Parkin Pomona College (1993)

INTRODUCTION

For nearly three weeks, we studied areas near Yum Yum Lake in Quetico Provincial Park, Ontario. This area straddles the proposed Quetico-Wawa belt junction (Woodard and Weaver, 1990). This junction is the boundary between two different lithologies which are thought to be two Archean terrains. These terrains consist of various metavolcanic and metasedimentary rocks. The boundary between the terrains crosses the Minnesota- Ontario border west of United States Point and trends 20 km to the northeast to the Yum Yum Lake area. A map of the study area appears in the project's summary, written by Dr. Henry "Chief" Woodard (Fig. 1, this volume) (Woodard, 1992).

For our individual project, we wanted to test for systematic differences between joint sets on either side of the proposed Quetico-Wawa boundary. We tried to find relationships between joint sets and possible faults, between joint sets and lineaments on aerial photographs, and between joint sets and geological structural settings. These observations were then geometrically related to the Quetico-Wawa junction in search of a common origin.

METHODS

Our process of collecting data was to measure the strike and dip of systematic, dominant joint surfaces in outcrops along the lakeshores. These lakeshore outcrops were the most useful because the more inland outcrops were covered by a thick surface of lichen which made it difficult to measure jointing.

We measured the joint surfaces which were aligned in parallel sets and clearly opened. We recorded the measurement of one representative joint of each set. A set of ten joints at one outcrop translated into one data entry, as did a set of three joints at the same outcrop. If the distinction was as obvious as the above ten to three ratio, we would note which joint set was the strongest. However, no matter how strong or weak a joint set was at a particular outcrop, it received a single data entry. This imbalance constitutes a problem because the overall data is not weighted towards the most prominent joints. For example, in a stereonet graph, every joint set, despite relative prominence, would receive a single plot. In order to accomplish a more accurate representation, we would have had to measure and record every joint at every outcrop, and this would not have been feasible given our time constraints. Another problem in measurement was that some of the outcrops were cliff faces. In order to obtain a measurement, one of us had to lean out of the canoe and, while trying to balance and keep from capsizing, hold the Brunton compass steady enough to take an accurate reading before the wind blew the canoe away from the outcrop.

We used the Macintosh computer program *Stereonet v. 3.75 KW* to combine data from specific areas, looking for concentrations of points over a more general geographic area.

DATA

We have divided our measurement area into five major geographic zones- Southwest Yum Yum Lake, Northeast Yum Yum Lake, "No-Name" Lake, McNiece Lake, and Grey Lake (Fig 1, Woodard, 1992). A N20E lineament runs through the approximate center of Yum Yum Lake. We arbitrarily used this lineament to split the lake into two geographic sections: northeast Yum Yum Lake and southwest Yum Yum Lake. All the areas are further broken down according to their location relative to the Wawa-Quetico belt boundary.

The figures used here are 1% area contours, the shaded areas indicate the highest concentration of points on a stereonet and thus represent the poles to major joint sets. All joint sets are listed in order of prominence.

The strikes of the major joint sets near the southern end of Yum Yum Lake, in the Quetico side, are approximately N40W, N40E, N75E, N15W, and N80W. The joint sets in the WaWa belt in the same area are N40W, N50W, and N55E.

The joint sets near the northern end of Yum Yum Lake, northeast of the N20E lineament which represents the boundary between the Quetico and Wawa belts, are approximately N45W, N75W, N40E, and N50E (Figure 1). On the Wawa side, the joint sets are approximately N65W, N40W, N50W, N45E, and N35E.