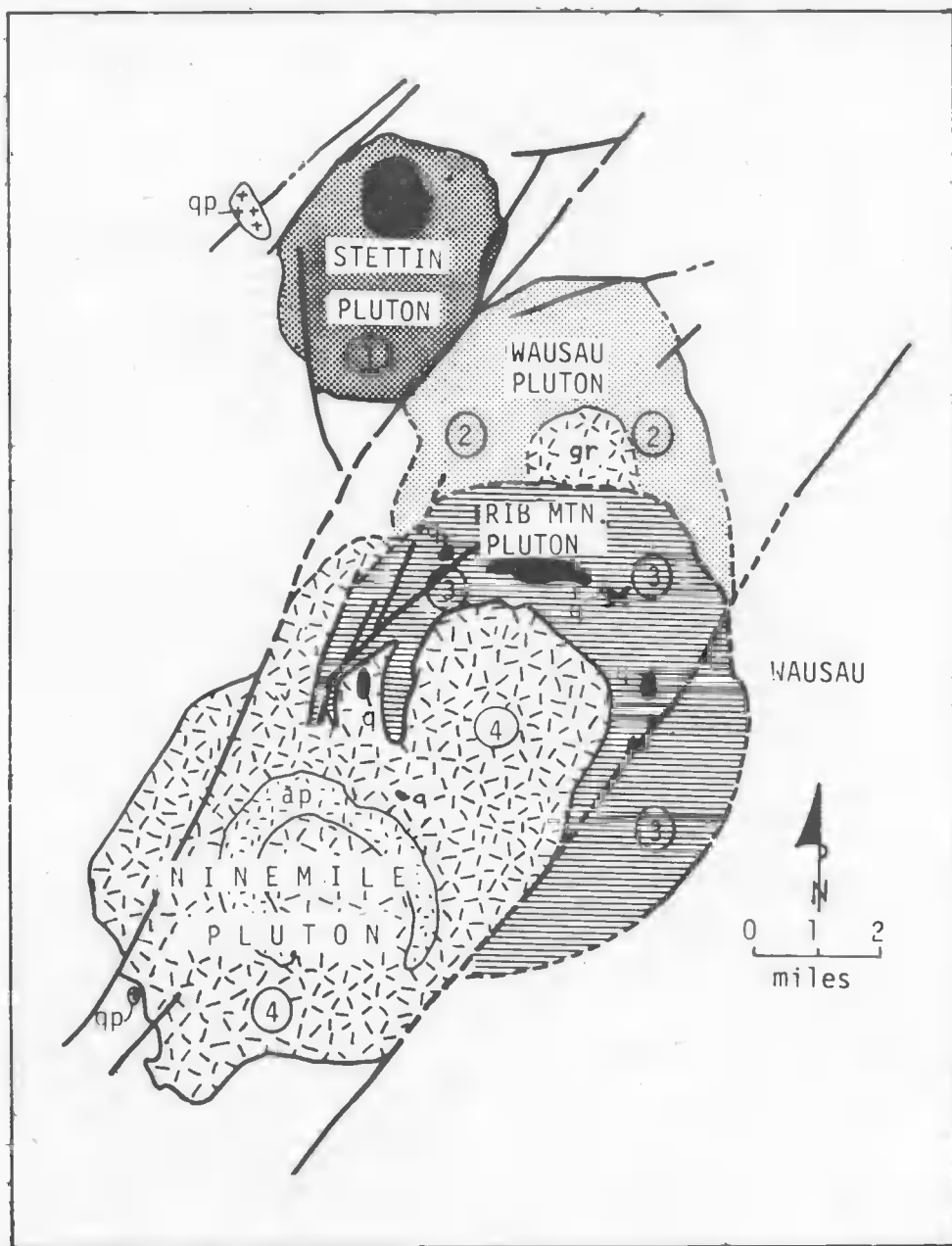




30th Annual
Institute on Lake Superior Geology

FIELD TRIP 3

THE WAUSAU SYENITE COMPLEX



April 28, 1984, Wausau, Wisconsin

30TH ANNUAL INSTITUTE ON LAKE SUPERIOR GEOLOGY

FIELD TRIP #3

THE WAUSAU SYENITE COMPLEX,
CENTRAL WISCONSIN*

by

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INTRODUCTION

This Guidebook is a major revision of one used in 1980 for the 26th Annual Institute on Lake Superior Geology. That volume was written by Sood, Myers, and Berlin. Subsequent more detailed mapping and analyses of rocks and minerals from the southern portion of the Complex have necessitated this revision. A comprehensive paper on the geology and petrology of the Wausau Syenite Complex is forthcoming.

Syenitic rocks of the Wausau area were first described by Weidman (1907) as part of a general report on the geology of northern Wisconsin. A greater than normal amount of attention was devoted in that report to the mineralogy of the syenites. Emmons and Snyder (1944), Turner (1948), and Giesse (1951) subsequently studied mainly the mineral associations of the Wausau Syenite. The plutons of the Wausau Syenite Complex were mapped in 1971-1976 as part of a mapping project by the Wisconsin Geological and Natural History Survey (LaBerge and Myers, 1984). Koellner (1974) studied the mineral chemistry of the various mapped units in the Stettin syenite pluton. Her excellent data have been incorporated in this guidebook with gratitude. Additional geochemical and mineral chemical-petrographic studies are being carried on by Falster (1984), Myers, Medaris, (University of Wisconsin - Madison), and Sood (Northeastern Illinois University).

GENERAL GEOLOGY

Central Wisconsin is on the southern edge of the exposed Precambrian Shield (Figure 1). The Precambrian rocks are sparsely exposed through glacial cover, along streams, and as scattered inliers. The aeromagnetic map by Zietz and others (1978) and the Bouguer anomaly gravity map by Ervin and Hammer (1974) permit extrapolation of contacts between isolate exposures.

Archean migmatites, gneisses, and schists of Archean age are confined to lenticular fault slices in the region between Stevens Point and Black River Falls. They have been referred to informally (LaBerge and Myers, 1984, p. 247) as the "Stevens Point Complex," and U-Pb zircon age dated at more than 2,800 m.y. old. by Van Schmus (1977, 1980). Syenitic augen gneiss at Neillsville yields a U-Pb zircon age of $2,535 \pm 10$ m.y. (Van Schmus, 1980). Archean gneisses and amphibolites occur north of the Niagara fault in northern Wisconsin, and it has been suggested (LaBerge, oral communication, 1984) that no Archean crust underlies the region between these roughly parallel east-northeast-trending fault systems.

Older Proterozoic rocks of the Wausau region are quartz-sillimanite schist, biotite schist, and amphibolite-grade metavolcanic rocks northwest of the Athens fault. Amphibolitic gneisses of volcanic and gabbroic parentage and tonalitic to trondhjemitic orthogneisses make up an east-northeast-trending belt of amphibolite-grade rocks comprising the Chippewa amphibolite complex (Myers, 1974) in the region west and north of Marathon County. Amphibolitic rocks of similar lithology are interleaved with Archean migmatites in the "Stevens Point complex" south of Marathon County. The older succession is characterized by amphibolite-grade metamorphic mineralogy and west- to northwest-plunging isoclinal folds deformed by more open, coaxial folds. Basal quartzite and pelitic metasedimentary rocks in this older succession are overlain by volcanic rocks, and intruded by numerous syntectonic tonalites, trondhjemites, and granodiorites (LaBerge and Myers, 1984, p. 246).

The younger Early Proterozoic succession consists primarily of greenschist-facies calc-alkaline basalt-rhyolite sequence that unconformably overlies the older succession (Myers and others, 1980). Structures in the greenschist sequence

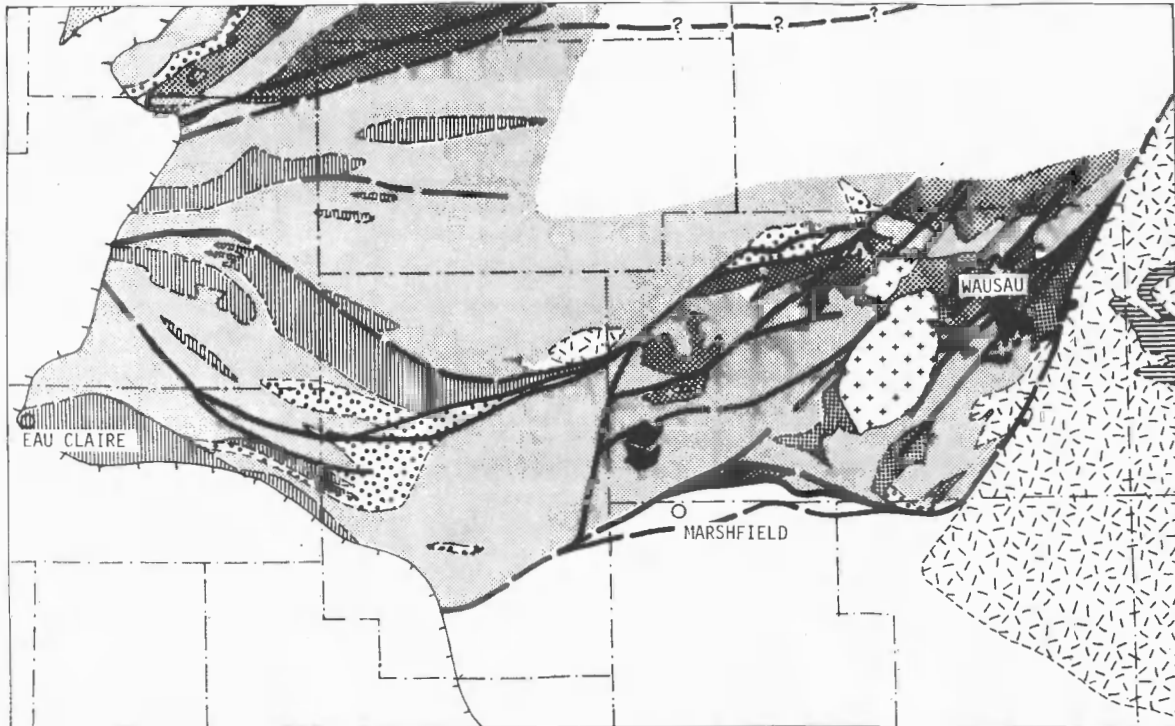


FIGURE 1

GENERALIZED PRECAMBRIAN GEOLOGY
of
WEST-CENTRAL WISCONSIN*

E X P L A N A T I O N

- Rapakivi-type granites and associated intrusive rocks of the Wolf River batholith
- Syenite, quartz syenite, quartz monzonite of the Wausau syenite complex
- Quartzite
- ~~~~~ UNCONFORMITY ~~~~~
- Metagabbro
- Anorthosite
- Calc-alkaline intrusive rocks consisting mainly of granite, granodiorite, tonalite, and quartz diorite; commonly foliated and/or lineated
- Metasedimentary rocks including phyllite, chlorite schist, micaceous quartzite, tuffaceous sandstone, siltstone; greenschist facies.
- Calc-alkaline metavolcanic rocks, mainly basaltic flows and andesite to rhyolite pyroclastic rocks; greenschist facies
- ~~~~~ UNCONFORMITY (?) ~~~~~
- Amphibolites

STRUCTURE SYMBOLS

- Approximate exposed edge of Precambrian basement
- Contact, dashed where inferred
- Contact based on aeromagnetic anomalies
- Fault or shear zone, dashed where inferred; commonly wider than line

* From LaBerge and Myers, 1984.



trend northeasterly and plunge easterly. LaBerge and Myers (1984) proposed that the amphibolite-grade succession is pre-Penokean in age and that it represents a major, yet-unrecognized part of Wisconsin Precambrian history. The amphibolite-grade succession may correlate with the Chocoma Group in western Michigan and northern Wisconsin, while the greenschist rocks may correlate with the Menominee and/or Baraga Groups. The isoclinal folds, higher grade metamorphism and tonalitic intrusives in the older succession may thus represent an older, pre-Penokean orogeny.

The Early Proterozoic amphibolite-grade and greenschist-grade rocks are overlain unconformably by rhyolite pyroclastics and intruded by anorogenic granites of approximately 1760 m.y. age (Smith, 1978). Similar rocks in the Brokaw area north of Wausau may belong to this younger sequence. Possibly also associated with these volcanic and intrusive rocks are younger quartzites such as those exposed at Baraboo, Flambeau Ridge, and Barron Hills, Wisconsin. The Rib Mountain and Mosinee Hill quartzites may also be of this age. These metasedimentary rocks are associated locally with dolomite, ferruginous slate, metaconglomerate and chert.

Widespread folding and wrench faulting at between 1630-1600 m.y. ago was of sufficient intensity to produce a significant resetting of Rb-Sr isotope systems. These wrench fault systems trend about east-west in the Stevens Point-Neillsville area and east-northeast in the region northwest of Wausau. The Jump River, Gilman, Monico, and Athens faults were probably developed or reactivated during this major kinematic event.

Although the Wausau Syenite Complex (WSC) was intruded after most of the faulting in this region, some reactivation of old faults caused minor offsets and local cataclasis.

THE WAUSAU SYENITE COMPLEX

The Wausau syenite complex (WSC) and coeval Wolf River batholith (WRB) are part of a NE-SW-trending belt of 1,770 to 1,030 m.y. anorogenic, granite plutons that extends from the Baltic Shield to the southwestern United States (Figure 2). These plutons represent the last major episode of Precambrian granitic intrusion in the Lake Superior region. Anderson (1983) has compared the characteristics of these anorogenic plutons, and shows that the dominant type is of rapakivi affinity. According to Anderson (1983, p. 133) crystallization of these potassic, iron-enriched magmas took place at temperatures between 640 and 790°C and low total pressures, generally less than 2 kb. The present linear continuity of this belt of roughly coeval plutons and their apparent shallow depth of intrusion signify a lack of major subsequent continental rearrangement or major uplift. He concludes that crustal derivation of the magmas was a result of thermal doming in the mantle and that cogenetic anorthositic and mangeritic magma emplacement may have played an active role in generating necessary heat of fusion at lower crustal levels. Anderson feels that the plutons do not show a consistent age progression of a track, and that the thermal event was related to development of a failed rift.

Four concentrically-zoned, cylindrical alkaline plutons make up the WSC. According to Van Schmus and others (1975a, 1975b, 1981), The Stettin syenite pluton crystallized 1,520 m.y. ago, while the WRB and Ninemile granite pluton crystallized 1,500 m.y. ago. He feels that the U-Pb systems are clean enough to assure that the difference in ages is real. This difference in radiometric age is in accord with cross-cutting relationships shown in the field. The oldest, most alkaline Stettin pluton (Figure 3, #1) has a wall zone and core rimmed by nepheline syenite. Following the emplacement of the Stettin pluton, three pipe-like plutons were intruded in series south-southwest from Wausau: the Wausau pluton (Figure 3, #2), the Rib Mountain pluton consisting mostly of quartz syenite with numerous large xenoliths (Figure 3, #3), and finally the Ninemile granite pluton (Figure 3, #4).

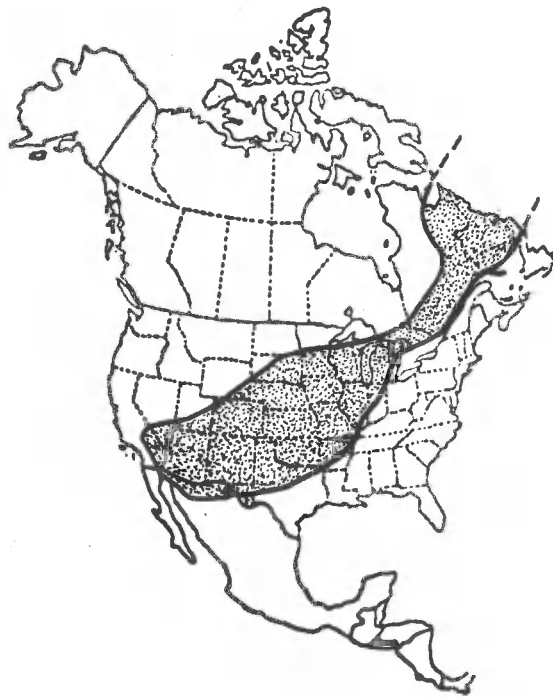


Figure 2 -- Proterozoic anorogenic granite complexes of North America (Anderson, 1983, p. 135)

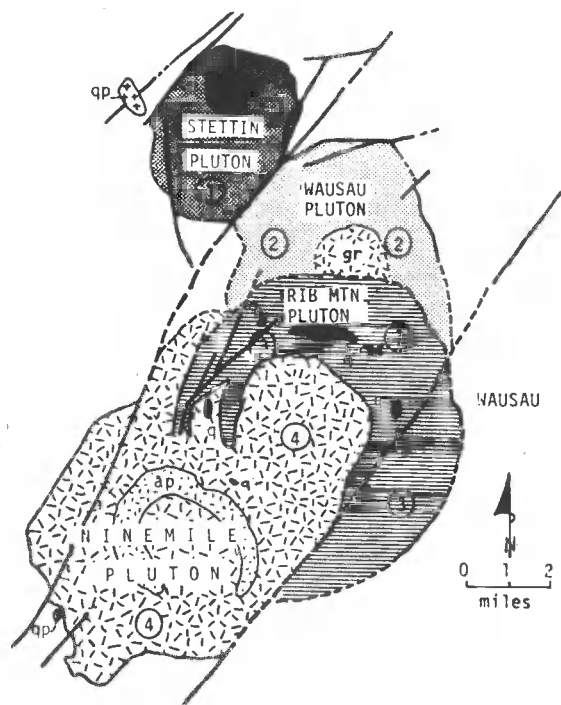


Figure 3 -- Components of the Wausau syenite complex.

The southern half of the Wausau pluton was stopped by the Rib Mountain pluton, whose core and southern rim were occupied by the Ninemile granite pluton. Granite and quartz monzonite aplites form a partial core rim in the southern lobe of the Ninemile pluton, and occupy several large, irregular areas west, southeast, and north of the Wausau complex. Subhorizontal pegmatite dikes and pods in the Ninemile granite contain miarolitic cavities whose mineral assemblages indicate thermal shock and shallow crystallization (Falster, 1984). Several younger, possibly related quartz monzonite porphyry plugs were intruded across faults that cut the syenites. The Wausau pluton has a small core of granite which closely resembles the Ninemile granite. In general the intrusive sequence represents a continual enrichment of the differentiating magmas in silica.

Figure 4 is a geologic map of Marathon County, which shows the context of the Wausau syenite complex and its discordance with respect to east-northeasterly trends in the older rocks. A portion of the Wolf River batholith can be seen in the eastern quarter of Marathon County. The Wolf River batholith is separated from the Wausau syenite pluton by a major fault system which bends abruptly westward along the southern border of Marathon County. The Wausau syenite complex occupies the concave portion of this bend. It is possible that the syenite complex had an important kinematic influence - as that of a knot - on the development of the faults, although the syenite is clearly offset by many of them (later reactivation).

Figure 5 is a geologic map of the Wausau syenite complex showing the stops for this field trip. Several extra stop descriptions are included so that one may use the field guide for self-guided field trips. The base map for the geology is from LaBerge and Myers 1984 report on the Geology of Marathon County being published by the Wisconsin Geological and Natural Survey. Additional mapping since submission of the map for the Survey report has resulted in some revisions - particularly of the Wausau, Rib Mountain, and Ninemile plutons.

Figure 6 is a topographic map showing locations of stops and routes. Some of these will not be visited during the field trip owing to time limitations. These maps were plotted on the following 15' topographic quadrangles (clockwise from the northwest: Hamburg, Merrill, Wausau, and Marathon).

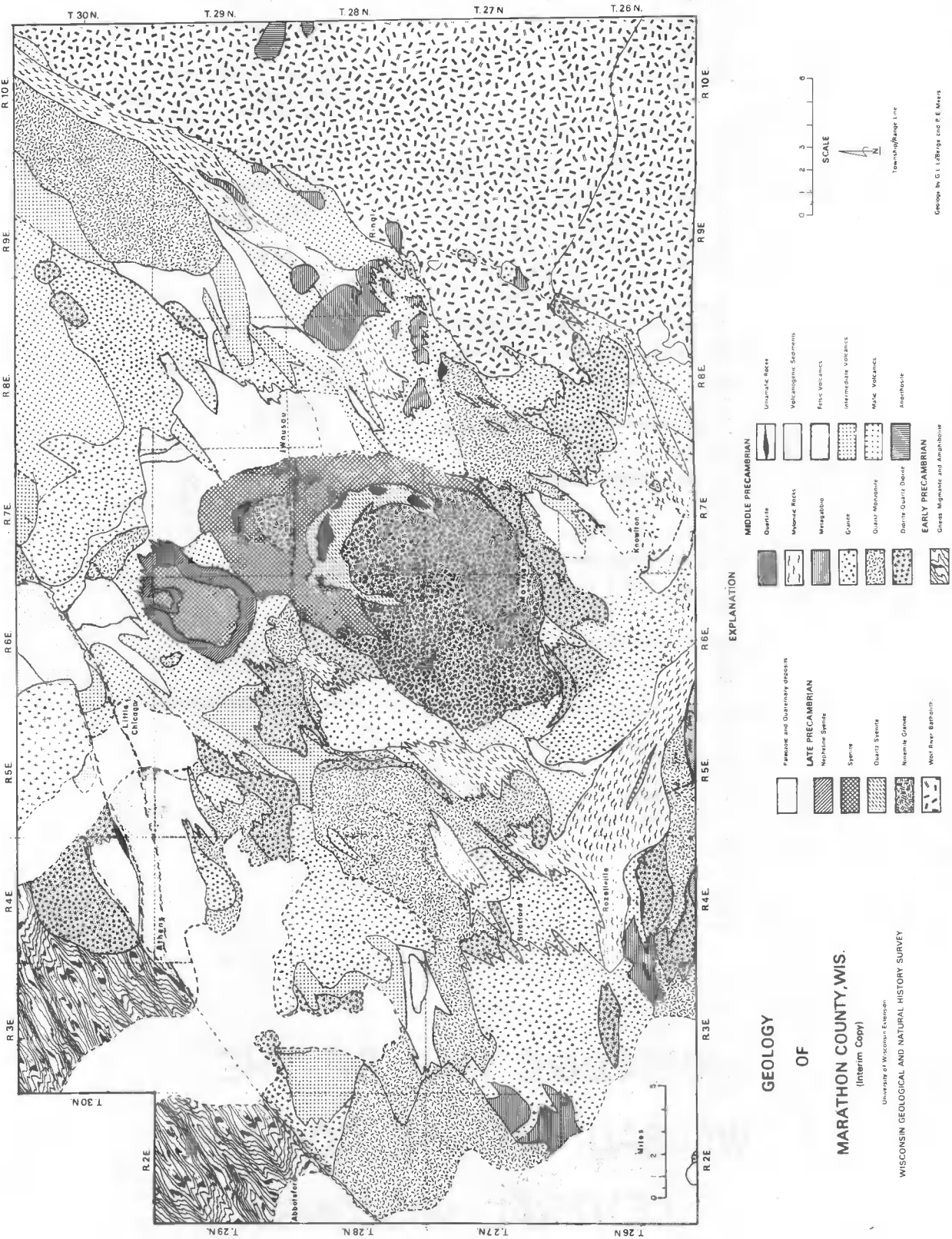


Figure 4 -- Geologic map of Marathon County by LaBerge and Myers, 1979 Wisconsin Geological and Natural History Survey, Interim Copy.

EXPLANATION

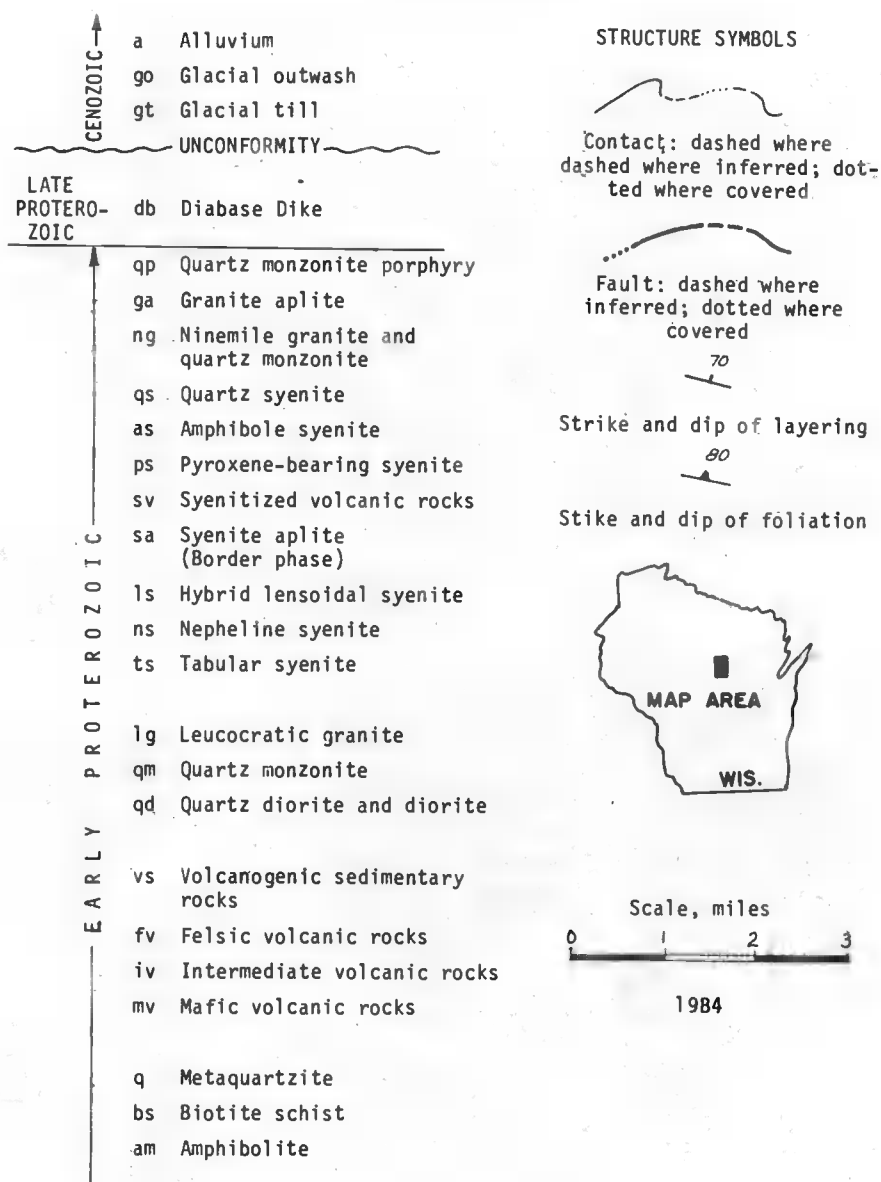


Figure 5 --

GEOLOGIC MAP OF THE WAUSAU SYENITE COMPLEX, CENTRAL WISCONSIN

by Paul E. Myers

STATE OF WISCONSIN
 MARATHON QUADRANGLE
 WISCONSIN-MARATHON CO.
 15 MINUTE SERIES (TOPOGRAPHIC)
 MARATHON QUADRANGLE
 WISCONSIN-MARATHON CO.
 15 MINUTE SERIES (TOPOGRAPHIC)

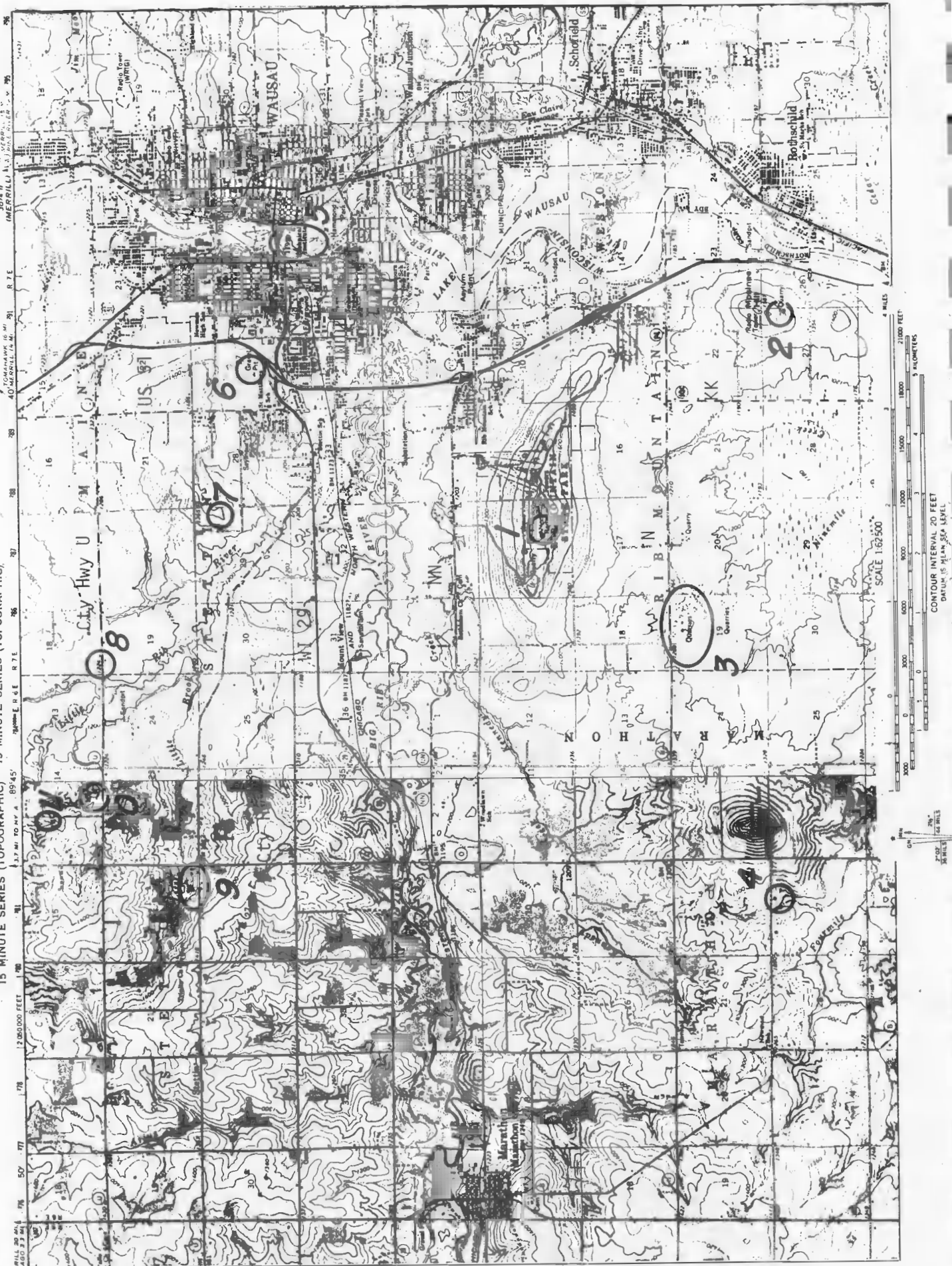


Figure 6-- Field trip route map for stops 1 through 11.

STOP #1

TITLE: RIB MOUNTAIN SUMMIT - GENERAL GEOLOGY

LOCATION: Rib Mountain State Park observation platform: SE/4 Sec. 8, T28N, R7E; Wausau 15' Quadrangle, Wausau West 7.5' Quadrangle

DATE: March, 1984

DESCRIPTION:

From this vantage point, one can get a general perspective of the major elements of the geology and geography of the Wausau region. This observation tower and all of Rib Mountain are on the upturned edge of nearly vertical beds of very coarse-grained metaquartzite with tops facing southward. Facing direction is indicated by sparsely exposed cross-bedding and occasional ripple forms. The Rib Mountain quartzite is an arcuate, keel-shaped xenolith embedded in quartz syenite: it is situated on the northern edge of the Rib Mountain syenite-quartz syenite pluton, whose core (just south of here) is occupied by granite and quartz monzonite of the northern lobe of the Ninemile pluton. Mosinee Hill southeast of here (the knob with the radio antenna on it) and Hardwood hill southwest of here are similar, but smaller quartzite xenolith remnants that are located in analogous positions in the cylindrical Rib Mountain pluton. The quartzite xenoliths form about three-quarters of a circle with a diameter of about 5 miles. Relict bedding in the quartzites at Mosinee Hill (STOP #2) and Hardwood Hill is parallel to elongation direction of the lenticular xenoliths.

A large, abandoned quarry, operated by 3M Corporation as a source of roofing granules, affords an excellent exposure of the quartzites. A porphyritic diabase dike cuts through quartzites on the south wall of the quarry, and is traceable in float for about 2 miles to the west-southwest. The quarry is located on the west end of Rib Mountain about one-half mile west of here.

The east end of the Rib Mountain quartzite body is offset by a small northeast-trending fault. This fault is parallel with larger faults of similar trend that cut the edges of the Rib Mountain pluton.

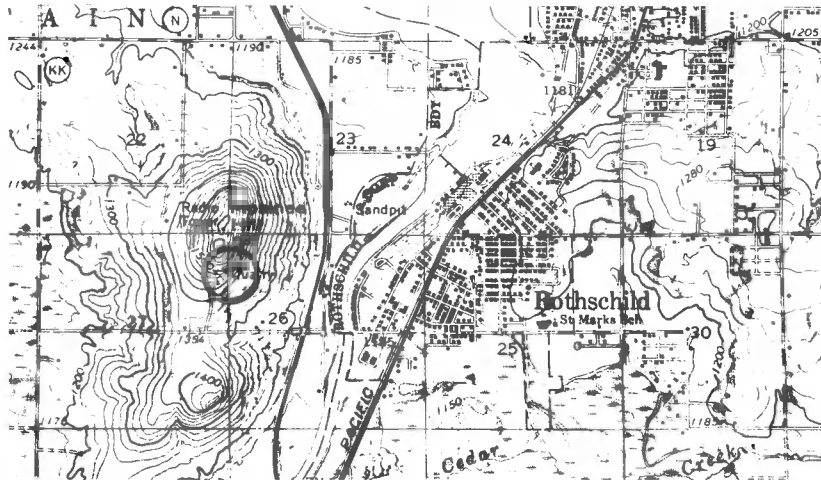
The Wausau pluton and the Rib Mountain pluton show an uncanny resemblance: their contact is covered by Rib River alluvium just north of Rib Mountain. Each of the plutons is cored by granite, and each contains a large mass of metaquartzite in its northern edge. One is tempted to suggest that the apparent "duplication" was produced by low-angle faulting. However, the two plutons are significantly different in mineral composition and in the types of xenoliths making up their intermediate zones. The Wausau syenite has a broad intermediate zone of amphibole syenite containing mainly metavolcanic xenoliths, while the Rib Mountain pluton intermediate zone is composed dominantly of quartz syenite (with a texture strongly resembling arkose) and xenoliths mainly of metaquartzite, biotite schist, and amphibolite.

Interesting questions arise as to the origin and mode of emplacement of these xenoliths. The schists, amphibolite, and possibly at least some of the metaquartzite xenoliths show higher grades of regional metamorphism than is displayed in the rocks surrounding the Wausau complex at its present level of exposure. It is therefore inferred that these xenoliths were brought up from a more highly metamorphosed basement. Volcanic xenoliths, like those seen in the Wausau syenite at Stop 3 may represent material collapsed into the pluton during caldera subsidence.

STOP # 2

TITLE: Large Quartzite and Biotite Schist Xenoliths in the Core Rim, Wausau Syenite Pluton

LOCATION: South end of Mosinee Hill, NE $\frac{1}{4}$, NE $\frac{1}{4}$ Sec. 27, T28N, R7E
Wausau 15' and Wausau West 7.5' quadrangles



AUTHOR: Paul E. Myers, University of Wisconsin-Eau Claire

DATE: February, 1980

SUMMARY OF FEATURES:

This abandoned 3-M quarry exposes the south end of a large quartzite xenolith and a much smaller xenolith of biotite schist (Figure 1). The lensoidal shape of the large xenoliths is extrapolated from shapes of smaller ones throughout the intermediate zone. Near its contact with quartz syenite the quartzite is impregnated with very fine-grained, interstitial pink microcline which selectively replaced certain layers in the quartzite. The abundance of interstitial K-feldspar diminishes toward the center of the quartzite xenolith. Smaller quartzite xenoliths have been thoroughly granitized. The question of whether these xenoliths were carried up or down along the cylindrical wall of the Wausau syenite pluton is still not answered.

The only significant bedrock occurrence of quartzite and biotite schist in this area is as xenoliths in the Wausau syenite pluton. The xenoliths have the following important characteristics:

1. They show concentric, zonal distribution and orientation around the quartz monzonitic core--the Ninemile pluton.

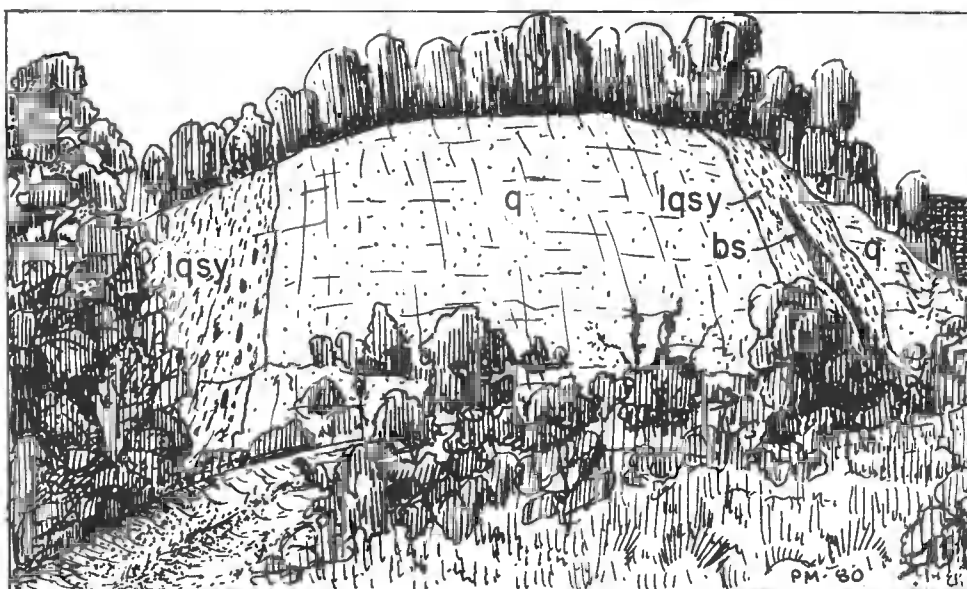


FIGURE 7-- Profile of the south end of Mosinee Hill

2. The largest xenoliths occur one mile outside the core.
3. The quartzite xenoliths are the largest because of their lower susceptibility to fragmentation and assimilation.
4. Flow structure in quartz syenite and feldspar lenticulation indicate intrusion of the quartz syenite as a viscous crystal mush.
5. Mafic xenoliths were biotitized, and quartzite xenoliths were granitized through the metasomatic addition of K_2O and Al_2O_3 with selective replacement of quartzite by fine-grained microcline along bedding planes.
6. Xenoliths north of the Rib River are dominantly metavolcanic rocks, whereas the xenoliths south of Rib River are dominantly quartzite, biotite schist and very subordinate non-foliated metadiabase.
7. Quartz grains in the quartz syenite and the outer part of the Ninemile pluton are granular, subangular, coarse grained and strained.

THE NINEMILE PLUTON:

The Ninemile pluton has a granite rim containing xenocrystic quartz. Samples taken at one-mile intervals across the pluton from north to south and from west to east show a decreasing percentage of xenocrystic quartz and an increasing amount of plagioclase toward the center of the pluton. The contact at the Ninemile pluton is locally discordant, as at Black Creek 1.7 miles northwest of here. Mirolitic cavities, some filled with large quartz crystals are common along the west side of the Ninemile pluton. They indicate shallow conditions of crystallization.

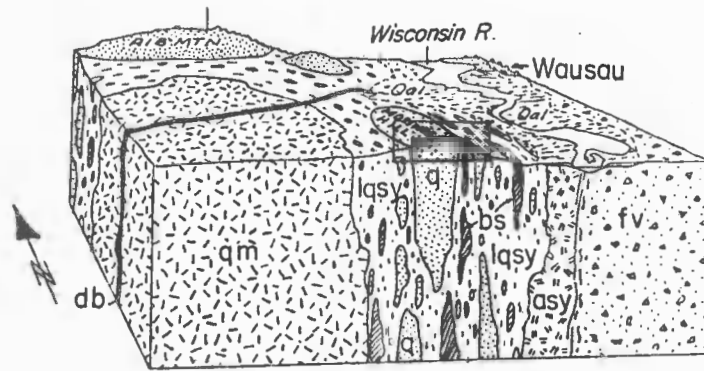


Figure 8--Block diagram of the northeastern corner of the southern segment of the Wausau syenite pluton at Mosinee Hill showing abundant, well-oriented quartzite (q) and biotite schist (bs) xenoliths in a flow-laminated, lensoidal quartz syenite (lqsy). The Ninemile quartz monzonite pluton (qm) intruded the quartz syenite with only a local discordance. The lensoidal syenite is bounded on the east by a thin wall of amphibole syenite (asy) which is itself in fault contact eastward with felsic volcanics. These rocks are cut with sharp discordance by a prominent diabase (db) dike which is characterized by a strong reverse polarity. The Qal is Wisconsin River alluvium. The shaded rectangle shows the location of the profile in Figure 7.

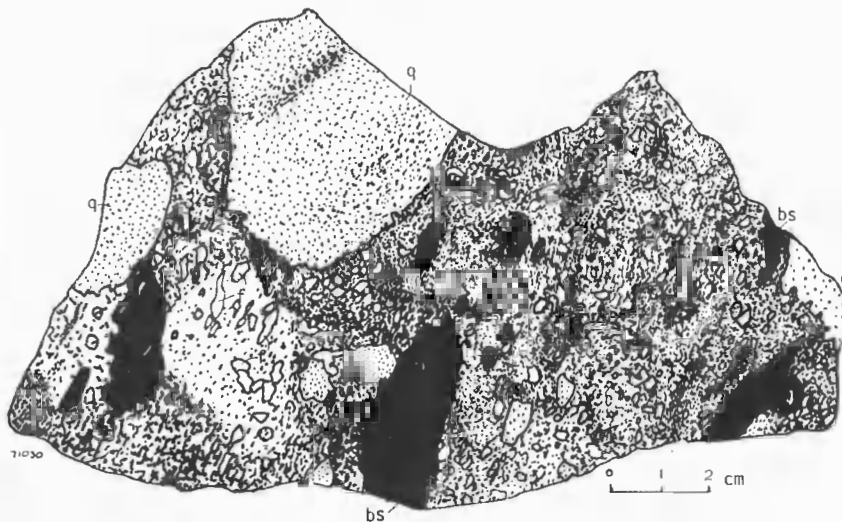


Figure 9-- Camera lucida drawing of slabbed specimen of quartz syenite breccia containing aligned, angular clasts of banded quartzite (q), biotite schist (bs), and feldspar (f). Quartzite clast boundaries are typically sutured and embayed by K-feldspar metacrysts. This rock is interpreted as a caldera rim collapse breccia. Specimen from the ridge west of Rib Mountain.

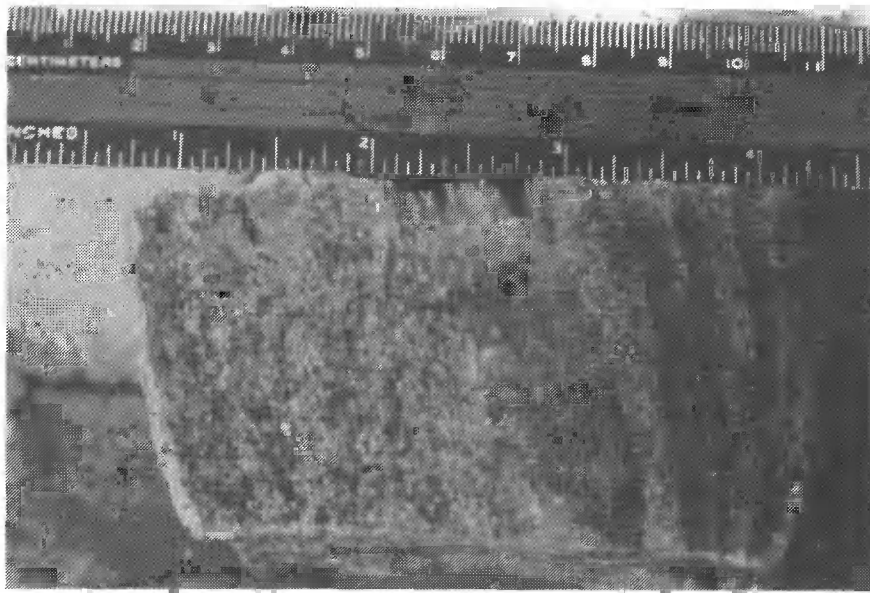


Figure 10-- Granitized quartzite from the east side of Mosinee Hill. Banding is relict bedding.

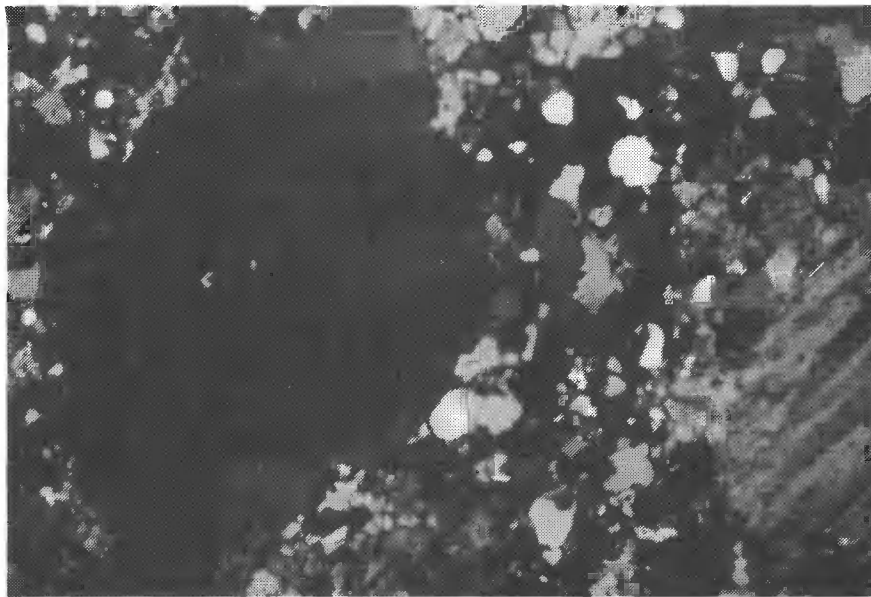


Figure 11-- Coarse microcline and quartz xenocrysts from quartz syenite from the west side of Mosinee Hill. The quartz grains have strain lamellae. The matrix is angular quartz and K-feldspar. Width of picture is 3.4 mm.

STOP #3

TITLE: Mineralogy of Pegmatite Bodies in the Ninemile Pluton

LOCATION: North Central Sec. 19, T 28 N, R 7 E, Wausau 15' Quadrangle. South side of County Highway N about 4 miles west of US-51. [See map, page 8]

AUTHORS: Al Falster, 920 McIntosh St., Wausau, and Paul Myers, University of Wisconsin - Eau Claire

DATE: March, 1984

SUMMARY OF FEATURES:

The Ninemile pluton was emplaced at shallow depth (probably less than 4 km) in the core and southern rim of the Rib Mountain pluton and in the older meta-volcanic, metasedimentary, and plutonic rocks surrounding it. The Ninemile pluton is composed of biotite-hornblende granite and quartz monzonite, and is locally crowded with inclusions of quartzite, schist, and syenite. Pegmatite pods in the Ninemile pluton occur as: (1) small schlierenlike masses, (2) zoned dikes with miarolitic cavities, (3) simple, poorly zoned bodies with vugs in the intermediate zone, and (4) late stage bodies showing selective etching and crystallization of accessory minerals.

DESCRIPTION:

The Ninemile pluton is composed of K-feldspar, Na-feldspar (together usually, but not always as perthite), quartz, biotite and amphibole. Quartz grains have rounded-polygonal shape, and closely resemble grains from quartzite like that exposed at Rib Mountain and Mosinee Hill. Hematite and Ti-rich biotite are locally abundant. The Ninemile pluton contains numerous pegmatitic pods and dikes, which are shallow dipping except near the margin of the pluton, a factor suggesting pegmatite emplacement in concentric zones of thermal contraction. Deep weathering of the Ninemile granites, especially in a circular zone near its rim, has produced a ferruginous gruss which has been quarried for use as paving materials for over 90 years. The abundance of fluorite and the concentric structure of the Ninemile pluton suggest that the zones of most intense weathering reflect the local effects of the formation of HF to cause etching and solution of quartz grains with consequent disaggregation of the rock.

Pegmatite Types and Mineralogy

Study of pegmatites in the Ninemile pluton is hampered by poor exposure. However, more than 800 miarolitic cavities in over 800 pegmatite bodies have been examined and described in detail by A. Falster. The search for pegmatite bodies is aided considerably by studying distribution of certain plants, infrared aerial photography, and subtle variations in topography. The average size of pockets is about 15 centimeters in maximum dimension, although pockets up to 4.5 x 1.2 x 1 meters have been found. In addition to regular pockets, some pegmatite dikes contain vuggy zones. Some very fine microcrystalline material has been taken from these vugs.

1. Simple, schlieren-like masses of small size and simple mineralogy. These masses are common in the vicinity of larger dikes. Zoning is generally not well developed. Grain size increases regularly inward, with the coarsest crystals in the hanging wall near the center (indicating vapor nourishment). Mineralogy: microcline, albite, quartz, and a few accessories including siderite (pseudomorphed by goethite, hematite, and other minerals), hematite, hisingerite, second generation feldspar and quartz, and rare phenakite, anatase, sulfides, and sulfosalts.

2. Complexly zoned, typically large dikes with well-formed miarolitic cavities. Dikes of this kind are typically larger than 10 x 10 x 0.2 meters and exhibit well-defined zoning with wall zones, intermediate zones, and core zones. While the wall zones are usually poorly defined, the intermediate zones generally consist of graphic zones, blocky zones (usually near cores) and pocket zones of aplite. Mineralogy is diverse: microcline, albite, and quartz are the essential minerals, often occurring in two or more successive generations. Accessory minerals include several or numerous species of the following: sulfides - pyrite, sphalerite, galena; sulfosalts - jamesonite, boulangerite and other identified species; carbonates - siderite (commonly replaced by Fe^{3+} minerals like goethite, hematite, and lepidocrocite) calcite, mangano-calcite and ankerite(?); Be-minerals such as phenakite, bertrandite, bavenite, euclase, and beryl; and REE-rich (Th-poor) cheralite, xenotime, monazite, and synchisite-parisite.

Dikes of this type commonly show the effects of thermal shock: i.e. brecciated pockets showing secondary overgrowths and cementation. In a few cases the pockets were rapidly evacuated of all fluids, and metastable feldspar assemblages crystallized from escaping fluids while coating all earlier pocket phases.

3. Simple bodies with extensive vuggy regions in the intermediate zone. These dikes are large, thick, and do not show well-developed zoning. Wall and intermediate zones contain patchy quartz cores. Large miarolitic cavities are rare, but myriads of tiny vesicles abound in the intermediate zone. Maximum size of these cavities is about 0.5 - 1.5 centimeters. Dominant minerals are microcline, albite, quartz, and tiny (<1.0 millimeter) hematite crystals. Accessory minerals include zircon, fluorite, F-apatite. Late stage milky quartz veins cut these dikes in about 50 percent of the cases.

4. Pegmatite bodies with late stage selective etching and crystallization of accessory minerals. Although similar in many respects to the complexly zoned large dikes described above, they differ in several significant respects. They typically show an inward diminution in quartz content owing to removal by corrosive fluids. Spaces originally filled with quartz were filled by graphic intergrowths of quartz and feldspar. Secondary growth of feldspars was accompanied by crystallization of Ti oxides (anatase brookite rutile) and ilmenite. Other minerals include Ti bearing hematite (Ti = 2-3 percent), zircon, muscovite, bertrandite, phenakite, cheralite, xenotime, and others.

Internal Evolution of Megmatite Dikes (Types 2 and 4 above)

Development of a very thin, fine-grained contact zone (0.5 - 2 centimeters) was followed by crystallization of an extensive wall zone containing elongate biotite. Vapor nourishment fed crystals growing down from hangingwall. Finer grained parts of the wall zone grew upwards from the footwall, with occasional development of a coarse-grained aggregate in pockets of vapor nourishment. Rising vapors initially formed coarse K-feldspar in graphic intergrowth with quartz, and later blocky K-feldspar. Quartz formed large monomineralic masses in the upper-median part of the dike. A few very large crystals of siderophyllite formed at the core margin. As the pocket stage was approached a pressure quench may have affected the fluid yielding an aplite, while in other sections of the dike, miarolitic cavities formed. These cavities may be singular, relatively large openings, or they may be extensive areas in the intermediate zone of tiny vesicles with material resembling a sponge. At later stages, metasomatism or hydrothermal replacement of some pocket constituents sets in with alteration of siderite, pyrite, and other minerals to goethite, hematite, hydration of phenakite to bertrandite, corrosion of quartz and feldspars (adularia-habit), pocket rupture and thermal shock of pocket constituents, resealing of the pocket, and continued crystal growth or complete degassing, deposition of metastable feldspar assemblages (high-sanidine, orthoclase, and intermediate microcline; R. Martin pers. com., 1983), and hermetical sealing of the pocket (any fluid entering the pocket

at this time would quickly react with the metastable phases.) Corrosive fluids then remove quartz from graphic intergrowths. "Alpine-type" minerals are then deposited in voids. The latest phase of pegmatite evolution involves the formation of clay minerals, etching of pocket constituents, and destruction due to weathering (Jahns, 1955 and 1982, Foord and Martin, 1979, Martin, 1982, Černý, 1982, Falster, 1983.)

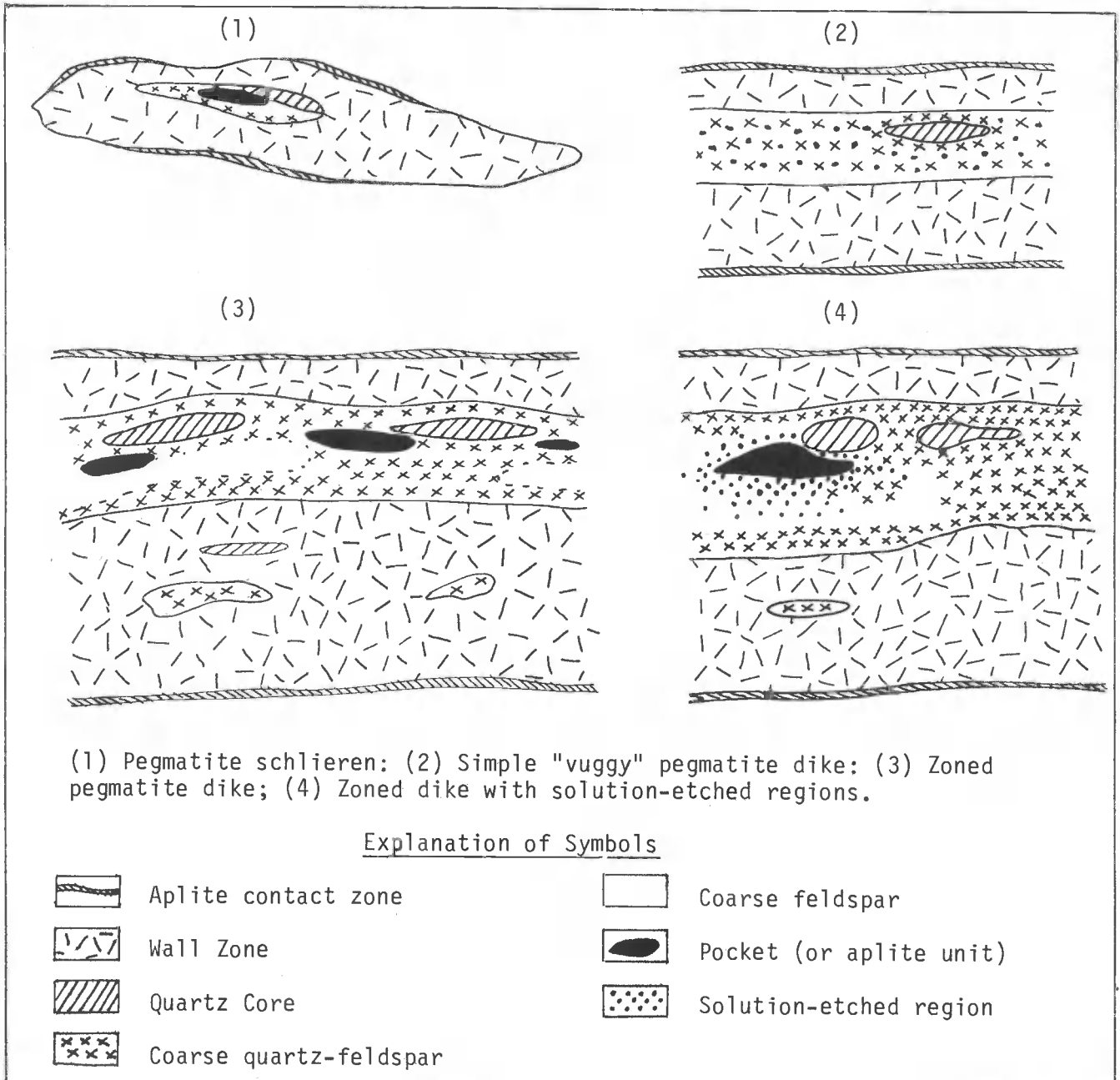


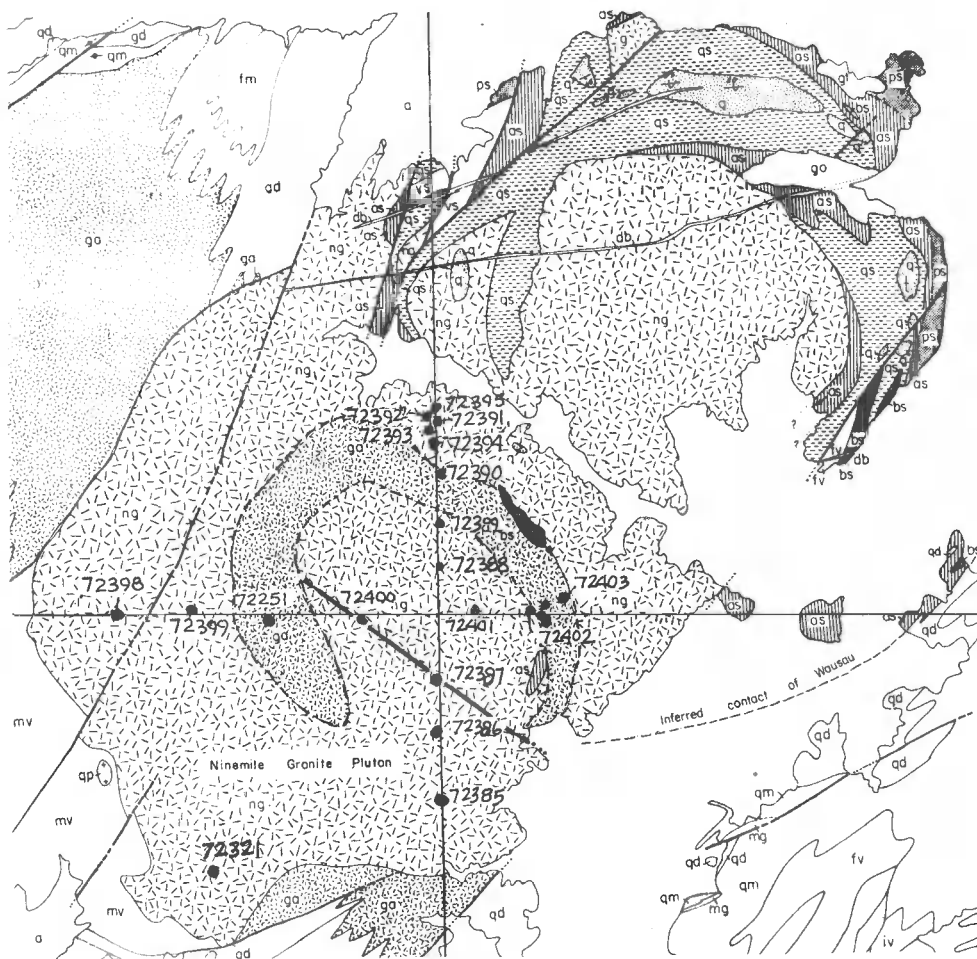
Figure 10-- Types of pegmatite bodies in the Ninemile pluton.

The Ninemile granite itself shows much compositional and textural variation: miarolitic cavities and xenolithic material are common, especially that portion of the Ninemile pluton occupying the southern rim of the Rib Mountain pluton, where much stope rim materials were never completely assimilated. Table 1 on page 16 gives brief descriptions and modal compositions for 17 samples taken in N-S and E-W traverses across the pluton.

TABLE 1 -- MODAL COMPOSITION OF NINEMILE GRANITE PLUTON *

SAMPLE NUMBER*	K-Feld	Perth	Plag	Q	Bi	Am	Rock Classification	North
72395	28	24	12	35	Tr	-	Leucogranite	
72392A	12	51	-	31	2	-	Biotite granite	
72392B	62	-	-	35	2	-	Quartz syenite w/ xenocrystic quartz	
72391A	6	62	-	29	3	-	Biotite granite	
72391B	10	55	-	21	-	-	Leucogranite	
72393	16	46?	-	35	2	<1	Gneissic qsy or granite aplite	
72394A	57	10	10	21	-	-	Hematitic quartz monzonite	
72394B	47	23	9	19	-	-	Quartz syenite or monzonite w/ q veins	
72390A	32	3	30	27	0.6	2	Biotite quartz monzonite	
72390B	-	60	5	28	4	1	Biotite granite	
72390C	28	12	21	32	7	-	Biotite quartz monzonite	
72390D	30	14	8?	35	3	-	Altered biotite granite	
72389	50?	30?	5	15	<1	-	Leucogranite	
72388A	42?	16?	5	26	7	2	Hornblende-biotite granite	
72388B	54	5	-	35	3	1	Biotite granite	
72387A	41	23	-	26	9	Tr	Biotite granite	
72387B	25	42	5	25	2	-	Granite protomylonite	
72386	70	5	-	22	-	-	Leucogranite	
72385	29	-	37	16	9	8	Biotite-hornblende quartz monzonite	
							↓ South West	
72399	-	35	10	40	5	10	Hornblende-biotite quartz monzonite	
72251	37	-	34	28	Tr	-	Leuco-quartz monzonite	
72400	-	65	-	31	2	-	Granite protomylonite	
72401A	-	76	4	15	2	-	Biotite granite	
72401B	-	40	5	2	25	21	Amphibole-biotite syenite (xenolith)	
72401C	-	-	34	2	26	28	Mafic syenogabbro (xenolith)	
72402A	26	-	46	-	8	16	Biotite syenite (xenolith)	
72402B	-	-	15	60	5	-	Schistose quartz-plagioclase aplite	
7294	10	64	25	-	1	-	Quartz monzonite flaser gneiss	
72403	-	60?	15	23	1	1	Quartz monzonite	
							↓ East	

Sample Location Map



STOP #4

TITLE: Metaconglomerate inclusion(?) in quartz syenite in the west edge of the Rib Mountain Pluton
 LOCATION: NW/4 NE/4, Sec. 22, T 28 N, R 6 E, Marathon 15' Quadrangle [See map, p 8]
 AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire
 DATE: March, 1984

DESCRIPTION:

Large boulder piles south of the road contain numerous boulders of highly deformed metaconglomerate which is cut by small dikes and veins of quartz syenite and granite. Despite lack of outcrop here, the size, abundance, and uniqueness of this rock indicate that it was broken loose from a bedrock ledge by a farmer and hauled into this pile. Ninemile granite is exposed just east and south of here, and quartz syenite with abundant metasedimentary and metavolcanic xenoliths similar to those seen at Stop #2 (Mosinee Hill) is exposed just east and north of here. There is good enough exposure in this area to indicate that there are several N-S and NE-SW trending faults which have broken the western edge of the Rib Mountain pluton into slices. Thus, the contact relations of the rocks seen in these rock piles, combined with distribution of rock types in the surrounding area, can be used to develop a conception of their relationships in spite of the lack of exposure.

The metaconglomerate contains flattened and folded clasts of banded quartzite, fine-grained biotite schist and gneiss (felsic volcanic or metasediment?), metamorphosed fine-grained andesitic(?) volcanic rocks with relict porphyritic, vesicular and tuffaceous textures, metadiorite, and metagabbro. One clast looks like amphibole syenite! The clasts have been differentially flattened with simultaneous development of a biotite-chlorite foliation. Quartzite clasts, because of resistance to flattening, remained quite round: the schistose metavolcanic clasts were greatly flattened, so that their length/thickness ratios are up to 12. (Figure 11). A later episode of close folding produced kink-like folds with consequent second-stage deformation of the clasts.

Granitic dikes and veinlets cutting the metaconglomerate discordantly show a pronounced reduction in grain size in the vicinity of the metaconglomerate xenoliths - probably due to a change in the water content in the granite magma as a result of stopping for much wallrock. Some of the granite contains granules of quartz (xenocrysts?) up to 10 millimeters in diameter. K-feldspar in this granite is highly perthitic. These relationships are compatible with the interpretation that the rocks here are near the contact between a xenolith-rich quartz syenite and the younger Ninemile granite (1500 m.y.).

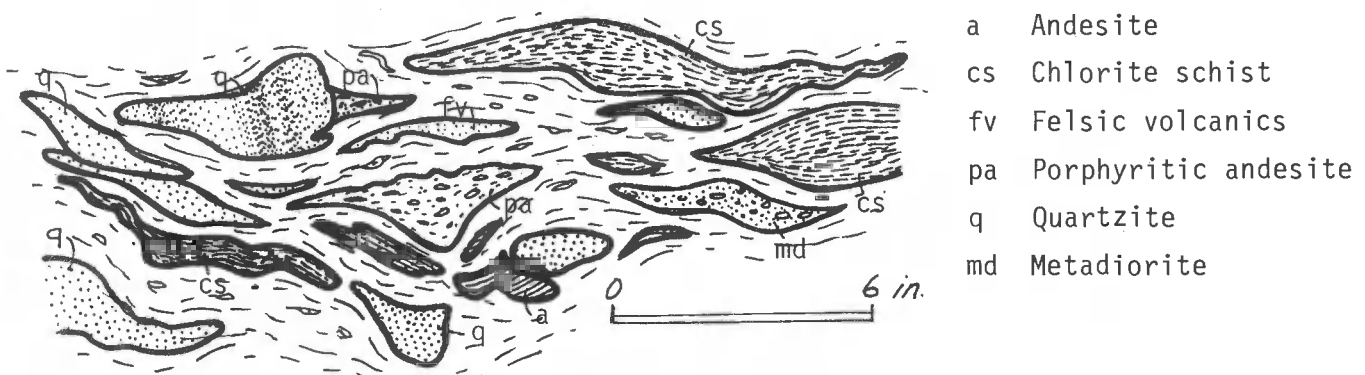


Figure 11-- Texture of deformed and metamorphosed polymictic conglomerate.

The matrix is foliated and micaceous with lenticular fragments of quartzofeldspathic rock (metavolcanic?), quartzite, and biotite. The clast lithologies indicate deposition near the contact between a cratonic terrane mantled by quartzite and a volcanic terrane. The volcanic portion of the conglomerate resembles those exposed nearby: the quartzite, however has no present nearby source. It is possible that the volcanics were overlain by platform quartzites, eroded, and then deformed first by flattening with development of foliation and then by close folding (Figure 12). These types of deformation are not seen in the greenschist facies metavolcanic and plutonic rocks of central Marathon County - the region surrounding the Wausau syenite complex.

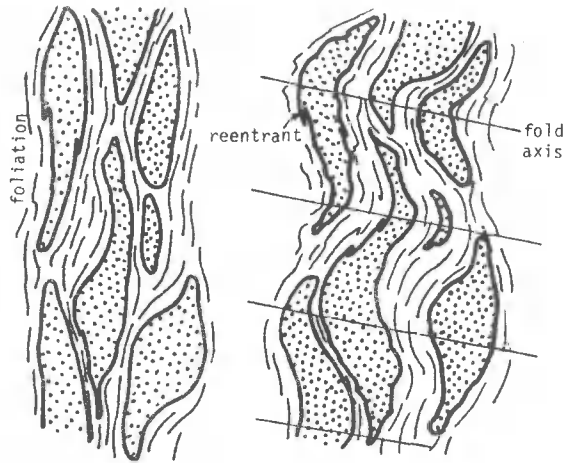


Figure 12- Sequence of deformation in the metaconglomerate. Foliation was probably developed during initial flattening of the quartzite clasts and later buckled by close-folding. Part of the chlorite was replaced by biotite during emplacement of the Rib Mountain pluton.

The absence of rocks showing these types of deformation and lithology favor the conclusion that they represent materials carried upwards during syenite emplacement.

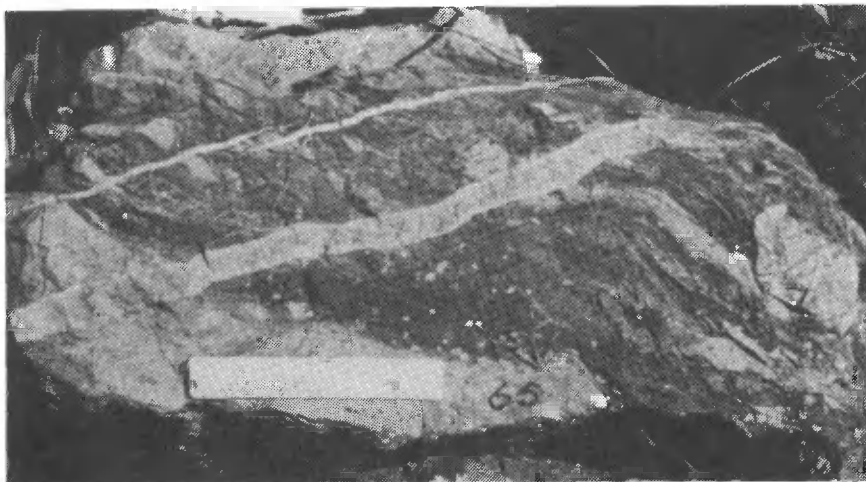
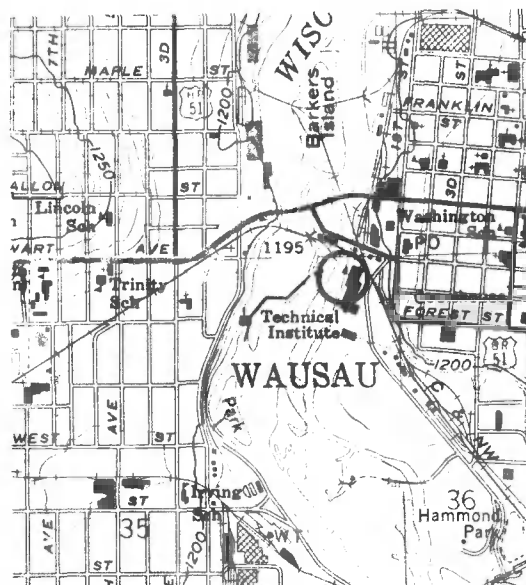
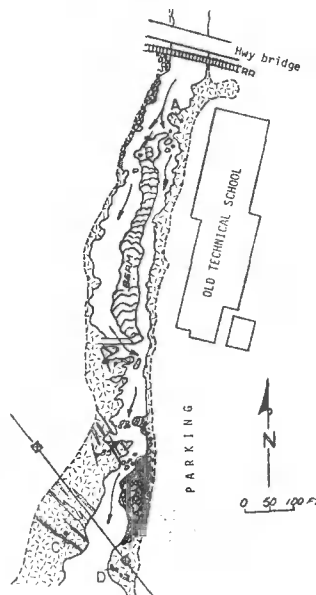


Figure 13-- Zoned dikes of aplitic Ninemile granite cutting foliated, schistose biotite metaconglomerate from Loc. 72065

STOP #5

TITLE: Border Phases of the Wausau Pluton

LOCATION: Wisconsin River at Old Technical Institute, Wausau. NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 35, T29N, R7E. Wausau 15' and Wausau West 7 $\frac{1}{2}$ ' quadrangles.



AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire

DATE: March, 1984

SUMMARY OF FEATURES:

Flow-lineated amphibole syenite containing sheet-like masses of syenitized siliceous metavolcanic rocks and mafic schist as well as blocky xenoliths of biotite amphibolite and metavolcanic rocks resembling those at Brokaw is well exposed along the overflow channel of the power dam in Wausau. Xenolith orientation is northwesterly here. The syenite is cut by zoned, rootless, steeply dipping pegmatite veins with quartz cores. Late fracture-filling veinlets of reibeckite are locally abundant.

DESCRIPTION:

Weidman's (1907, p. 203-208) "Wausau-type" quartz syenite is composed of alkali feldspars: orthoclase, microcline, albite, and microperthite and less abundant barkevikite, hedenbergite, fayalite, biotite, and quartz. Accessory minerals include fluorite, apatite, magnetite, zircon, and allanite(?).

Cross-cutting relationships here typify those seen throughout the Wausau pluton. Major components are described below in order of decreasing age.

1. The oldest rocks are xenoliths of schistose biotite amphibolite and slightly altered felsic metavolcanics resembling those at Brokaw. Sheet-like masses of siliceous and foliated mafic rocks occur on the south end of the exposure (Figure 14, Loc. C). These inclusions have a pronounced northwesterly strike and nearly vertical dip. This fabric is consistent with the concentric structure of the Wausau pluton northwest of here. A highly altered mafic xenolith at Location A (Figure 15) has swirled foliation and is cut by rootless pegmatite veins with K-feldspar walls and quartz cores. Some of the mafic volcanic xenoliths have relict porphyritic textures: mafic xenoliths are now biotite-rimmed subhedral crystals of hastingsite and ferrohastingsite (Figure 15, Loc. B).

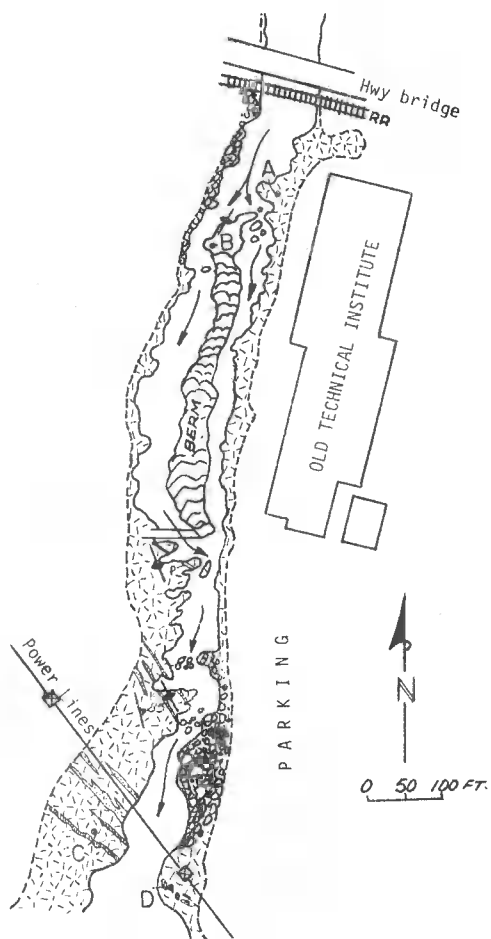


Figure 14-- Sketch map showing locations of points of interest



Figure 15-- Amphibolite (a) xenolith with swirled lineation and thin seams of syenite (Loc. A, Fig. 14). Pegmatitic veins have K-feldspar (Kf) cores and quartz (q) cores. Late fracture-filling veins are filled with coarse laths of sodic amphibole. Biotite and amphibole in amphibolite are about the same composition as those in the enclosing, flow-lineated syenite (determined by microprobe). Bar scale in sketch is 6 inches long. View is oblique toward northwest.

2. An early, flow-laminated, foliated quartz syenite containing lenticular xenoliths of porphyritic felsic volcanic rocks and biotite amphibolite with relict mafic phenocrysts is exposed at Location B.
3. Coarse-grained, flow-lineated amphibole quartz syenite cuts the fine-grained phase (Loc. B) with sharp discordance. Although the lensoidal and tabular inclusions in this rock show a northwesterly orientation, the enclosing syenite shows highly discordant flow lineation with swirls and eddies suggesting considerable turbulence and viscosity. Considering the lack of deformation in the sheets of biotite amphibolite and siliceous metavolcanic rock in this syenite, a model requiring turbulent flow in the enclosing syenite magma runs into trouble. The appearance of discordance may be produced by obliquity of lineation with respect to the eroded rock surface.
4. Late-stage, rootless" granite pegmatite veins with quartz cores probably represent residual liquid segregations along incipient thermal contraction fractures in the crystallized syenite. The pegmatites may derive from unassimilated siliceous rocks, possibly feldspathized quartzites.
5. Coarse, sodic amphibole (arfvedsonite and riebeckite) crystallized along fracture surfaces, and appear to cut all other structures.

At Location B, mafic and felsic xenoliths are aligned N10W, vertical in a medium-grained tabular syenite with a fabric similar to that seen in the margin of the Stettin pluton. This rock is cut discordantly by coarse gray amphibole

syenite. Thin, lenticular aplite veinlets have an orientation of N75°W, 40°S. These shallow dips are common in granitic pods and veinlets in the syenite.

The sheet-like, foliated biotite amphibolite at Location C has the appearance of a dike (Figure 16), but its contacts are highly convoluted, and foliation is deformed, although it is also locally cut by the syenite. The cusped edge of the amphibolite sheet has wisps which tail out into the syenite (Figure 17). The trace of lineation on the rock surface gives the impression of sharp discordance between the amphibolite sheet and the lineated syenite. Irregularities in the shape of the syenite-amphibolite contact can give the impression that the amphibolite contains syenite inclusions (Figure 18). The same amphibolite sheet on the east side of the channel at Location D is broken into angular fragments which can be fitted back together again. It is therefore apparent that the mechanical behavior of the amphibolite in the syenite varied significantly over short distances.

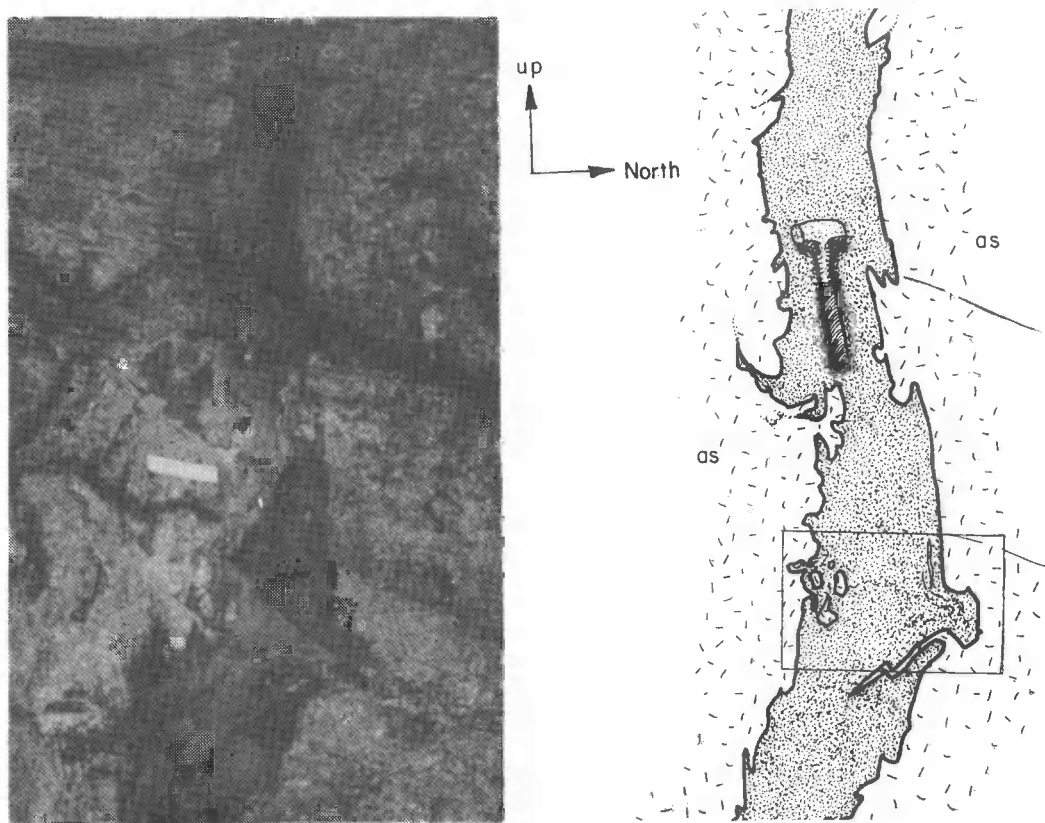


Figure 16-- Deformed, foliated biotite amphibolite sheet in amphibole syenite at Location C. Is it a dike which was intruded at an early stage of syenite crystallization, then carried to its present location during intrusion of a syenitic crystal mush?

Slight, but probably significant differences in mineral chemistry can be seen when amphibole and biotite compositions in various inclusions are compared to their composition in the coarse and fine grained varieties of the amphibole syenite. Table 2 is a compilation of microprobe data for these minerals as well as plagioclase, which is a persistent accessory mineral in the syenite and in the inclusions.

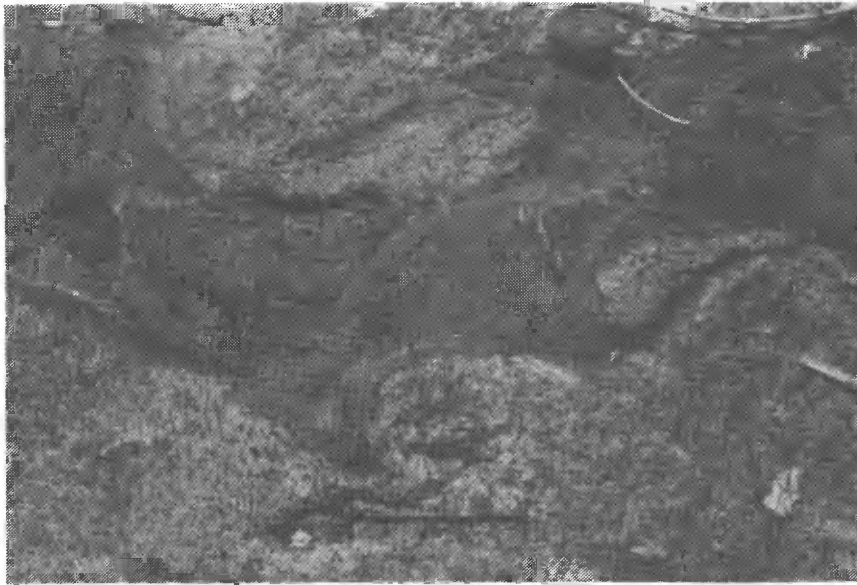


Figure 17-- Cuspate edge of foliated, sheet-like mass of biotite amphibolite in lineated amphibole syenite. Location C. Bar scale is 6 inches long.

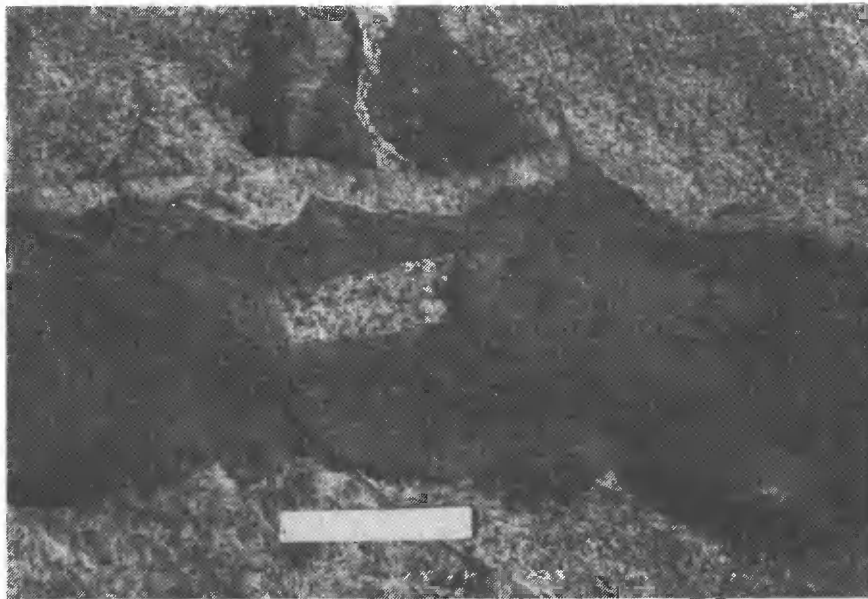


Figure 18-- Pseudoxenolith of syenite in biotite amphibolite at Location C.

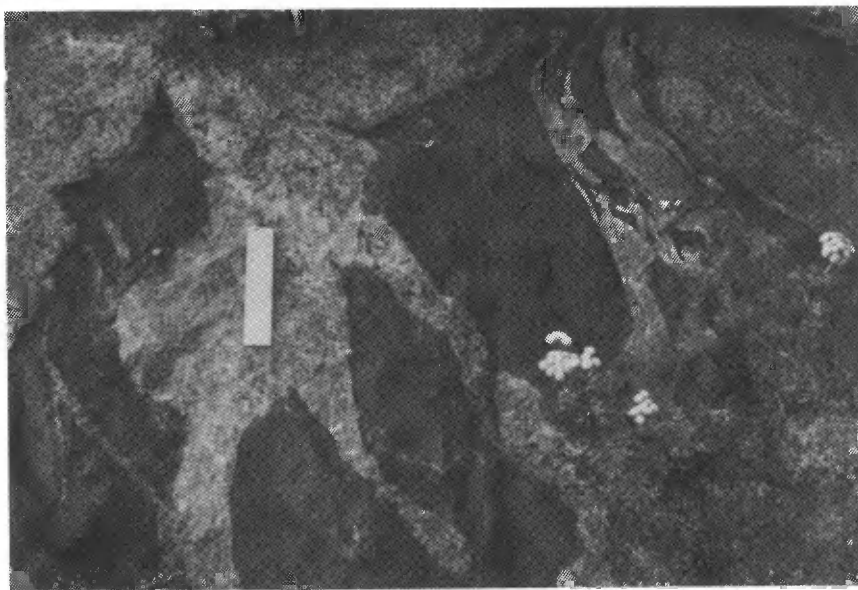


Figure 19-- Segmented biotite amphibolite sheet in lined, coarse-grained amphibole syenite. Location D. Rule is six inches long.

TABLE 2
ELECTRON MICROPROBE ANALYSES OF MAJOR MINERALS IN SYENITES AND INCLUSIONS AT FIELD TRIP STOP #5

AMPHIBOLES											
	SiO ₂	TiO ₂	Al ₂ O ₃	FeO + Fe ₂ O ₃	MgO	CaO	MnO	Na ₂ O	K ₂ O	TOTAL	DESCRIPTION
A/4*	43.30	1.44	6.64	28.84	3.60	9.93	0.99	2.24	1.03	98.01	Green amphibole in foliated biotite amphibolite xenolith in syenite
B/3	42.07	1.40	6.32	32.55	1.56	9.28	0.69	2.24	1.16	97.27	Medium-grained, early phase amphibole syenite: green amphibole
D/6	43.20	1.54	6.35	29.63	2.75	9.72	0.79	2.32	1.14	97.44	olive green to olive brown amphibole in lined amphibole syenite
G/5	42.20	1.77	8.14	25.92	5.03	10.79	0.62	2.12	1.23	97.82	green amphibole in brown biotite clots or plagioclase
H/2	41.32	1.36	8.10	29.04	2.76	10.63	0.81	1.89	1.32	97.23	Green amphibole in lined, coarse-grained amphibole syenite, late phase
BIOTITES											
A/2	35.54	3.77	11.67	31.07	4.34	0.02	0.45	0.04	9.10	96.00	Yellow-brown with metamict zircon in green amphibole: amphibolite xeno.
B/1	35.29	3.34	11.43	35.77	1.93	0.04	0.35	0.00	8.93	98.08	Olive brown with apatite in green amphibole clusters
D/4	36.39	2.36	10.96	32.87	3.65	0.14	0.27	0.01	8.98	95.84	Yellow-brown anhedral biotite with fluorite in green amphibole
G/5	35.96	3.62	12.36	27.14	6.70	0.02	0.34	0.06	9.21	95.41	Yellow-orange to orange-brown folia in biotite-amphibole schist
H/2	35.64	3.49	12.82	30.74	3.91	0.02	0.52	0.02	9.19	96.35	Ragged yellow-brown with green, anhedral amphibole and fluorite
PLAGIOCLASE FELDSPAR											
D/2: 1.73%An G/3: 10.24-18.41%An Avg. 13.12%An H/3: 8.83-12.44%An Zoned Plag. = 10.68-8.67%An.											
Sample Locations: Samples A and B are from Location B in Figure 14: Sample G is from Location C, and H is from Location D in Figure 14.											

* Field number/number of analyses averaged

TITLE: Contaminated Amphibole Quartz Syenite - Wausau Pluton
LOCATION: Old quarry behind Employers' Mutual Insurance Company offices,
NW/4, SE/4, Sec. 27, T 29 N, R 7 E; Wausau West 7.5' Quadrangle
AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire
DATE: April, 1984
DESCRIPTION:

Coarse pink and brownish gray amphibole quartz syenite is well exposed in relatively fresh faces of an old quarry along a road leading into the offices of Employers' Mutual Insurance Company. Four facies were recognized: (1) brownish gray quartz-bearing syenite, (2) coarse, dark gray amphibole syenite, (3) pink quartz syenite with abundant volcanic xenoliths, and (4) medium-grained pinkish brown to brownish gray amphibole quartz syenite with magnetite segregations. (See Table 3). The pink syenites have a distinctly higher Fe^{3+}/Fe^{2+} ratio than the gray syenites. Magnetite sheets and irregular masses occur in the medium-grained syenite along the road on the east side of the outcrop. The magnetite-bearing quartz syenite forms a large, crescentic aeromagnetic anomaly on the map by Henderson, Tyson, and Page, (1963). The anomaly is concentric and concordant with the structure of the Wausau pluton.

The concentric structure of this pluton is accentuated by the occurrence just north of here on the tree-covered hillside of numerous, large quartzite xenoliths. Unlike the Rib Mountain quartzite xenolith, this mass comprises many smaller quartzite blocks. Orientation of xenoliths here and elsewhere in the Wausau pluton is concentric and nearly vertical - a factor strongly suggesting subvolcanic emplacement with successive collapse and intrusion of magma into concentric fracture systems of the caldera rim. The xenoliths at this location are quite unlike those anywhere else in the Wausau pluton: they consist almost entirely of felsic volcanics showing virtually no pre-intrusion metamorphism. (See Figure 20).

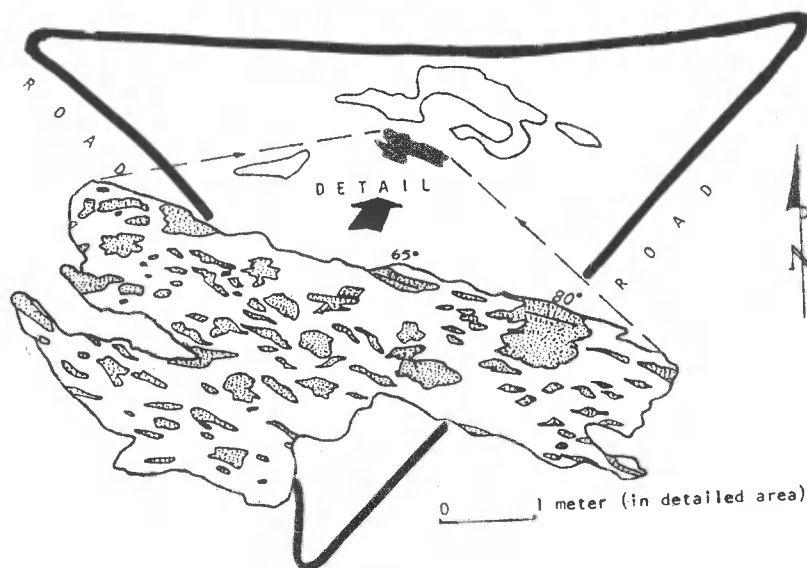


Figure 20-- Felsic volcanic xenoliths (dotted) in flow-lineated amphibole quartz syenite.

TABLE 3

Bulk chemical compositions of the four principal quartz syenite facies from Employers' Mutual Insurance Company Quarry.

	EW-3 (WEST)	EW-5 (EAST)	NSI (SOUTH)	SEI (NORTH)
Description →	Brownish-gray	Coarse, dark gray	Pink syenite, with volcanic xenoliths	Medium-grained syenite
SiO ₂	63.05	63.55	63.90	64.10
TiO ₂	0.78	0.54	0.47	0.48
Al ₂ O ₃	12.60	15.16	14.14	15.17
Fe ₂ O ₃	1.91	1.25	5.42	4.58
FeO	7.72	3.48	1.32	1.44
MnO	0.34	0.16	0.14	0.12
MgO	0.41	0.16	0.45	0.09
CaO	2.66	1.72	1.35	1.50
Na ₂ O	4.80	5.52	6.32	5.17
K ₂ O	4.22	5.67	6.34	5.57
H ₂ O	0.76	0.42	0.56	0.26
P ₂ O ₅	0.22	0.06	0.05	0.06
CO ₂	0.28	1.92	0.62	0.09
BaO	0.094	0.066	0.024	0.036
ZrO ₂	0.222	0.114	0.062	0.071
Rb	154	118	80	80
Sr ppm	78	83	67	42

In comparison with Nockolds' (1954) average syenite composition (see Table), these quartz syenites are richer in SiO₂ and total iron and poor in alkalis and lime. Their Rb and Sr contents are also low compared to other similar rocks.

* From Sood, Myers, and Berlin, 1980, p. 21

STOP #7

TITLE: Quartz-sillimanite-muscovite schist and quartzite xenoliths in quartz syenite of the Wausau pluton.

LOCATION: SE $\frac{1}{4}$, NE $\frac{1}{4}$, T29N, R7E; Wausau 15' quadrangle [Figure 6]

AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire

DATE: March, 1984

DESCRIPTION:

Xenoliths in the Wausau syenite pluton are mainly syenitized mafic and intermediate metavolcanic rocks. Felsic metavolcanic rocks are locally abundant, as at the old Technical School (Stop 5), and may represent portions of the volcanic cover sequence which collapsed and were stopped by the rising syenite magmas. Mica schist and quartzite are commonly associated in the intermediate zones of both the Wausau and Rib Mountain plutons and may represent samples of basement rocks which underlie the volcanic rocks. Considerable variation in lithology, size, shape, and relative abundance of xenoliths suggests mixing of basement and cover rocks by complex subsidence and resurgence of the syenite magmas at shallow depth. Not only is the concentric structure of these plutons expressed by compositional layering and orientation of xenoliths, but xenolithology shows a crude concentric zoning within each pluton.

The dominant lithology of xenoliths at this locality is sillimanite-bearing lineated, quartz-muscovite schist with a pronounced tectonite fabric (Figure 21).

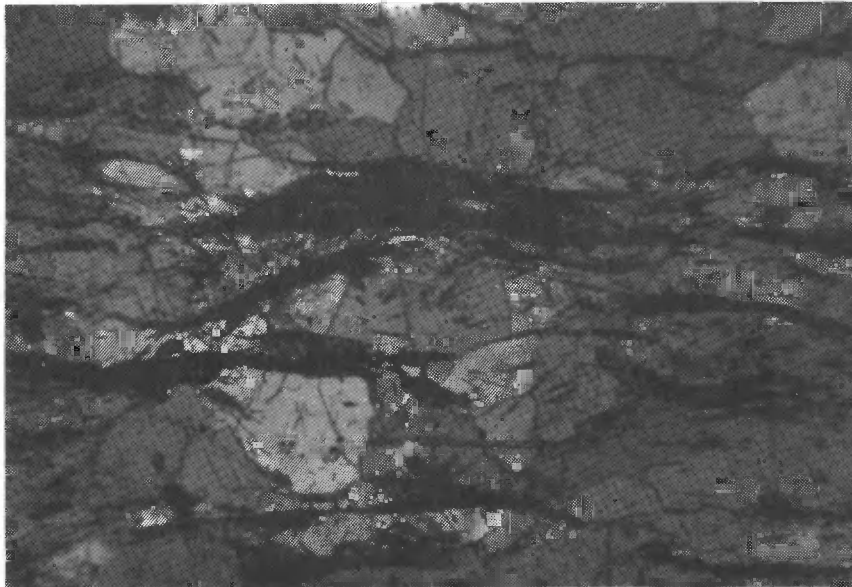


Figure 21-- Photomicrograph (with half-crossed polars) of quartz-sillimanite-muscovite schist. Elongated, polygonal quartz grains show similar extinction positions and elongation parallel to sillimanite tufts. Width of photomicrograph is 4.0 mm.

A nearby xenolith is coarse-grained which metaquartzite with sutured grains and no strain lamellae. Sillimanite is absent. This rock closely resembles the meta-quartzites of Rib Mountain. The strong contrast in the textures and mineral compositions of these two rocks suggests widely different origins. Although sillimanite can form metasomatically in metasomatic aureoles of granitic plutons, its occurrence here in a schistose rocks with a distinct tectonite fabric tends to rule out that possibility. (See Figure 22.)

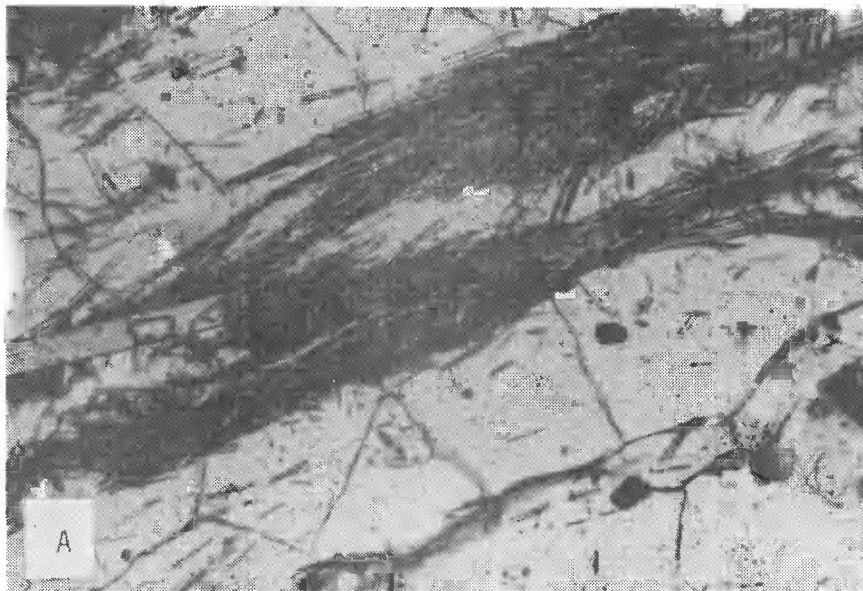
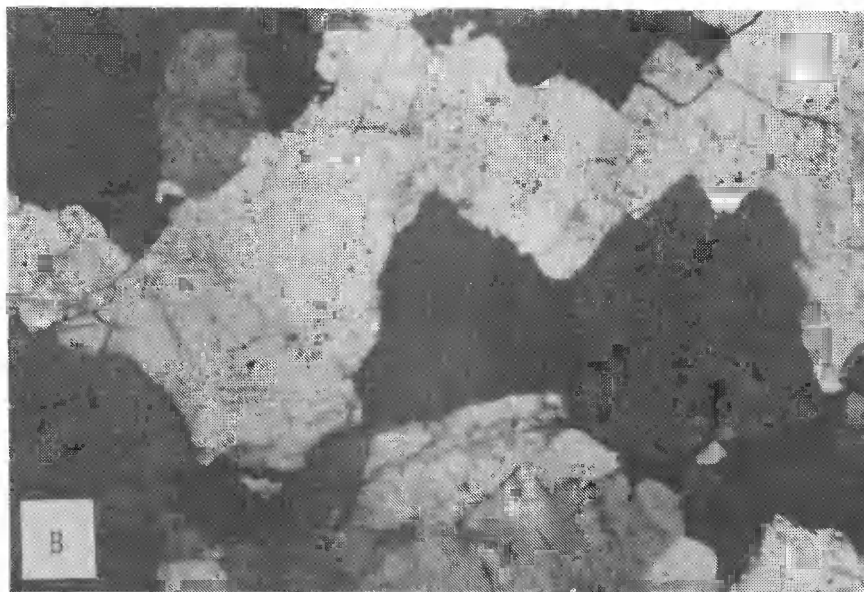


Figure 22-- Photomicrograph of quartz-sillimanite schist (A) and metaquartzite (B). Note sutured grain boundaries and lack of sillimanite in B. Width of image is 1.5 mm.

THE STETTIN SYENITE PLUTON

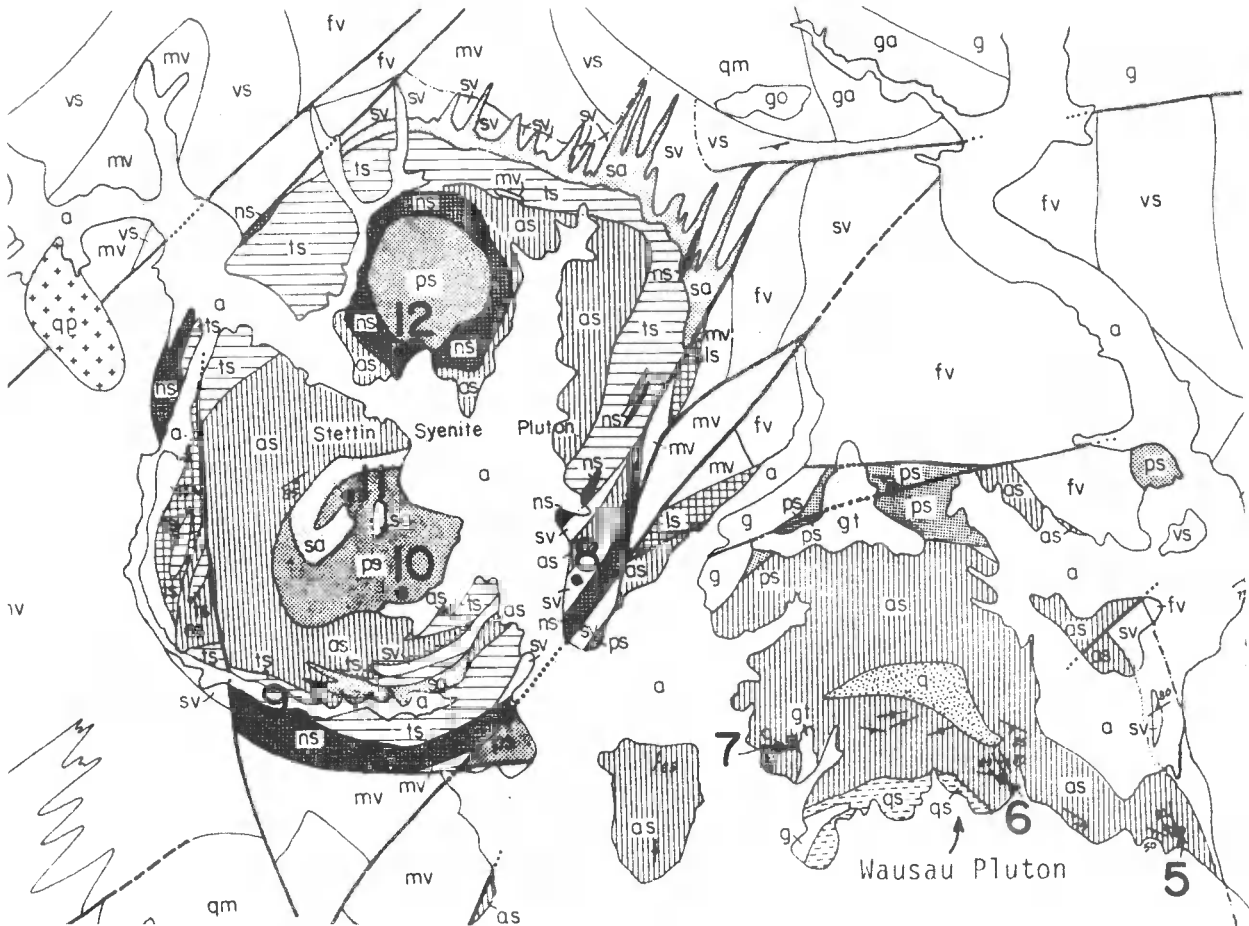


Figure 23-- Generalized geologic map of the Stettin syenite pluton. Excerpted from Figure 6 in this guidebook.

Although Weidman (1907) mapped the geology of north-central Wisconsin and paid special attention to the mineralogy of the syenites near Wausau, Emmons and Snyder (1944) hypothesized formation of the Stettin syenite body by metasomatism of feldspathic rocks along shear zones with alkali-rich solutions derived from a subjacent granite batholith. Turner (1948) studied the heavy accessory minerals and radioactivity of the Stettin pluton, and Geisse (1951) described the petrography of this pluton. Petrographic and geochemical investigation of the mafic minerals and nepheline of the Stettin pluton initiated analytical studies which have been extended by the work of Sood and Berlin (in Sood and others, 1980).

The concentrically zoned Stettin pluton (Figure 23) is oval in plan, elongated northeasterly, with a length of 5.5 miles and a width of 4.0 miles. Older volcanic rocks enclosing the pluton have been extensively syenitized. The eastern and southern margin of the pluton is a complexly laminated series of altered volcanic screens and pendants and various, contaminated intrusive phases of the syenite including nepheline syenite. The wall zone comprises a discontinuous outer rim of gneissic nepheline syenite, and an inner layer of tabular syenite (Stop #). The intermediate zone (Stops #6 and #7) is composed of amphibole and pyroxene syenite showing consider-

able variation in composition and texture. The amphibole syenite is commonly quartz-bearing. The core zone (Stop #8) is one mile in diameter and is located asymmetrically near the north end of the pluton. The core zone comprises a well-defined, cylindrical rim of indistinctly banded nepheline syenite surrounding a core of pyroxene syenite. Field relations indicate the following intrusion sequence: (1) pyroxene syenite, (2) nepheline syenite, (3) tabular syenite, (4) amphibole syenite. Numbers 3 and 4 could be reversed. This evidence is based wholly on field relations (Myers). It should also be emphasized that the intrusion sequence may not be the same as the crystallization sequence. Analytical work (Sood and Berlin, this guidebook) suggests a very late age for the nepheline syenite. (See discussion of petrochemistry beginning on page 31).

A summary tabulation of paragenetic relations of minerals in each zone of the Stettin syenite pluton is presented with modification from Koellner (1974) in Figure 27, p. 36.

The section on Mineral chemistry and petrology, originally contained in the 1980 Wausau field trip Guidebook #3 by Sood and Berlin has been excerpted unchanged and incorporated in this guidebook.

MINERALOGY AND MINERAL CHEMISTRY

(STOP NO's 8 through 12)

M.K. Sood, P.E. Myers, and L.A. Berlin

The principal mineral phases in Stettin Complex are perthitic feldspars, nepheline, sodic and calcic pyroxenes, and sodic amphiboles whose representative chemistry is given in Table and characteristics described below:

Feldspars

The major phase of feldspar is a microperthite in uniform veins showing parallel, subparallel, or wavy lamellar intergrowths, or as patches of one feldspar in the host. Both perthite and antiperthite are present, although perthite is more common than antiperthite. Frequently the tabular feldspar grains exhibit Carlsbad twinning and less commonly Mannebach twinning. The perthitic feldspar constitutes 80 to 90 percent of the syenites and 60 to 75 percent of the nepheline syenites (Table 4).

Distinct grains of albite have an average extinction angle of 15° , but are not common in any of the syenites.

Microcline, also present as distinct grains, show its characteristic spindle-shaped polysynthetic twinning and wavy extinction, but is less abundant than albite as individual grains.

The bulk compositions of the perthitic alkali feldspars were determined for nine samples of three major zones of the Stettin complex. The samples were homogenized to a sanidine phase at 1050° in a muffle furnace for 48 hours; then $\Delta 2\theta = 201$ feldspar - 101 KBrO_3 $\text{CuK}\alpha$ was measured and the molecular percent orthoclase was determined using the homogenized natural microcline-low albite x-ray determinative curve of Jones *et al.* (1969) The compositions are given below in Table 4

Table 4

THE MOLECULAR PERCENT ORTHOCLASE OF HOMOGENIZED PERTHITIC ALKALI FELDSPARS OF THE STETTIN ROCKS

Sample	$\Delta 2\theta$ $\text{CuK}\alpha$	Mol % Or
<u>Core Zone</u>		
pyroxene syenite	1.40°	39
<u>Intermediate Zone</u>		
amphibole syenite	1.45	35
3 amphibole syenites	1.40	39
<u>Rim Zone</u>		
tabular syenite	1.43	37
nepheline syenite	1.35	44
nepheline syenite	1.39	41

The molecular percent orthoclase ranges from 35 to 44%; however, Or% is above 40% for the nepheline syenites and is less than 40% for the nepheline-free syenites.

The intensity ratios of the $\bar{2}01$ peaks of microcline and albite were determined for the perthitic feldspars by scanning in both directions between 20° and $23^\circ-20^\circ \text{ CuK}\alpha$ at $1/8^\circ-2^\circ$ per minute using 200 counts per full chart scale, a time constant of 5 seconds and a chart speed of 15 inches per hour. The angular positions were averaged from three scans. Then the goniometer was exactly centered on one peak at a time and the intensity was measured using a fixed time of ten seconds with a 2 second time constant. The background intensity was measured at the midpoint between the two peaks.

Then: A = number of counts on microcline $\bar{2}01/10 \text{ s}$
 B = number of counts on low albite $\bar{2}01/10 \text{ s}$
 C = number of counts on the background/10 s

The intensity ratio $I_o/I_a = (A - C)/(B - C)$.

The intensity ratio and the value of the bulk composition of Or%/Ab% for each of the perthitic feldspars studied were plotted on the graph of Kuellmer (1959)(Figure 24).

From this diagram, implications can be made as to the temperature-structural state of the feldspars. From the plots a broadening ratio (B) is obtained.

The broadening ratio is a measure of the distortion or structural mistakes in the two phases of perthite. The broadening ratio will decrease with slower crystallization and lower temperature since these conditions are favorable for the attainment of an ordered arrangement of Si and Al ions in the tetrahedral sites of the feldspar structure (Smith, 1974).

The broadening ratios for the perthitic alkali feldspars of the Stettin rocks range from low ($B = 0.30$) to intermediate values ($B = 0.9$). This is an indication of the low temperature-structural state of these perthites, corresponding to the maximum to intermediate microcline-low albite series determined from the positions of the $\bar{2}04$ and 060 reflections.

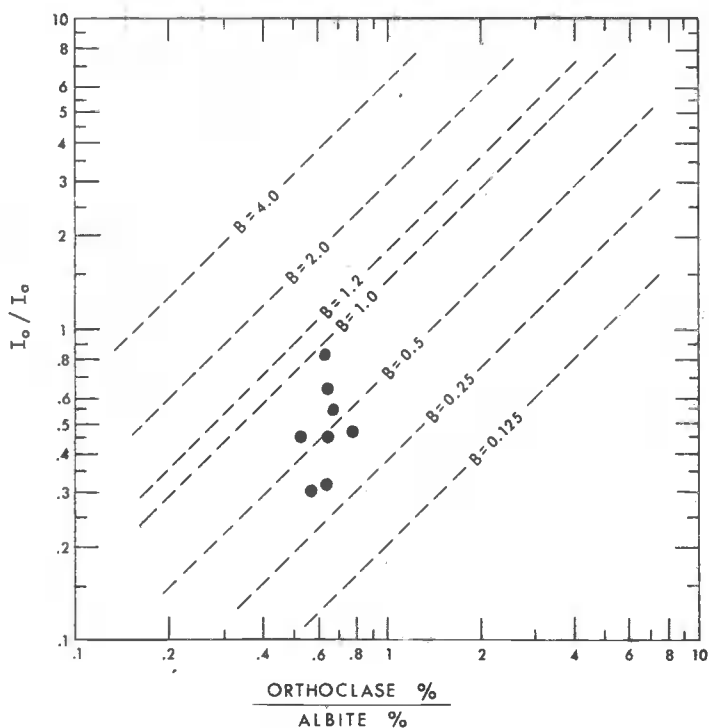


Figure 24-- Plot of bulk compositions Or%/ Ab% versus I_o/I_a for the $\bar{2}01$ reflections of the two feldspar phases in the Stettin perthite for determination of broadening ratios (B) after Kuellmen, 1959.

TABLE 5

ELECTRON MICROPROBE CHEMICAL ANALYSES OF MAJOR MINERALS OF STETTIN COMPLEX

	Feldspar		Amphiboles		Pyroxene*			Nepheline*	Fe-Ti Oxides
					nsy	psy	tsy		
SiO ₂	67.42	68.23	40.45	39.90	48.1	50.1	50.8	46.5	0.44
Al ₂ O ₃	19.23	19.72	8.70	9.28	1.0	0.59	1.34	33.1	0.25
TiO ₂	--	--	3.17	1.31	0.1	0.26	0.30	--	7.57
FeO	--	--	29.1	34.22	26.8	23.70	26.40	0.18	90.40
MnO	--	--	0.81	1.00	1.52	0.89	0.71	--	1.19
MgO	--	--	2.28	0.73	0.62	4.41	0.99	--	--
CaO	0.44	0.25	10.3	8.89	17.8	20.30	11.00	0.13	--
Na ₂ O	7.40	11.23	2.14	3.30	2.40	0.57	6.80	15.20	--
K ₂ O	6.39	0.27	1.57	1.75	--	N.D.	N.D.	5.46	--

ATOMIC PROPORTIONS									
	Feldspars Based on 8 oxygens		Amphiboles Based on 23 oxygens		Pyroxene* Based on 6 oxygens			Nepheline* Based on 32 oxygens	Fe-Ti Oxides Based on 24 oxygens
Si	2.987	2.988	6.73	6.43	2.001	1.990	2.074	8.76	0.119
Al	1.004	1.018	1.52	1.76	--	0.010	--	7.352	0.079
Al	0	0	0.118	0	0.42	0.017	0.064	--	1.530
Ti	--	--	0.372	0.147	0.004	0.008	0.010	--	20.310
Fe	--	--	3.89	4.61	0.930	0.786	0.902	0.29	0.272
Mg	--	--	0.515	0.172	0.38	0.261	0.060	--	--
Ca	0.021	0.012	1.765	1.536	0.797	0.862	0.480	0.27	--
Na	0.635	0.954	0.690	1.031	0.194	0.044	0.538	5.52	--
K	0.361	0.015	0.323	0.361	--	--	--	1.315	--
Ar					16.0	3.9	47.3		
Di					3.5	25.2	5.3		
Hd					75.1	60.8	42.8		

* From Koellner (1974)

Nepheline

Nepheline is characterized by its subhedral to euhedral, rectangular, blocky form and parallel extinction in thin section. Nepheline syenite pegmatites contain nepheline crystals up to 5 cm long. In hand specimen the nepheline is pinkish and greasy in appearance. Alteration leaves gray, etched surfaces of negative relief against feldspar and quartz. Cancrinite is common at STOP 8, and paragonite has been reported. Koellner (1974) reports that the nephelines from the Stettin pluton are enriched in Si by about 15% and deficient in alkalis by about 13%.

Pyroxenes

Both sodic and calcic clinopyroxenes occur in the Stettin pluton. Representative chemical compositions are given in Table 5 above. Aegirine and aegirine-augite may or may not be rimmed by sodic amphiboles. Some are color zoned with bright green rims and pale yellowish green cores. Average extinction angles of pyroxene cores is 28°, whereas that of the rims is 13 to 24°. This suggests an outward increase in aegirine content. Calcic pyroxenes (diopside-hedenbergite) are iron-rich with aegirine content up to 10% (Koellner, 1974). In general, Na + Fe³⁺ is highest in the wall zone. See photomicrograph, Figure 24.

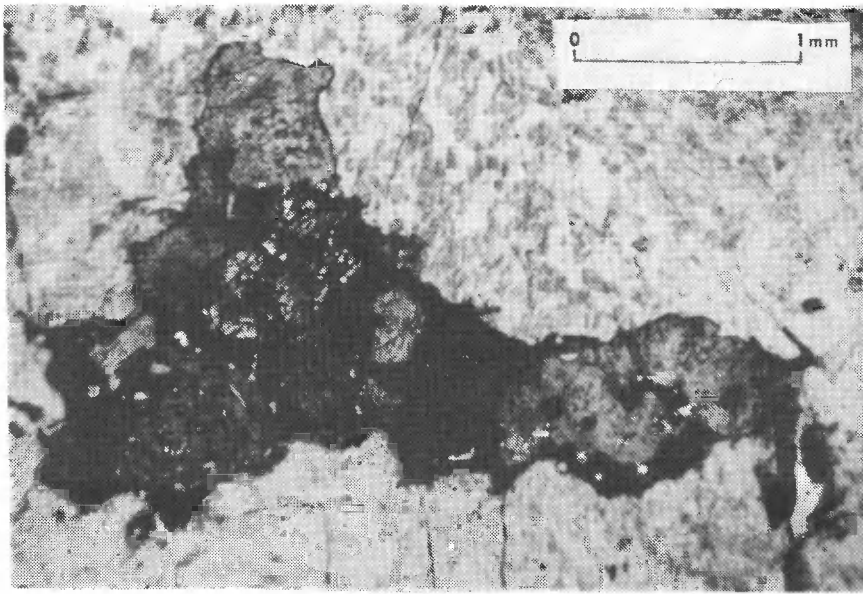


Figure 25-- Photomicrograph of pyroxene syenite. Zircon crystals (left of center) surrounded by dark arfvedsonite and aegirine-augite. Mafic cluster enclosed in stained alkali feldspar. Plane polarized light.

Amphiboles

The dominant mafic mineral is a bluish green sodic amphibole with an absorption scheme closely resembling arfvedsonite: X = bluish green or greenish blue; Z = greenish brown or light brown. Average extinction angle is 16° . Late blue amphibole is riebeckite with absorption scheme: X = deep blue; Z = light blue. Extinction angle of these grains is very low. X-ray diffraction powder patterns of the riebeckite give 8.42Å for the $[110]$ reflection compared to 8.50Å for arfvedsonite $[110]$ reflections. All of the amphiboles are iron-rich.

Biotite

Two varieties of biotite occur sparsely in the Stettin pluton: dark orange-brown, and light olive green to brown. This indicates two genetic associations of biotite with bimodal partitioning of Ti, Fe^{2+} , Fe^{3+} , and Mn^{2+} . Electron microprobe analysis of biotites from the Stettin pluton by Myers shows the orange-brown varieties to be Ti and Fe^{3+} rich.

Accessory Minerals

Numerous accessory minerals have been identified. They include zircon, fluorapatite, fayalite, magnetite, sphene, fluorite, calcite, cancrinite, allanite, pyrochlore, and many others.

Modal compositions of Stettin rocks are included in Table 6. (from Koellner, 1974).

TABLE 6
MODAL COMPOSITIONS OF THE STETTIN ROCKS

ROCK TYPE	INTERMEDIATE ZONE				CORE ZONE	WALL ZONE			
	Amphibole Syenite				Pyroxene Syenite	Tabular Syenite	Nepheline Syenite		
SAMPLE NUMBERS*	10	77	503	108	6 and 504	65	46	2	92
Quartz	7.1	6.6	2.9	1.4					
Nepheline							26.4	17.6	6.6
Perthite	80.7	83.5	90.3	83.0	87.4	80.2	63.6	75.7	61.4
Albite	0.5		0.2						
Amphibole	11.2	8.6	5.1	13.6	5.5	19.1	8.4	4.6	29.5
Pyroxene				0.6	4.1				
Biotite	0.2				0.5	0.2	0.6	0.4	0.4
Biotite (alter.)		0.6	0.3	0.5					
Zircon		0.2	0.2	0.1	0.7				
Apatite					0.1				
Fluorite	0.2		0.5						
Calcite				0.3	0.1				
Sphene									1.1
Opaque minerals	0.1	0.1	0.3	0.2	1.3	0.1	1.0		0.5
Alteration		0.4	0.2	0.3	0.3	0.4			0.5

from Sood, Myers, and Berlin, 1980, p. 28.

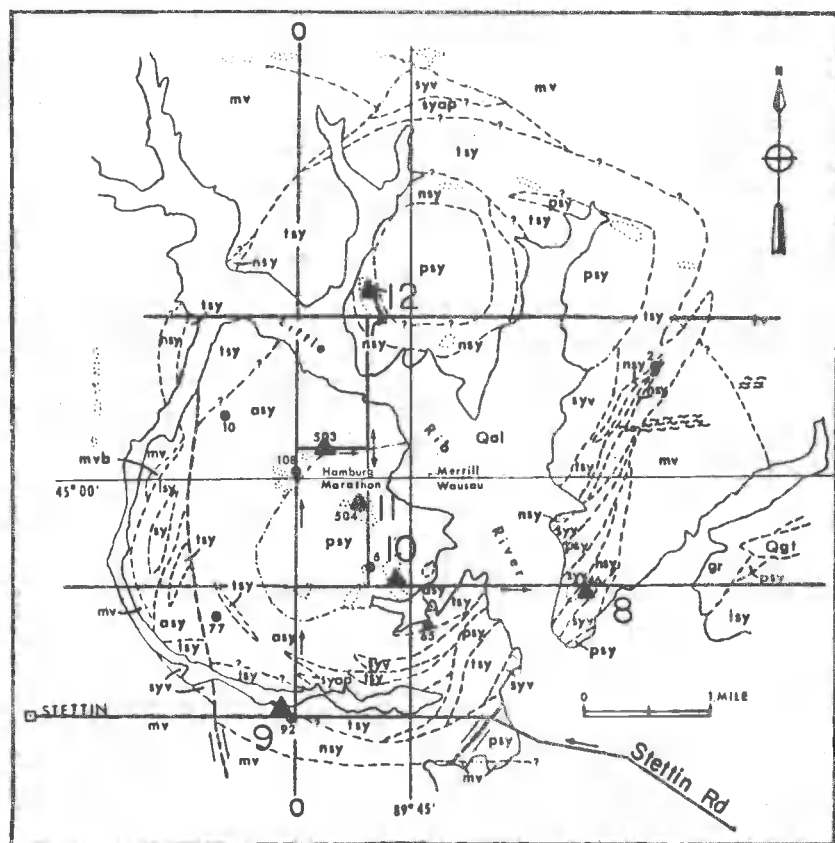


Figure 26- Geologic map of the Stettin complex (after Myers, 1973) including localities of samples and field trip stops.

FIGURE 27
PARAGENETIC RELATIONS OF MINERALS IN EACH ZONE OF THE STETTIN PLUTON

	ROCK TYPE	CRYSTALLIZATION SEQUENCE
<div> <div>WALL ZONE</div> <div>CORE ZONE</div> <div>INTERMEDIATE ZONE</div> </div>	TABULAR SYENITE (Myers, 1973)	<div>zircon</div> <div>pyroxene</div> <div>alkali feldspar</div> <div>opaques</div> <div>green amphiboles</div> <div>biotite</div>
	NEPHELINE SYENITE (Koellner, 1974, p. 12)	<div>nepheline</div> <div>alkali feldspar</div> <div>olivine</div> <div>pyroxene</div> <div>opaques</div> <div>green amphiboles</div> <div>biotite</div>
	PYROXENE SYENITE (Koellner, 1974, p. 12)	<div>alkali feldspar</div> <div>apatite</div> <div>opaques</div> <div>olivine</div> <div>pyroxene</div> <div>green amphibole</div> <div>biotite</div> <div>carbonate</div> <div>blue amphibole</div>
	AMPHIBOLE SYENITE (Koellner, 1974, p. 33)	<div>alkali feldspar</div> <div>apatite</div> <div>opaques</div> <div>pyroxene</div> <div>green amphibole</div> <div>biotite</div> <div>blue amphibole</div>

STOP #8

TITLE: Nepheline syenite and syenitized volcanic rocks, Stettin pluton wall zone

LOCATION: County Highway U on hill crest 0.5 mile east of Little Rib River; SW, SW, Sec. 18, T29N, R7E; Wausau 15' quadrangle. (See Fig. 6).

AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire

DATE: April, 1984

SUMMARY OF FEATURES:

Intrusion of the Stettin pluton was accomplished by peeling slices away from the cylindrical walls and carrying them upward while causing much metasomatic alteration through the addition of alkalis and alumina. The border phases and alterations typical of the eastern border of the Stettin pluton are well exposed along the highway at this location.

DESCRIPTION:

The dominant rock types at this location are: (1) pyroxene, amphibole, and olivine-bearing nepheline syenite pegmatite, and variously syenitized mafic volcanic rocks. Many hybrid types are present also. Through addition of K, Na, and Al the volcanic rocks were converted locally to aplitic rocks composed of sodic amphibole(s), biotite, and alkali feldspar (perthite). The altered volcanic rocks have a characteristic splotchy or streaked appearance owing to local variation in mineral proportions: fine-grained K-feldspar imparts a pinkish color to the altered portions of the volcanic rocks, and primary pyroxenes are altered to Na-Fe pyroxenes.

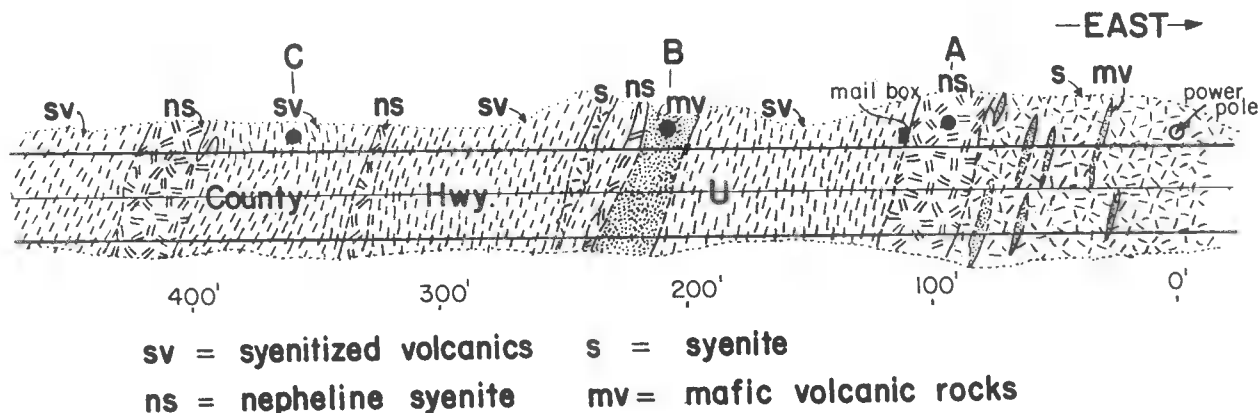


Figure 28-- Geologic strip map along County Highway U.

The nepheline syenite pegmatite at Location A (Figure 28) is composed of very coarse subhedral grains of ribbon perthite and 1 to 2 centimeter subhedral crystals of pinkish, altered nepheline (10-20%). Dark mineral is mainly dark green to yellow green amphibole. Accessory minerals are zircon, apatite, and monazite.

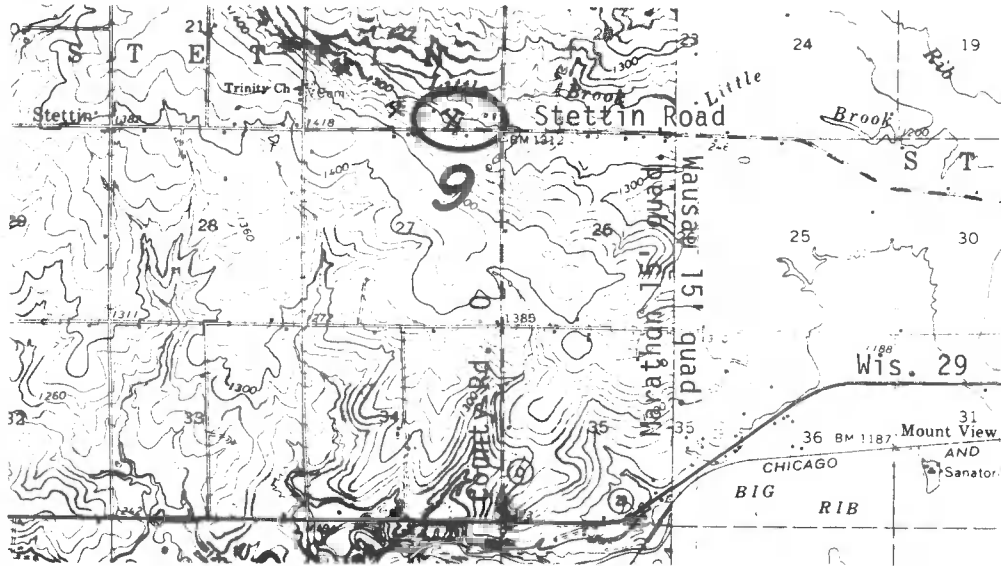
The mafic volcanic rocks at Location B are composed of plagioclase, perthitic alkali feldspar, green amphibole, brown biotite, and anhedral epidote. It is locally cut by syenite veinlets.

Syenitized volcanic rocks at C have dark areas of residual mafic rock now composed of anhedral green amphibole (X = dark yellow green; Z = dark olive green to brown) clustered with subhedral blue-gray amphibole (riebeckite) and clots of pale yellow-green epidote. Brown biotite occurs in coarser varieties.

STOP #9

TITLE: Contact relations and minerals in the Wall Zone, Stettin syenite pluton

LOCATION: County Highway 0 at 10146 Stettin Road, Paul Knopp property, SE $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 22, T29N, R6E, Marathon 15' quadrangle, (Sample Location 92)



AUTHORS: P.E. Myers and M.K. S6od

DATE: February 1973, February 1980

SUMMARY OF FEATURES:

The outermost rim of the Stettin pluton is gneissic nepheline syenite composed mainly of alkali feldspar, perthite, nepheline, aegirine, sodic amphibole and biotite. It is in sharp contact with, and veined by, tabular syenite composed of coarse, well-oriented laths of perthite, sodic amphibole, pyroxene, and lensoidal mafic inclusions composed essentially of the same minerals but in different proportions and of finer grain size. The mafic inclusions are well-oriented parallel to the tabular fabric of the enclosing syenite and to the wall of the pluton. They contain large perthite porphyroblasts of similar composition and size as those in the enclosing syenite. Zircons were mined at this site in the 1950's. Zircons from this site have given a U/Pb age of 1520 ± 20 m.y. by W.R. Van Schmus (oral communication).

The chief questions to be answered at this site are: (1) how were the nepheline syenite and tabular syenite emplaced, and (2) to what extent is the present mineral assemblage a result of metasomatic replacement?

The abundance of zircon and hastingsite amphibole, biotite and carbonate indicates a miaskitic trend for the nepheline and pyroxene syenites. The compositions of the nepheline and pyroxene syenites are very similar (Table 6). According to Koellner (1974, p. 144) the amphibole syenite is agpaitic and could contain a carbonatite body.

DESCRIPTION:

The nepheline syenite (Figure 30, Tables 6 and 7) is a gray, banded rock composed here of perthitic feldspar nepheline, olivine, pyroxene, magnetite, amphibole, and biotite. Contorted aplitic and pegmatitic bands lie roughly parallel to the wall of the pluton about 1500 feet south of here. The nepheline occurs as blocky, pinkish grains which weather much more readily than the associated minerals, giving the rock a characteristic pitted appearance. Nepheline is partially altered to cancrinite and iron oxides. Banding, and mafic content of the nepheline syenite increase outward toward its contact with syenitized mafic volcanics which trend west-northwesterly. In addition to the essential minerals listed above, common accessory minerals include zircon and sphene of unusually large size and abundance, apatite, fluorite, allanite, sodalite, pyrochlore and thortogummite(?). U/Pb dating of the zircons from this site by S. Goldich (oral communication) gave a minimum age of 1400 m.y. More recent analyses of these zircons by W.R. Van Schmus yielded a U/Pb age of 1520 ± 10 m.y. Thus, the Stettin syenite is about 20 million years older than the Wolf River Batholith (oral communication).

The gneissosity and isoclinal folding exhibited by the gneissic nepheline syenite of the wall zone on the south side of the Stettin pluton suggest considerable differential movement of material along its outer wall. The extent to which metasomatism was involved during and after emplacement is not known. However, metasomatism was extensive, and that the nepheline syenite may consist in large part of metasomatized wall rocks.

Zircon from this locality is deep red-brown, doubly terminated euhedral prisms up to 14 mm in length. Some crystals display geniculate twinning similar to that of rutile. Chemical analyses of three zircons from a nearby site (NW $\frac{1}{4}$ of Sec. 22) by F.B. Hall (in Weidman, 1907, p. 313) indicates an Al_2O_3 content of between 4.28 and 7.80 percent and an Fe_2O_3 content between 1.21 and 4.47 percent. Ca, Ti, Th and rare earths were sought but not detected.

Brown pyrochlore octahedra up to 2 mm in diameter were found at this location by Weidman (1907, p. 308-309).

Allanite is confined mainly to pegmatitic portions in the nepheline syenite.

Apatite and sphene of unusually large size show affinity for clusters of mafic minerals in the nepheline syenite. Large sphene crystals up to 7 mm in length can be collected from nepheline syenite lenses and masses near its contact with tabular syenite.

The tabular syenite (Figure 29, Tables 6 & 7) is composed dominantly of coarse laths of microperthite. Vein and patch type perthites predominate. Poikilitic amphibole (hastingsite) rims pyroxene (intermediate between acmite and hedenbergite according to Koellner (1974, p. 65). The tabular fabric (Figure 29) is characterized by a random orientation of perthitic feldspar tablets in a plane parallel to the outer wall of the pluton and parallel to the long dimensions of mafic inclusions. Perthitic feldspar tablets within mafic inclusions and across their contacts are identical to those in the enclosing tabular syenite. The inescapable conclusion is that the perthitic feldspar is at least partly of metasomatic origin. Veins of tabular syenite locally cut the nepheline syenite gneiss in the old quarry face at this location. Mafic inclusions comprise from 5 to 80 percent of the tabular syenite. As the volume of mafic inclusions increases, the mafic minerals, mainly sodic amphibole, become coarsely poikilitic. Individual amphibole grains up to 12 centimeters long were observed in a small roadside excavation 1.5 miles east-southeast of here. Although the mafic inclusions contain a much higher percentage of pyroxene and olivine than the enclosing tabular syenite, they are of about the same chemical composition.

The tabular syenite forms the outermost layer on the north and west sides of the Stettin pluton where the nepheline syenite is absent. The abundance of mafic inclusions increases outward in the tabular syenite, suggesting considerable contamination by the basaltic wallrock. A unit mapped as lensoidal syenite and a closely associated syenite aplite (Myers, 1973) are found locally where the nepheline syenite is absent. The lensoidal syenite is an aplitic, gneissose rock consisting of mafic inclusions rich in biotite enclosed in an aplitic syenite. The syenite aplite is similar in texture and mineral composition but relatively free of mafic inclusions.

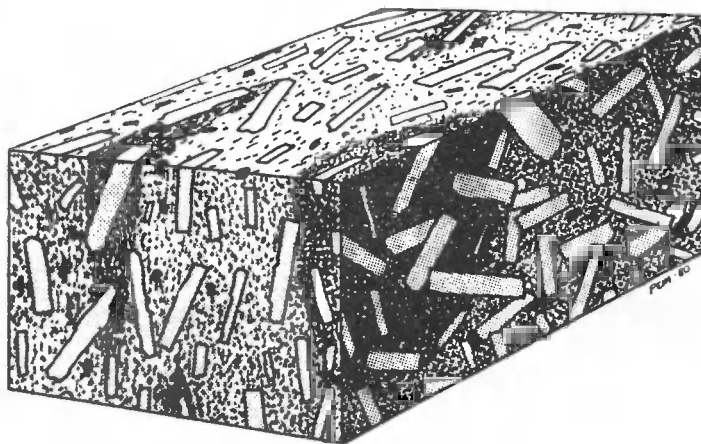


Figure 29 Typical fabric of tabular syenite showing coarse tablets of microperthite in random orientation parallel to the wall of the pluton. Microperthite laths in the lensoidal mafic inclusions tend to have a preferred orientation parallel to those in the enclosing syenite. Some of the laths crystallized across the edges of inclusions, thus indicating a metasomatic origin of at least part of the microperthite.

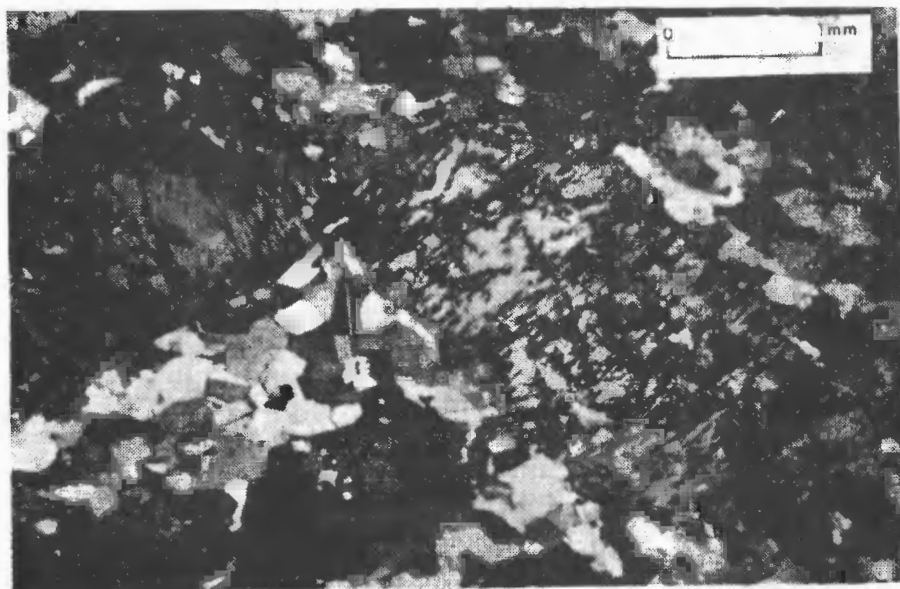


Figure 30-- Photomicrograph of nepheline syenite showing euhedral, rectangular nepheline surrounded by albite and green amphibole. Crossed polars.

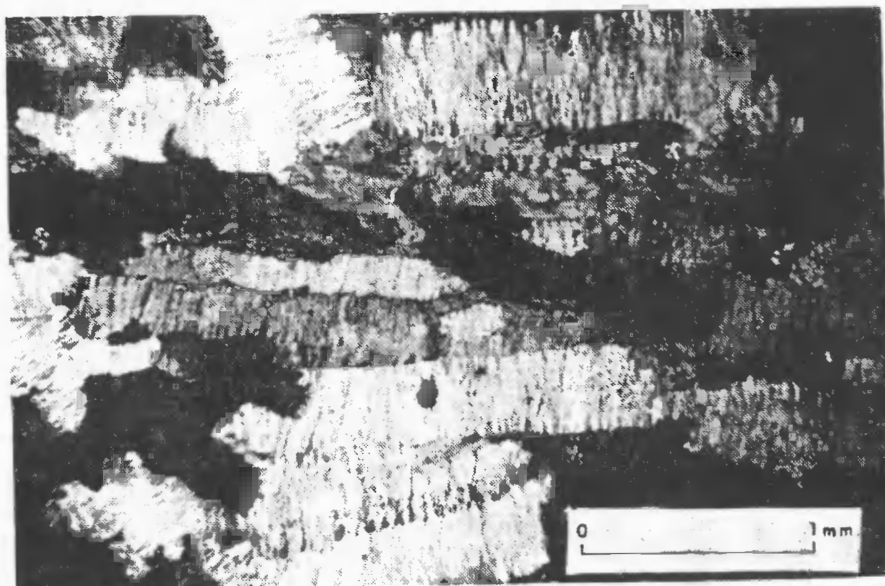
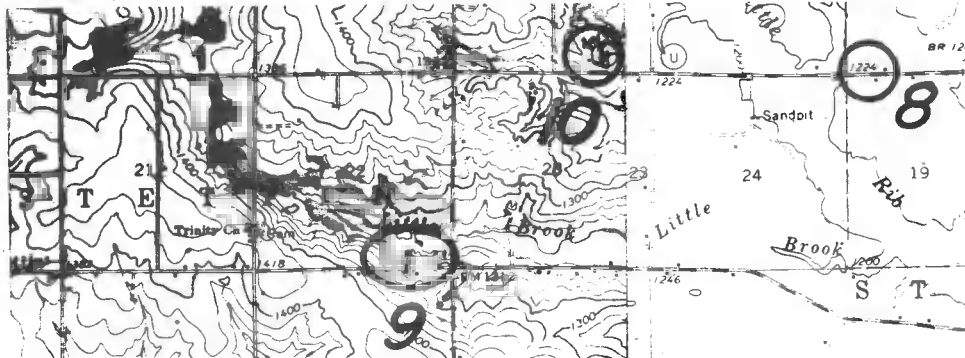


Figure 31-- Photomicrograph of tabular syenite showing parallel alignment of perthitic feldspar laths or tablets. Crossed polars.

STOP #10

TITLE: "Moonstone" dikes in pyroxene-amphibole syenite of Intermediate Zone of the Stettin syenite pluton.

LOCATION: North side of County Highway U, 0.7 miles east of County Highway O; SW $\frac{1}{4}$, SE $\frac{1}{4}$, Sec. 28, T29N, R6E; Marathon 15' quadrangle [See Figure 6]



AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire

DATE: April, 1984

DESCRIPTION:

Coarsely crystallized syenite pegmatite dikes containing perthitic feldspar crystals up to 35 centimeters long cut dark brownish gray amphibole-pyroxene syenite in this weathered roadside outcrop. The "moonstone" is characterized by a soft irridescence and brownish sheen imparted by close-spaced ribbon perthite lamellae. Interstitial poikilitic dark green to bluish green amphibole and dark greenish brown to green pyroxene occur both in the pegmatite dikes and enclosing syenite.

A large stone quarry in the woods just north of here was operated sporadically until about 20 years ago by Mr. Gilbert Schultz who is, incidentally, disturbed when rockhounds invade his quarry without permission. he quarry has vertical rock walls and is filled with deep water - DANGEROUS! The syenite in this quarry is predominantly massive, coarse-grained, medium brownish gray syenite composed of perthite laths with poikilitic amphibole and very subordinate green pyroxene. Pegmatite dikes exposed in the Schultz Quarry are nearly vertical, reach 0.7 m width, and show a distinctive "comb structure" (Figure 32). Interstitial amphiboles are coarser in the dikes, and tend to be concentrated along dike margins. The dikes appear to have crystallized into opening fissures under conditions of extension. Several large, fresh boulders of a very mafic dike rock - lamprophyre (?) wer observed in the quarry, but their relationship to the syenite is unknown.

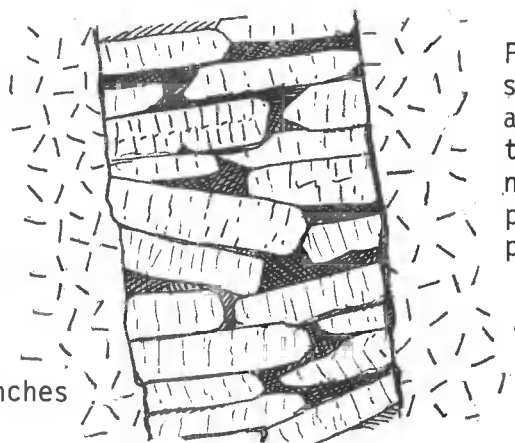


Figure 32-- "Comb" structure in syenite pegmatite dike cutting amphibole-pyroxene syenite in the Schultz Quarry 0.2 miles north of here. Amphibole is poikilitic, and occurs with green pyroxene.

STOP #11

TITLE: Amphibole and Pyroxene Syenites in the Intermediate Zone
LOCATION: NW , SW , Sec. 14, T29N, R6E; Marathon 15' quadrangle: See Fig. 6.
AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire
DATE: April, 1984
SUMMARY OF FEATURES:

Massive and flow-lineated, gray to pinkish orange amphibole-pyroxene syenite of the Intermediate Zone is well exposed on both sides of the road at this locality. This rock closely resembles the pyroxene-bearing syenite described on page 42. The syenites just north and west of here contain little or no pyroxene, and display complex flow structures resembling those at the Old Technical Institute (Stop #5). The amphibole syenite north of here contains abundant riebeckite. Although the dominant mafic mineral in the pyroxene-bearing syenite here is amphibole, the pyroxene occurs as grains rimmed by amphibole. Quartz-bearing aplites are common in amphibole syenites they were not observed in the pyroxene-bearing syenites.

DESCRIPTION:

Whereas the amphibole is characteristically pink in outcrop, the pyroxene syenite is a moderate-to-light olive gray with islands of coarse mafics enclosed in coarse tablets of randomly oriented feldspar. The amphibole syenite shows considerably greater textural variation, even at mesoscopic scale. Although vein-like and irregular masses of zoned pegmatite and aplite are common in all outcrops, the dominant rock type is medium-grained amphibole syenite with a faint to conspicuous lamination, with or without lineation created by alignment of feldspar tablets and lensoidal clots of mafic minerals--mainly amphibole and subordinate pyroxene. Pegmatitic phases of the amphibole syenite contain up to 12% quartz as coarse segregations commonly rimmed by blue (riebeckitic) amphibole.

In thin section, mafics are clustered in acicular or radiating fibers. This zone to the southwest contains small sill-like masses of tabular syenite.

The major mineral is micro-to mega-perthitic feldspar surrounding the mafic minerals which seemingly are later than the feldspars. The principal mafic mineral is bluish-green arfvedsonite-riebeckite amphibole (Table), sometimes mantling minor Fe-augite pyroxene. However, pyroxene is absent in some samples of this zone. Alteration of amphiboles to brown-red biotite is common in patches and along borders. The interesting feature of the amphibole grains is containment of a dark blue riebeckitic phase which is most common only in this unit. Some amphiboles poikilitically enclose euhedral feldspars (Figure).

Accessories include zircon which is commonly zoned, quartz (up to 12%), fluorite, calcite, FeTi-oxides, apatite and allanite.

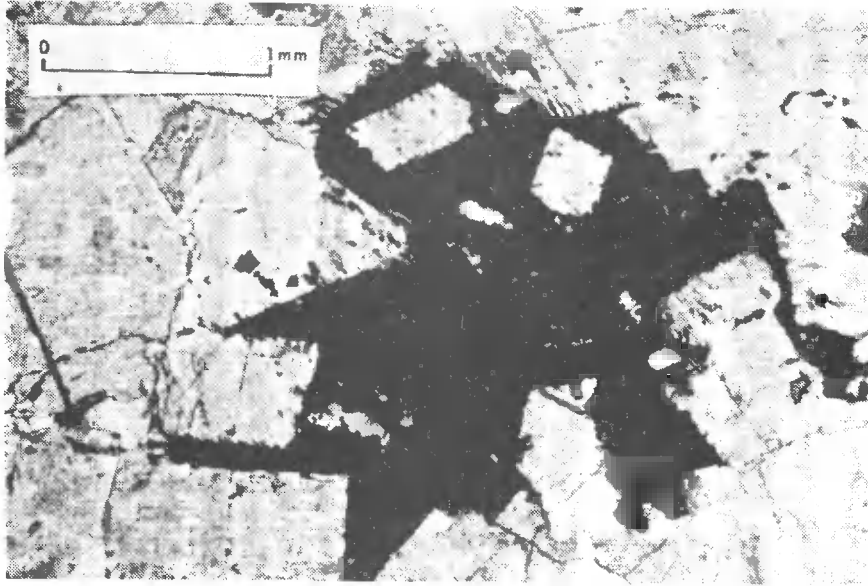


Figure 33-- Photomicrograph of amphibole syenite showing poikilitic amphibole enclosing euhedral feldspar grains. (From Sood, Myers, and Berling, 1980, p. 34).

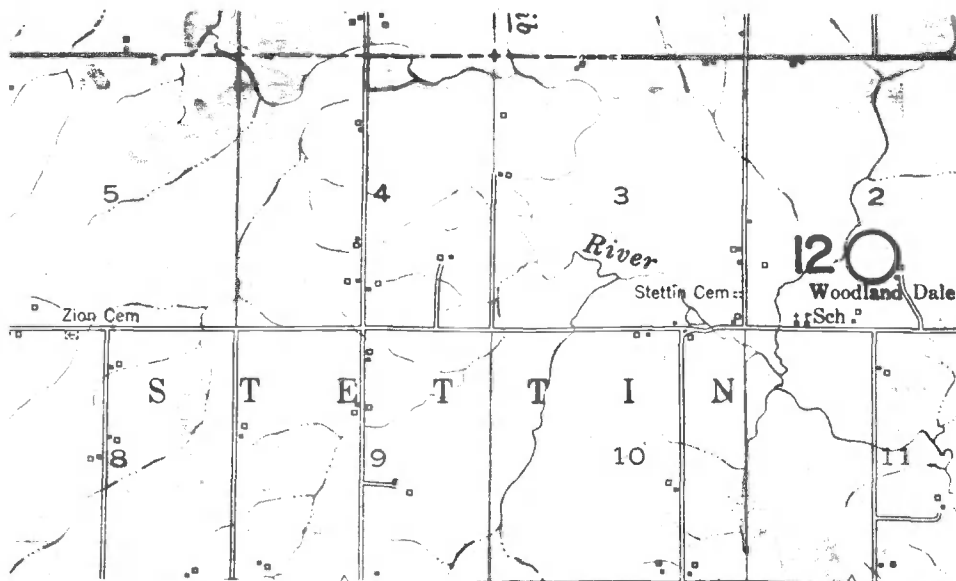


Figure 34-- Photomicrograph of pyroxene syenite with zoned aegirine-augite mantled by arfvedsonite. Crossed polars. (from Sood, Myers, and Berline, 1980, p. 35).

STOP #12

TITLE: The Core Zone of the Stettin Syenite Pluton

LOCATION: SW 1/4, SE 1/4 Sec. 2, T29N, R6E; Hamburg 15' quadrangle
William Powell property. Permission required for entry.



AUTHOR: Paul E. Myers, University of Wisconsin - Eau Claire

DATE: February, 1980, April, 1984

SUMMARY OF FEATURES:

The core of the Stettin syenite pluton comprises two distinct parts: (1) a cylindrical core margin of indistinctly banded or lineated, medium-grained nepheline syenite and (2) an inner core of pyroxene syenite. Bent and crushed feldspar grains and a crude southeast-dipping layering were formed during or after emplacement of the core margin. The nepheline syenite core margin produced a pronounced donut-shaped magnetic anomaly about one mile in diameter. Drilling by Bear Creek Mining Company in the southeast corner of the inner core retrieved about 250 feet of core classified by company geologists as larvikite. No carbonatite has been found, although the agpaitic trend of the rocks here suggests that such a carbonatite is possible (Koellner, 1974, p. 144).

DESCRIPTION:

The nepheline syenite of the core margin here is indistinctly banded or lineated. The weathered surface is pale yellowish gray with pitting due to differential weathering of the nepheline. The fresh nepheline is pale greenish brown and occurs as well-oriented, subhedral to euhedral grains enclosed by tablets of feldspar up to 2 cm long. The feldspars, nepheline, and islands of mafic minerals are elongated in a plane dipping southeast at between 60 and 70°. This lamination is not parallel to the outer edge of the core margin at this location. Bent and broken feldspar and nepheline grains and lenticulation of mafic mineral clusters suggest shearing during or after intrusion.

The dominant mineral is tabular microperthite (60% orthoclase with 40% oligoclase ribbons). An additional 25% of the rock is subhedral to euhedral nepheline, which is partially altered to cancrinite. Mg-rich pyroxene and pleochroic, olive brown amphibole are of about equal abundance and make up about 20-30% of the rock. Accessory (2-5%) Mg-rich olivine and dark brown biotite accompany the other mafic minerals in lenticular clusters and islands occurring interstitially in the nepheline syenite. The biotite partially rims the amphibole and was probably formed at a late stage of crystallization.

This unit produced a pronounced, donut-shaped magnetic anomaly about one mile in diameter. Wiedman (1907, p. 251) reports unusually large and abundant magnetite octahedra from streams northwest of here. The magnetite is apparently associated most closely with the olivine.

PETROCHEMISTRY *

Chemical compositions of the Stettin rocks are presented in Table 7. Table 8 compares average compositions of the Stettin rocks to those of Nockold's (1954). The average of the Stettin nepheline syenites show distinct differences from Nockold's average syenite. These Stettin samples, while only slightly higher in silica, are lower in Al_2O_3 and Na_2O and higher in FeO , CaO and P_2O_5 . The amphibole and pyroxene syenites, also slightly higher in silica than Nockold's average syenite, are lower in Al_2O_3 , MgO , CaO and K_2O , while higher in FeO , Na_2O and MnO . The differentiation indices ($DI = \text{normative quartz} + \text{orthoclase} + \text{albite} + \text{nepheline} + \text{leucite} + \text{kalsilite}$) (Thornton and Tuttle, 1960) for these Stettin rocks are given in Table 9. The average DI for these rocks is 84.7, which represents a high degree of differentiation. However, nepheline syenites have the highest DI of 88.9 and 93.9 respectively, indicating the greatest extent of differentiation among these rocks.

The agpaitic indices of the Stettin samples are shown in Figure 35-A. Rocks of lower SiO_2 content, the nepheline bearing rocks, have lower agpaitic indices than the more silica rich rocks. This is a reflection of the higher alumina content, due to the presence of nepheline, in the nepheline syenites. The ratio Na_2O/K_2O versus SiO_2 (Figure 35C) increases with increasing SiO_2 . This diagram shows two trends suggesting that the Stettin rocks belong to two series. Amphibole and pyroxene syenites appear to follow a continuous differentiation sequence. (Figures 35E-G). C.I.P.W. normative compositions are presented in Table 9. The normative compositions of the analyzed Stettin rocks were calculated in terms of $NaAlSiO_4$, $KAlSiO_4$ and SiO_2 and are plotted in the systems $NaAlSiO_4 - KAlSiO_4 - SiO_2$ at 1000 bars P_{H_2O} (Figure 36). All of the rocks fall within the low temperature trough.

TABLE 7

CHEMICAL COMPOSITION OF STETTIN PLUTON ROCKS

ROCK TYPE	INTERMEDIATE ZONE				CORE ZONE	WALL ZONE			
	Amphibole Syenite				Pyroxene Syenite	Tabular Syenite	Nepheline Syenite		
Sample #	10	70	503	108	6+504	65	46	2	92
SiO_2	66.10	65.20	64.70	61.95	59.75	61.50**	57.45	56.95	54.10
Al_2O_3	13.24	15.59	15.86	16.04	16.23	16.62	16.93	21.02	16.32
Fe_2O_3	2.61	2.36	2.45	3.13	2.55	5.20	2.58	2.93	3.41
FeO	4.12	2.22	2.10	2.70	5.66	1.68	5.98	2.12	7.08
MgO	0.43	0.01	0.02	0.08	0.14	0.24	0.21	0.07	1.22
CaO	0.70	0.50	0.95	1.10	2.15	1.43	2.64	0.51	4.03
Na_2O	5.92	6.92	7.07	6.51	5.97	6.49	6.71	7.81	5.01
K_2O	4.31	5.11	5.19	5.51	5.67	5.15	5.02	5.99	4.84
H_2O	0.73	0.83	0.70	1.95	0.51	0.63	0.98	1.43	0.77
CO_2	0.38	0.35	0.36	0.40	0.22	0.17	0.18	0.40	0.09
TiO_2	0.72	0.42	0.27	0.32	0.75	0.31	0.59	0.38	1.32
P_2O_5	0.11	0.04	0.06	0.07	0.13	0.07	0.13	0.50	0.49
MnO	0.23	0.12	0.15	0.18	0.26	0.22	0.30	0.07	0.29
S	0.010	0.004	0.003	0.008	0.034	0.009	0.023	0.000	0.044
ZrO_2 }	0.102	0.165	0.260	0.171	0.11	0.100	0.140	0.001	0.079
		0.215		0.143			0.241		0.105
Cl	0.03	0.013	0.024	0.010	0.010	0.345	0.02	0.025	0.02
BaO		0.071		0.150	0.160	0.103	0.086		0.208
Rb (ppm)		199.		152.	66.	133.	115.		102.
Sr (ppm)		44		105.	174.	109.	57.		345.

*Analyst-K. Ramlal, University of Manitoba

**Tabular Syenite

*Modified from Sood, Myers, and Berlin, 1980.

TABLE 8

COMPARISON OF CHEMICAL COMPOSITIONS OF STETTIN WITH NOCKOLOS (1954) AVERAGES

	Average Stettin Nepheline Syenite	Average Nepheline Syenite (Nockolds, 1954)	Average Stettin Syenite	Average Syenite (Nockolds, 1954)
SiO ₂	56.17	55.38	63.54	61.86
Al ₂ O ₃	18.09	21.30	15.39	16.91
Fe ₂ O ₃	2.97	2.42	2.62	2.32
FeO	5.06	2.00	3.36	2.63
MgO	0.50	0.57	0.14	0.96
CaO	2.39	1.98	1.08	2.54
Na ₂ O	6.78	8.84	6.49	5.46
K ₂ O	5.28	5.34	5.16	5.91
H ₂ O	1.06	0.96	0.94	0.53*
TiO ₂	0.76	0.66	0.50	0.58
P ₂ O ₅	0.37	0.19	0.08	0.19
MnO	0.22	0.19	0.19	0.11

* includes only H₂O

from Sood, Myers, and Berlin, 1980, p. 48.

TABLE 9

C.I.P.W. NORMATIVE COMPOSITIONS OF THE STETTIN ROCKS

ROCK TYPE	INTERMEDIATE ZONE				CORE ZONE	WALL ZONE			
	Amphibole Syenite				Pyroxene Syenite	Tabular Syenite	Nepheline Syenite		
Sample Numbers*	10	77	503	100	6 and 504	65	46	2	92
Q	12.44%	4.86%	2.80%	1.79%		1.80%			
Or	25.61	30.06	30.62	32.28	33.40%	30.62	29.50%	35.62%	28.39%
Ab	44.05	51.92	52.97	51.92	47.72	52.44	56.48	38.39	34.16
An					0.88	2.22	1.47	2.11	4.26
Ne					1.28		7.93	14.86	8.10
Ol					3.41		3.00	0.96	4.67
Hy	7.22	2.36	1.36	1.65					
Ac	5.31	5.91	5.89	2.70					
Di		1.89	3.88	2.70	6.66		9.82		10.65
Mt	1.04	0.51	0.54	3.28	3.70	5.06	3.70	4.17	4.86
Il	1.36	0.76	0.46	0.61	1.36	0.61	1.06	0.76	2.43
Pr	0.12	0.01	0.01	0.01	0.06	0.02	0.06		0.06
Ru	0.02								
Hm						1.62			
C								0.91	
Ap	0.34	0.10	0.13	0.17	0.34	0.17	0.34	0.13	1.01
Z	0.18	0.18	0.37	0.18	0.02	0.15	0.18	0.001	0.11
Hl	0.06	0.02	0.04	0.02	0.02	0.58	0.03	0.06	0.04
Tn	1.70								
CC				0.90	0.50				0.20
DI	82.1	86.8	86.4	86.0	82.4	84.9	93.9	88.9	70.6

*Tabular Syenite

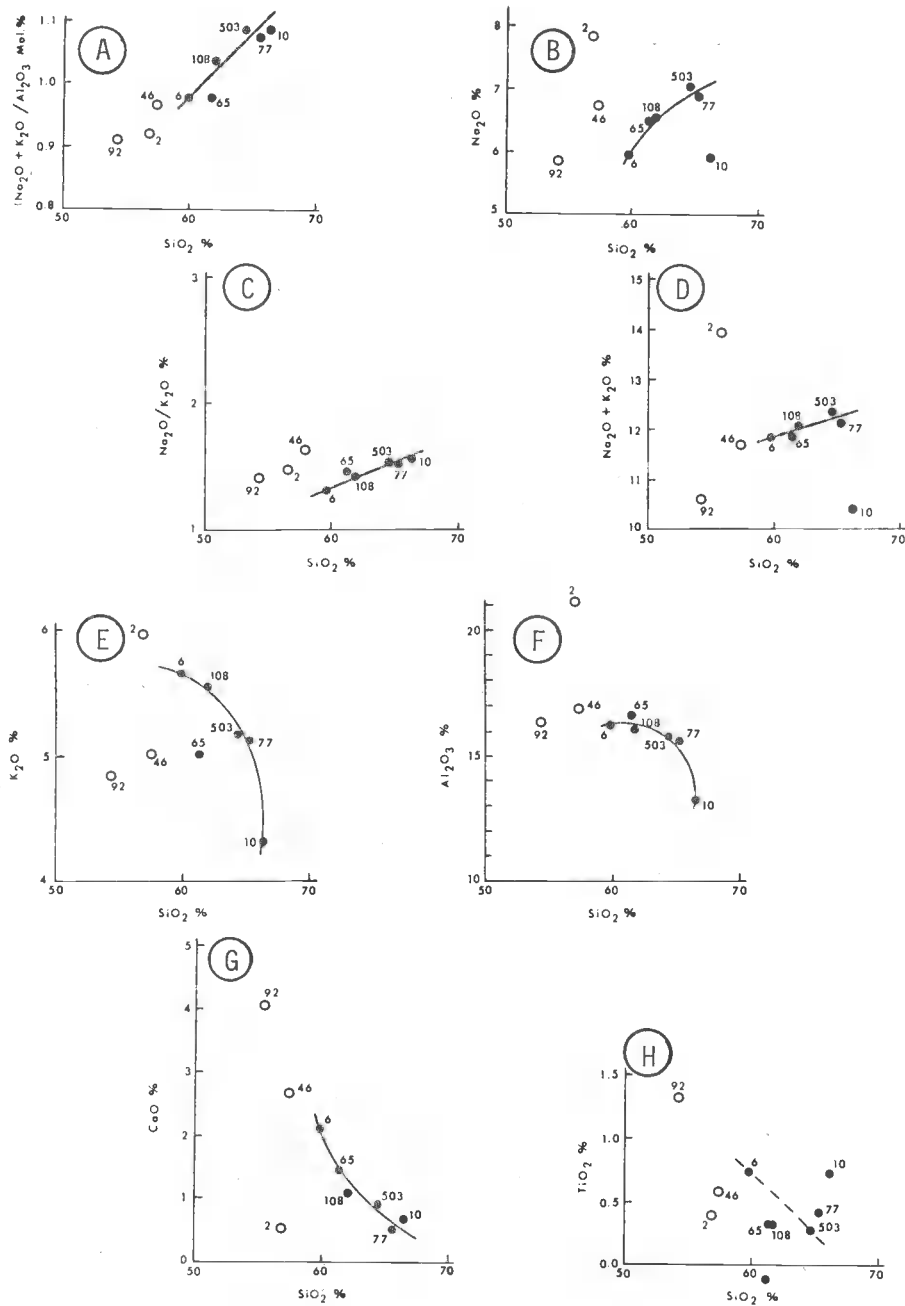


Figure 35-- Chemical trends of major elements versus SiO_2 for Stettin pluton rocks (from Sood and others, 1980, p. 50)

DISCUSSION

M. K. Sood and L. A. Berlin

Due to chemical and mineralogical heterogeneity, the origin of alkaline igneous rocks is, in many cases, very complex and may be the result of several processes. Experimental studies of chemically equivalent synthetic silicate systems (Bailey and Schairer, 1966; Hamilton and MacKenzie, 1965; Schairer, 1967; Sood and Edgar, 1972; Sood, Platt and Edgar, 1970; Tuttle and Bowen, 1958) have provided a physicochemical framework to explain the crystallization behavior of alkali magmas.

Any petrogenetic model for the formation of alkaline rocks of the Wausau area must take into account:

- 1) the zoned nature of the complex
- 2) the presence of quartz-bearing aplitic and pegmatitic stages in the intermediate ring of amphibole syenite;
- 3) the fenitized zone surrounding the pluton;
- 4) the presence of volatile bearing minerals (fluorite, calcite, apatite) in most syenites, and in the quartz monzonite "core" (?) of the Wausau pluton;
- 5) major and trace element geochemistry of the syenites.

Consideration with Respect to the System Nepheline-Kalsilite-Silica

In Figure 36 normative composition of the Stettin rocks is plotted in the system Nepheline-kalsilite-silica at 1Kb P_{H_2O} along with the composition of the rocks from Kangerdlugssuaq intrusion, H_2O East Greenland (Wager, 1965). These analyses may be interpreted to show a trend of silica depletion away from the SiO_2 apex.

Rocks of the Intermediate Zone of amphibole syenite plot in the alkali feldspar-quartz region, near the alkali feldspar join, while pyroxene syenites of the Core Zone plot just below the alkali feldspar join. The positions of these syenites in the field show a silica depletion trend toward the center of the complex.

From Figure 36, it appears that the trend of these amphibole and pyroxene syenites is up the alkali feldspar surface and "over" the thermal barrier, which is similar to the interpretation by Wager (1965) for the nordmarkites, pulaskites, and foyaïtes of the alkaline Kangerdlugssuaq intrusion.

(In the nepheline-kalsilite-silica system at 5 Kb P_{H_2O} , these rock webs plot close to the feldspar cotectic or nepheline-feldspar H_2O cotectic. This is in agreement with mineral paragenetic and textural relations.) Further interpretations await the accumulation of additional data, especially on the Wausau pluton.

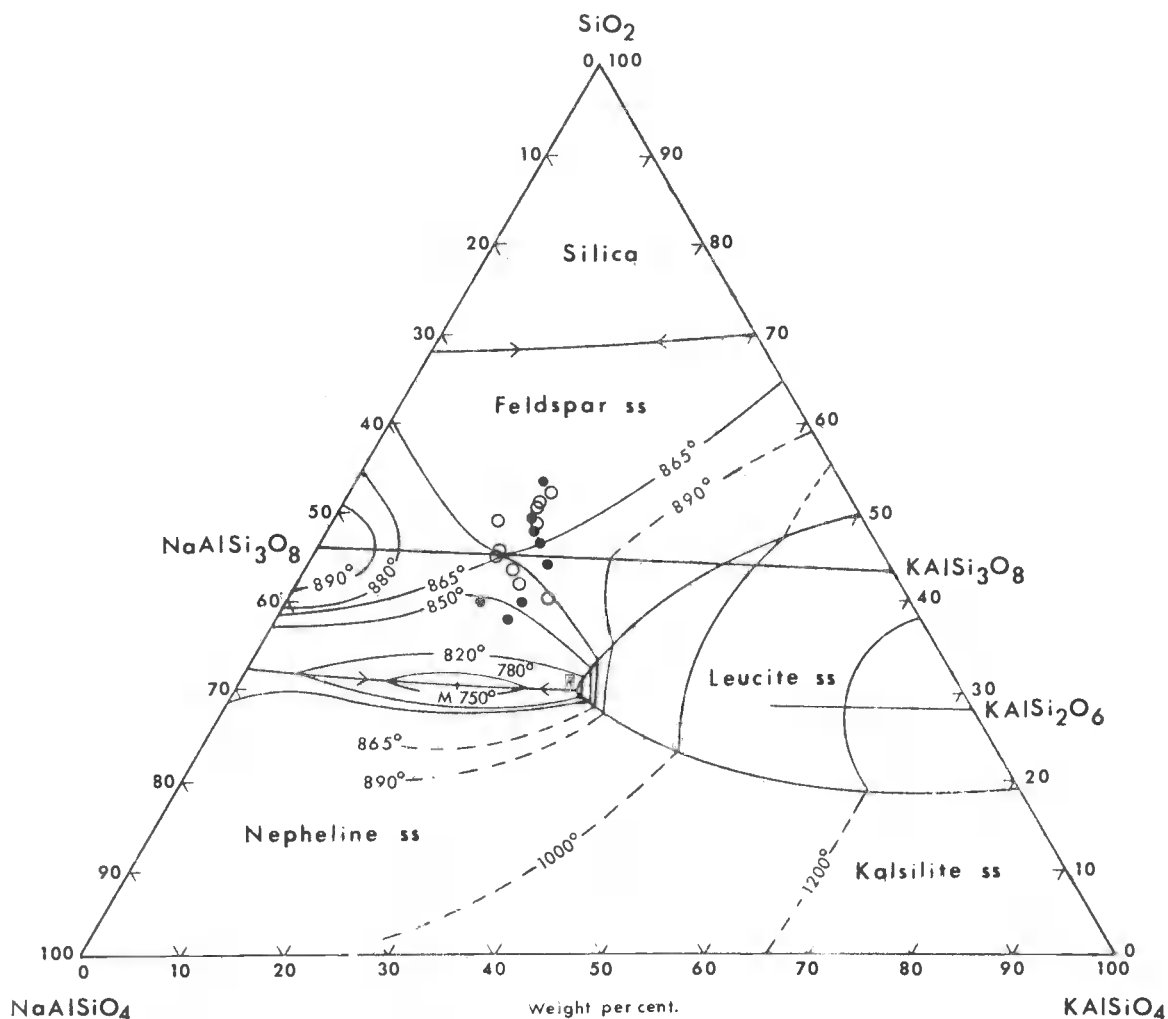


Figure 36 -- Normative compositions of the Stettin rocks (closed circles) and the alkaline rocks of the Kangerdlugssuaq intrusion, East Greenland (open circles) (Wager, 1965) plotted in the system $\text{NaAlSi}_3\text{O}_8$ - KAlSi_3O_8 - SiO_2 at $P_{\text{H}_2\text{O}} = 1000$ bars (Fudali, 1963; Hamilton and MacKenzie, 1965).

How could such inward silica depletion be caused? Two possible explanations are:

- (1) Loss of the volatile phase in equilibrium with the melt. Such a volatile phase has alumina, alkali, and silica in the same proportion as feldspars (Tuttle & Bowen, 1958; Mackenzie, 1960). The presence of aplitic and pegmatitic phases and fenitization of the surrounding volcanics may be a reflection of separation of volatiles into a gaseous phase and eventual loss. The plot of the Stettin rocks close to cotectics in pertinent synthetic systems may be indicative of crystallization of major phases within narrow temperature limits. Short crystallization intervals are also related to silica and alkali content which control volatile distribution in liquid and gaseous phases (Sood & Edgar, 1970; Kogarko & Rhyaschikov, 1961).
- (2) The substitution of Fe^{+3} Al^{+3} in feldspars may contribute to silica depletion with crystallization of iron-rich albite ($\text{NaFe}^{+3}\text{Si}_2\text{O}_8$). Only a small amount of Fe-Al substitution is necessary to fix silica and cause the liquid to shift from silica saturated to silica undersaturated trend (Bailey & Schairer, 1966). The general iron-rich and alumina-deficient nature of the syenites in comparison to Nockold's (1954) averages and a limited Fe-content of feldspars favor such substitution.

The Nepheline syenite in the Stettin pluton may, therefore, represent last residual liquids injected into the sheared wall zone.

It may be concluded that alkaline rocks of Marathon County represent a "genetically related comagmatic series." The study of silicate systems and melting relations of rocks have amply demonstrated that magma composition lies close to the univariant lines or the invariant points, and very slight changes in initial liquid composition can give decidedly distinct liquid trends. Compositional differences in these alkaline rocks may be related to slight changes in magma composition by fractional crystallization or by wallrock assimilation, or both. It is important to further refine their genetic and tectonic relations. Systematic geochemical data both on rocks and minerals are needed to assess if these rocks are formed from mantle derived magmas (tentatively note the low Rb and Sr contents for Wausau rocks) which reached crust through recurrent fracture systems. Such information will also be useful in the estimation of economic mineral potential of this area. Such rocks form in environments favorable to the concentration of a wide variety of elements.

DISCUSSION

P.E. Myers

The four plutons of the Wausau syenite complex share many characteristics of lithology and chemistry which link them in age and origin. Moreover, they show a general differentiation trend from the peralkaline Stetting syenite with its nepheline syenite rim and cor margin through the Wausau and Rib Mountain plutons which are characterized by a southeastward increase in silica, and finally to the Ninemile pluton with its core rim of aplitic granite. Although there is no obvious structural control of the complex, it does occupy a major flexure near the boundary between mafic and intermediate Early Proterozoic metavolcanic rocks on the west and felsic to intermediate metavolcanic rocks on the east. The complex lies only about 25 miles west of the exposed western edge of the coeval Wolf River batholith, and the Ninemile granite shares many mineralogical and chemical characteristics with the Wolf River batholith: they both have rapakivi affinities. Aspects of concentric zoning of each pluton permit some conclusions as to intrusion sequence, although problems remain as to the actual mechanism(s) of emplacement. Xenoliths are nearly absent in the Stettin pluton, the oldest in the sequence, possibly because the conduit was developed more rapidly and/or because the Stettin pluton has been more deeply eroded. The occurrence of metavolcanic xenoliths closely resembling rocks exposed nearby along with xenoliths of high-grade mica schists and quartzites suggests considerable vertical mixing of wallrock fragments along the walls of the Wausau and Rib Mountain plutons. These plutons were penetrating a high-grade metamorphic terrane at depth, a factor suggesting the presence of an earlier Proterozoic succession beneath the volcanic rocks. The problem of the "two Proterozoic successions" has been recently discussed by LaBerge and Myers (1984.) The xenoliths in the intermediate zones of the Wausau and Rib Mountain plutons indicates the initial emplacement of syenite magma during a first high-volume surge, probably with venting at the surface. The first-surge magma then crystallized inward from the cylindrical walls, forming the wall zones. Then (for the Wausau and Rib Mountain plutons), with repeated resurgence and collapse along cylindrical shear zones, the deeper wallrock fragments were mixed with those carried downward by an earlier collapse phase. This would explain the tendency for concentric elongation of xenoliths and their zonal distribution. If the southwesterly track of the plutonic sequence can be generalized, it is possible that other syenitic plutons exist in Wisconsin, but are obscured beneath younger rocks and glacial deposits. The aeromagnetic map of Wisconsin shows many circular anomalies similar to those characterizing the Wausau syenite (See LaBerge and Myers, 1983, Plates 1 and 2).

Features indicating shallow intrusion depth are: (1) abundance of nearly horizontal pegmatite pods and miarolitic cavities in the Ninemile granite; (2) concentric, cylindrical, discordant structure of the plutons, and (3) low metamorphic grade and relative simplicity of structure in wallrocks.

Some problems exist concerning the age and genetic relationships of the granite aplite, which occupies a large area outside the plutons, but is confined mainly to the region adjacent to the Ninemile pluton. In essence, the aplite is a finer grained variety of the Ninemile granite. However, miarolitic cavities and pegmatite pods and dikes are very rare in the aplite. However, the aplite may represent an early phase of granite intrusion which preceded emplacement of the Ninemile granite. The aplite contains plagioclase phenocrysts of euhedral plagioclase and tends to be leucocratic: biotite is usually the only mafic mineral, and its abundance is usually less than 5 percent. Mantling of K-feldspar by sodic plagioclase is common. It is tentatively concluded that the granite aplite is an early intrusive phase of the Ninemile granite.

Another problem concerns two quartz monzonite porphyry plugs (See Figure 5). These small plug-like bodies consist of a light-colored, aphanitic matrix and large K-feldspar phenocrysts showing partial fragmentation and resorption. Quartz phenocrysts are granular and anhedral. These plutons are strung out along a NW-SE axis across Marathon County, and were intruded through post-syenite faults. They are interpreted as being the "last gasp" of the Ninemile granite emplacement episode.

Whole rock and trace element geochemistry are under way by Myers and Sood, while Falster will continue to study mineralogy and mineral chemistry of the pegmatites in the Ninemile pluton. A comprehensive genetic-petrological model is being developed, and should be published within the next year. It is hoped that the reader/participant may find a research project of interest in this relatively well exposed part of the Precambrian shield of Wisconsin.

P. Myers wishes to express his gratitude to the Wisconsin Geological and Natural History Survey for sponsoring field work during the summers of 1971-1976 with Gene LaBerge in Marathon County. The Survey has also provided many thin sections and the assistance of the Survey Staff as consultants.

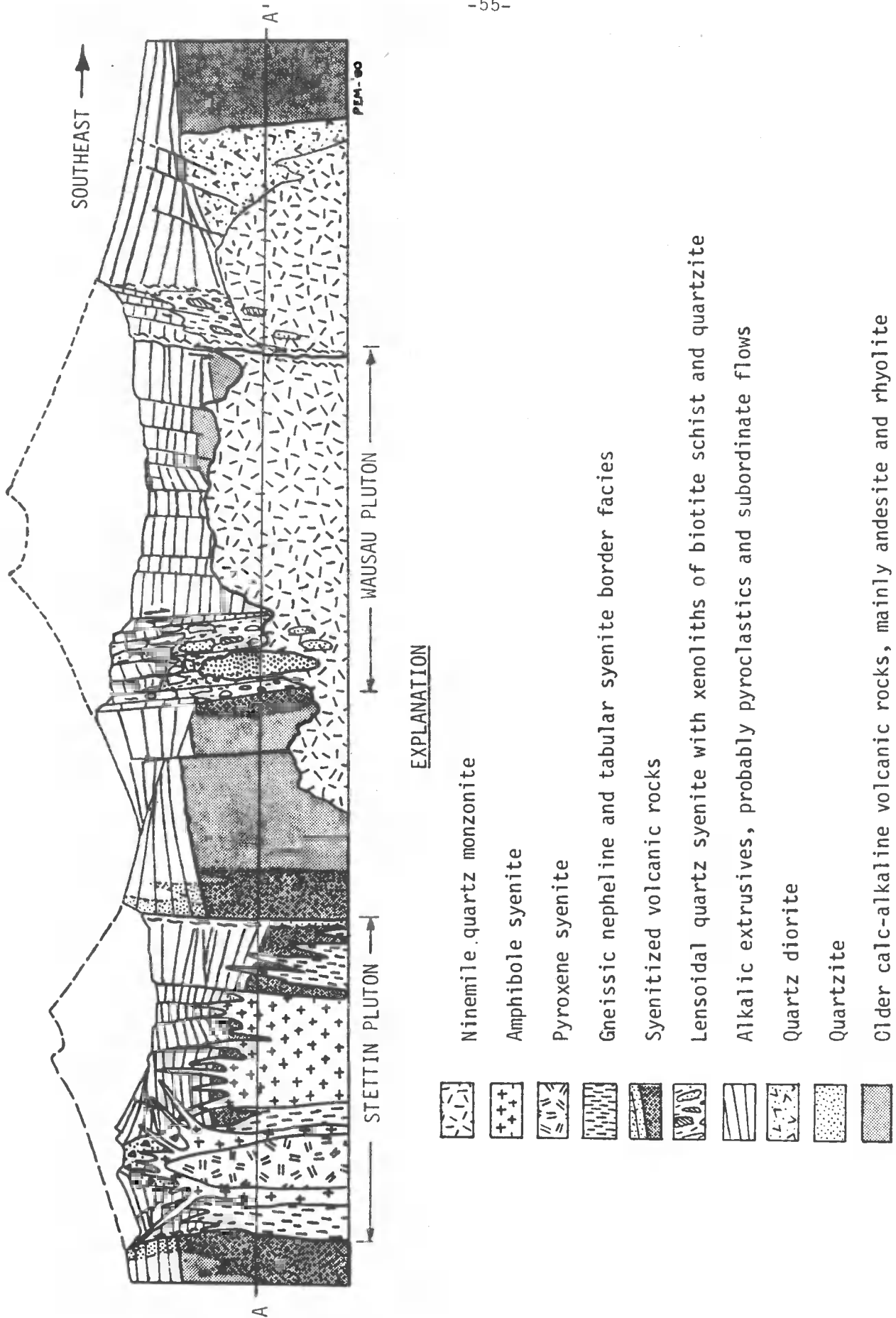


Figure 37-- Hypothetical northwest-southeast section across the Stettin and Wausau syenite plutons as they would have appeared about 1450 m.y. ago. Line A-A' represents the present land surface.

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