PETROLOGY AND PETROFABRICS AT THE NEWTON FALLS PIT, STAR LAKE, NEW YORK

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By

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ABSTRACT

The Newton Falls Pit constitutes the northern portion of the Benson mines, located in the Precambrian complex of the Adirondack highlands. The results of field observations supplemented by the analyses of twenty-one oriented thin sections are presented with brief interpretations relative to the ancestry of the rocks comprising the area.

The study revealed three major rock units: (1) "hanging-wall gneiss," (2) pegmatites, and (3) "host rock." "Host rock" is believed to represent the oldest unit, and is interpreted as a portion of the ancient Grenville complex. The present rock has evolved in conjunction with extensive injection and soaking of the stratified rocks by magmatic fluids, emanations, and solutions. Petrographic and field evidences favor a magmatic origin for the "hanging-wall gneiss." The presence of exsolution perthites, plagioclase exhibiting complex twin patterns, and the proximity of textural and structural characteristics to rocks forming from the consolidation of a magma, causes considerable ambiguity in relating this unit to Grenville metasediments. Pegmatitic intrustions represent the youngest rocks in the

area; their injection took place after the "hanging-wall gneiss" was at least partially solidified.

All the rock types have been subjected to intense deformation and metamorphism. The major structure consists of the eastern limb of a syncline, slightly overturned to the west, and plunging north. Numerous crenulations, almost entirely isoclinical and overturned, are superimposed on the major structure. Parallelism of lineations, foliation, banding, and rock contacts are the general rule. Discordant relationships were observed when considering certain localities in detail.

Mapping of over 1,980 joint planes revealed an abundance of typical ac and bc tension joints, but generally the pattern is haphazard.

Orientation analyses of the c-axes of nearly 3,000 quartz grains indicated only weak point maxima near a. For the most part, quartz orientations appear independent of major structural features. A petrofabric study of biotite revealed a strong concentration of flakes parallel to the inferred ab plane.

Nearly complete obliteration of all cataclastic and relix textures resulted from postdeformational intrusions of emanations and solutions. Extensive recrystallization has further masked pre-existing textures.

The emplacement of iron ore is believed postdeformational. Iron oxides replace all minerals, but indicate a preference for ferromagnesium minerals, especially biotite. The nonmagnetic ore is believed to be martite, which in part occurs at the grain boundaries of magnetite, appearing as an oxidation product.

ACKNOWLEDGMENTS

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INTRODUCTION

Location and Accessibility

The Benson mines are located in the township of Clifton, St. Lawrence County, New York, approximately two miles east of Star Lake. The area investigated was restricted to the Newton Falls Pit extending from the property line to the northernmost stripping limit (Fig. 1).

The Carthage and Adirondack branch of the New York Central Railroad provides freight and express accommodations extending from Carthage to Benson Mines. Route No. 3, a main highway extending east and west across most of northern New York, passes the immediate vicinity of the mines.

Physical Features and Climate

The principal industries of the region are lumbering, paper manufacturing, mining, and agriculture.

The terrain consists of low rounded hills with altitudes ranging from 900 to 1900 feet. The many small lakes and streams generally drain to the north and northwest. With the exception of the stripped area at the Benson Mines most of the bedrock is covered

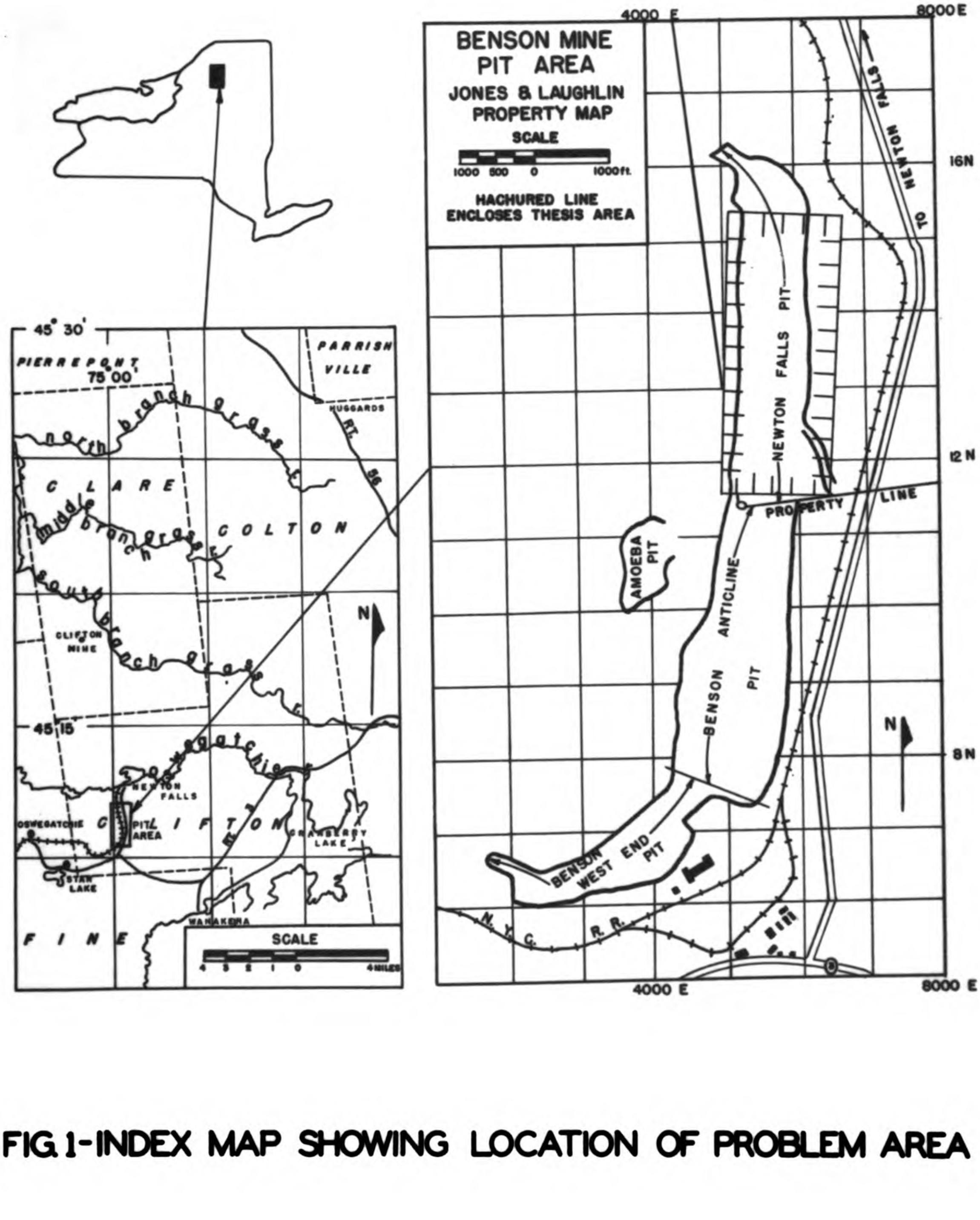

FIG. 1-INDEX MAP SHOWING LOCATION OF PROBLEM AREA

by a veneer of Pleistocene glacial deposits. The region is thickly wooded with pine, spruce, birch, maple, and poplar trees, and where the original timber has been cut there is extensive underbrush and second growth.

Winters are severe, with heavy snowfall and recorded temperatures as low as -45° F. Summers are mild, but there is considerable rainfall during early spring and late fall.

History and Production

Systematic mining was started in 1889, although ore bodies were mentioned in reports earlier than 1850 (Newland, 1908). Operations were intermittent until 1919, at which time, due to a combination of increased production costs and decreased demands for iron ore, mining was discontinued. During July, 1941, new open-cut operations were resumed when the Jones and Laughlin Steel Corporation leased the mine and adjacent properties (Millar, 1945). By adding new surface plants and employing more recent technological advances, the capacity of the mines was greatly increased. More recent utilization of Humphreys spirals providing gravity concentration of the extensive body of nonmagnetic ore has increased the output of concentrates. Annual production at the present time is approximately 1,000,000 tons of magnetite concentrates and 600,000 tons of nonmagnetic[1] concentrates, all of which are sintered at the mines and shipped by rail to blast furnaces at Pittsburgh, Aliquippa, and Cleveland (West, personal communication).

Regional Geologic Setting

The most thorough studies of the Precambrian complex in the northwest adirondacks have been presented by Buddington (1939, 1948, 1952), Leonard (1951), and Engel and Engel (1953). It is generally agreed by these authors that approximately 85 percent of the bedrock within the Highlands belt is igneous and 15 percent metasediments and migmatites of the Grenville series.

The metasediments of the Grenville series are the oldest rocks in the region. In the Highlands belt these extremely variable metasediments have been intruded, incorporated, and to an uncertain extent granitized by later igneous magmas. In very general terms the dominant rock types comprise amphibolites of questionable origin, garnetiferous and sillimanitic paragneisses, quartzites, and marbles.

Buddington (1948) has proposed two major periods of dominantly granitic intrustion. The oldest of these is a quartz syenitic

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[1] The nonmagnetic ore is locally termed "martite." Martite is defined by Dana (1951): "A name applied to Fe_2O_3 occurring in octahedral or dodecahedral crystals and pseudomorphous after magnetite; perhaps in part also after pyrite."

series ranging from pyroxene syenite to biotite granite along with minor pegmatitic development. Quartz syenite forms the major element of this complex. The entire series is thought to be due to consolidation of magma intruded from depth and variations in composition effected by gravity stratification and incorporation of country rock.

Following the intrusion of the quartz syenitic series the entire complex was subjected to orogenic forces that resulted in a series of intensely folded and deformed metasediments and intrusive sheets.

Next followed the second major period of granitic intrustion which Buddington (1948) commonly refers to as the "younger granitic series." This series is predominately a hornblende granite with associated biotitic alaskite. Extreme differentiates include alaskite, microcline granite, and soda granite. Much of this granite forms conformable lenses and phacolithic masses in the older complex. The usual characteristic gneissic structure is thought by Buddington (1948) to have been inherited during a renewed period of deformation at the time of, and subsequent to, its emplacement.

This brief summary of the major geologic events in the northwest Adirondack highlands is generally accepted as the most satisfactory hypothesis, with some minor modifications, by the majority of geologists who have studied the area.

Purpose and Scope

This thesis reports the results of a joint field and laboratory study of the Newton Falls Pit. Limited reconnaissance work was done during the summer of 1952. Field work was resumed during the summer of 1955, with detailed mapping of joint systems. The area was again visited in December, 1955, at which time the majority of samples were obtained. Petrographic and petrofabric examinations were made of twenty-one thin sections cut from nine samples.

The purpose of the study was to provide preliminary data on the petrology and petrofabrics of the complex (deformed rocks) comprising the area.

PETROGRAPHY AND PETROLOGY

Extraordinary mineralogical variations within relatively small localities seriously impede systematically subdividing the area into logical rock units. From the writer's field and petrographic observations, only a general framework can be proposed, at best. The complex includes three general units, each possessing certain distinctive characteristics relative to mode of origin, mineral assemblage, spacial relationships, and textures. These rock types are designated (1) "hanging-wall gneiss," (2) pegmatites, and (3) "host rock"--names which conform with the terminology employed locally.

"Hanging-Wall Gneiss"

"Hanging-wall gneiss" borders the eastern portion of the Newton Falls Pit and extends beyond the area southward and eastward (Fig. 2). Locally the rock is sharply truncated a few hundred yards to the west by a generally north-south trending contact. Detailed study was restricted to the vicinity of samples 9 and 19 (Fig. 2), with only cursory field observations in other localities. The rock is fine- to medium-grained, and has generally a gneissic texture. In the vicinity of samples 9 and 19 the segregation into bands is not

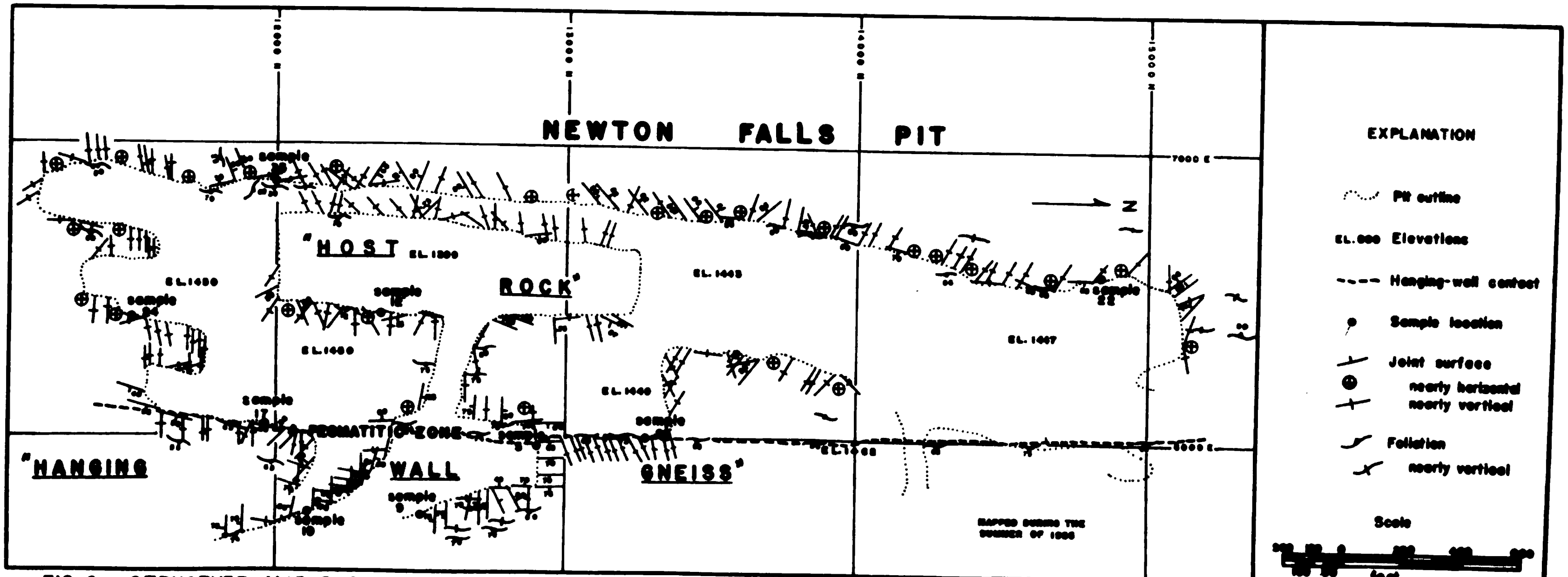

FIG. 2.—STRUCTURE MAP SHOWING FOLIATION, JOINTS AND LOCATIONS OF SAMPLES.

well defined, and the layering that does occur appears upon close megascopic examination to be due in part to variations in the relative abundance of quartz admixed with feldspar. The gneissic texture best presents itself on the entire face of an outcrop, and is only slightly conspicuous in hand specimens. Megascopically, the rock consists mainly of quartz and feldspar with subordinate mica, pyrite, magnetite, garnet, and tourmaline.

Sample No. 9. In thin section the rock is fine- to medium-grained with hypidiomorphic-unequigranular texture. Quartz and feldspar constitute the major minerals (Table I). Mica, apatite, zircon, antigorite, pyrite, and sericite occur in minor amounts. Quartz is present in two different habits. The most abundant one forms relatively large lobate protuberances extending as irregular bodies indenting or including all other minerals except pyrite and magnetite. Earlier quartz is restricted to a few small, irregular, more or less equidimensional grains occurring as inclusions within the later quartz. Quartz is also present in a few small patches of myrmekite. Planes of liquid inclusions are ubiquitously associated with the younger quartz traversing grains independent of crystallographic orientation. Undulatory extinction is for the most part perceptible, but granulation at grain boundaries is absent.

TABLE I

MODAL ANALYSES OF "HANGING-WALL GNEISS"

Analysis	Sample	
	No. 9	No. 19
Quartz	56	49
Plagioclase (Ab90·An10)	8	6
K-feldspar	6	
Microperthite and/or microantiperthite	20	37
Magnetite and/or martite	tr.	tr.
Biotite	4[a]	5
Tourmaline		1
Apatite	1	tr.
Zircon	tr.	tr.
Sercite	tr.	tr.
Chlorite[b]	2	tr.
Garnet		tr.
Pyrite	2	
Total	99	98

[a]Biotite includes bleached variety and/or phlogopite.

[b]Chlorite includes for the most part antigorite.

The predominant feldspar is microperthite (Fig. 3). A more detailed description of perthitic feldspars with relation to the origin of the "hanging-wall gneiss" is discussed below. Sodic plagioclase relatively clear of free potash feldspar occurs in two habits. The most abundant forms small blocky grains typically twinned. The second is an untwinned variety which is definitely younger than the former. Both varieties were determined as albite of a composition near Ab90 . An10. The potash feldspar is untwinned and appears to be orthoclase. The possibility that the untwinned potash feldspar is triclinic rather than monoclinic was considered, but no differentiating criteria could be established employing usual flat stage methods.

Part of the mica is normal biotite, but there is also a light orange-brown variety exhibiting weak birefringence and no perceptible pleochroism. The similar relationship of both types to surrounding minerals suggests the light-colored variety is a product of hydration and leaching forming bleached biotite. The possibility that some of the light mica approaches the magnesian variety phlogopite merits note, but the close approximation of the optical properties with bleached biotite makes distinguishing characteristics extremely difficult, if not impossible, to detect when standard petrographic equipment is employed.

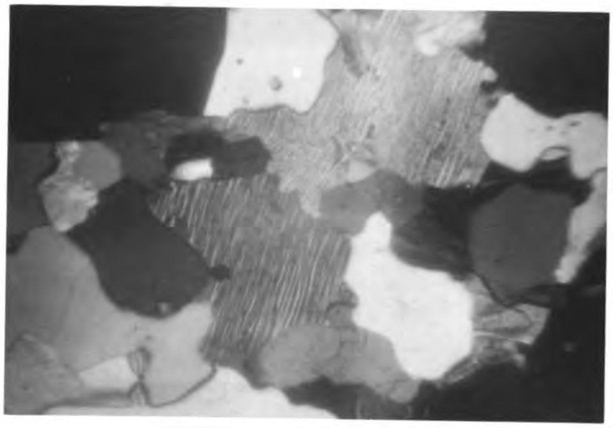

Figure 3. Photomicrograph of sample 9 showing complex microperthitic intergrowth. Crossed nicols, ×32 diameters.

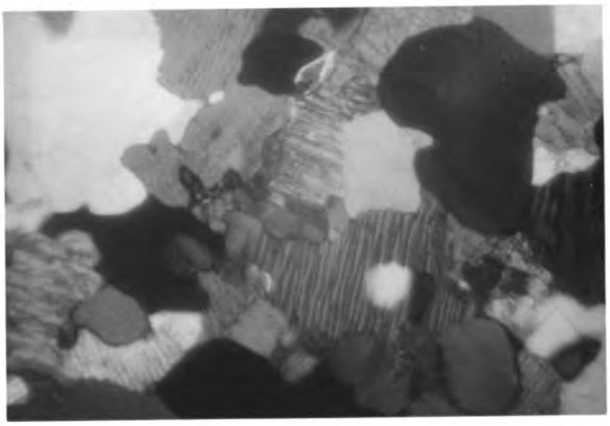

Figure 4. Photomicrograph of sample 19 showing perthitic blebs uninfluenced by inclusions of quartz and magnetite. Crossed nicols, ×32 diameters.

Minor accessories of apatite and minute zircons are included in both quartz and feldspar. Pyrite is in part idiomorphic, and appears to be introduced late in the rock alteration. Chlorite forms sporadic aggregates which appear pseudomorphic after material with the crystal outline of a pyroxene. To a limited extent, sericite can be detected spotting the generally clear feldspar.

Sample No. 19. Mineral assemblages and textural characteristics generally approximate sample 9 (Table 1). Grain size is slightly smaller, averaging 0.5 mm. Quartz and feldspar again constitute the major minerals, with subordinate biotite. Sparsely occurring tourmaline, apatite, zircon, garnet, magnetite, chlorite, and sericite complete the mineral assemblage. The habit and abundance of quartz closely resembles that previously described. Perthitic feldspar is abundant, but varies slightly relative to host-inclusion relationships. The ratio of the potash and soda constituents is such that a 1:1 relationship is almost exclusively present. Albite-oligoclase also occurs in separate blocky grains always exhibiting polysynthetic twinning. Greenish-brown biotite is in part altered to chlorite and magnetite. All the biotite exhibits strong pleochroism. Small brown tourmaline crystals, all of which are anhedral, appear as a product of later introduction. Traces of apatite, zircon, and garnet are observed as inclusions in the feldspar and quartz. Sericitization of the feldspars was more extensive than noted in sample 9.

Petrologic interpretations. Due to the restricted nature of the study any possible interpretations with reference to the petrogenesis of the "hanging-wall gneiss" are merely suggestive. From such limited observations many desultory interpretations can be proposed. However, a few observations are believed to merit mention, with possible implications pertinent to the origin and history of the "hanging-wall gneiss."

At first glance the large quantity of quartz seems to suggest a sedimentary ancestry, and implies the present granitic texture is the result of granitization.[1] However the occurrence of most of the quartz replacing or engulfing and penetrating other minerals suggests introduction into a rock which was, for the most part, solid. The minor occurrence of an older quartz further substantiates a secondary introduction of silica. If the quartz was all originally present and the present texture a product of recrystallization, obliterating previous relationships, certainly the dual habit would not have persisted.

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[1] The term "granitization" is used as defined by Read (1948, p. 5): "The process by which solid rocks are converted to rocks of granitic character without passing through a magmatic state."

Therefore, the high content of silica in itself can relate little with reference to the original nature of the gneiss.

The perthitic intergrowth is of particular interest (Figs. 3 and 4). No single process could satisfactorily explain the variable textural characteristics of the perthitic blebs. The similarity of some intergrowths with those described by Tuttle (1952, pp. 113-123) and Alling (1932, pp. 43-65), who attribute this phenomenon to exsolution, leaves little doubt that at least in part the perthitic feldspars are related to a magmatic ancestry (Figs. 3 and 4). Tuttle (1952, pp. 120-121), in discussing the relationship of perthites to grantiization, states:

> Perthites consisting of nearly equal amounts of albite and microcline, typified by those found in granites, such as the Quincy, Massachusetts, are prima facie evidence of magmatic ancestry. When perthites of this type are present, granitization by any low-temperature process can be ruled out as improbable, if not impossible.

The original perthitic intergrowths, interpreted as having formed from the unmixing in a solid state, have since been modified. Additional blebs of albite randomly truncate the original structure, forming patches and protuberances. The modification appears analogous to perthites of metosomatic origin described by Postel (1952, pp. 14-16) and Alling (1932, pp. 54-63). The degree of secondary replacement appears most prevalent in sample 9, and almost complete replacement by albite can be observed in some grains.

The possibility that metamorphic processes have further modified the perthitic texture certainly merits note. Buddington (1939, p. 251) and Phemister (1926, p. 25) attribute to stress the complete dissociation of microperthite into its individual components. This could possibly explain the segregation of small patches of microperthite completely included in albite, which is in optical continuity with the sodic blebs.

Albite twinning in primary sodic plagioclase is omnipresent. Combined Carlsbad and albite twinning is subordinate to the simple albite twins, but may be observed throughout both samples. Complex combinations of albite, Carlsbad, and pericline twinning are rare, but present. Turner (1951, pp. 581-589), in studying the variations of twinning in plagioclase of metamorphic and igneous origin, encountered certain consistent differences. He generalized that plagioclases of magmatic origin commonly exhibit complex twin combinations, while this phenomenon is rare or absent in plagioclases of metamorphic origin. Untwinned grains or those consisting of simple albite twins characterize plagioclase of metamorphic origin. The observation of primary plagioclase ubiquitously twinned in accordance with the albite law and the presence of grains complexly twinned would therefore indicate a magmatic ancestry for the samples studied. This is based on a broad generalization and is presented merely as an indication, certainly not as conclusive proof.

It is interesting to note that in adjacent areas the plagioclase within the "hanging-wall gneiss" is reported to have a composition near andesine (Crump, personal communication). Possibly the plagioclase within the samples studied has undergone a change in composition effected during the formation of the secondary perthitic textures by emanations or solutions rich in soda. A detailed study of the nature of perthitic textures relative to the composition of the primary plagioclase might reveal some pertinent data relative to the effect of albitization on feldspars.

In part the biotite appears to have been hydrated and leached as indicated by the presence of a bleached variety. Evidence of late hydrothermal solutions is also indicated by the addition of pyrite, seritization of feldspar, crystal pseudomorphs of amphibole or pyroxene completely altered to chlorite, and extensive addition of silica and soda.

Although field and laboratory observations were limited, the tendency to postulate a magmatic origin for the "hanging-wall gneiss" is favored. If this were the case certainly the rock has undergone extensive postmagmatic alterations. Hydrothermal solutions and recrystallization are believed to have obliterated much of the cataclastic texture induced during periods of extensive folding. From the observations cited above the writer finds difficulty in relating the "hanging-wall gneiss" to granitized Grenville metasediments.

Pegmatites

A pegmatitic seam ranging in width from several inches to ten feet is nearly everywhere present between the contact of the "hanging-wall gneiss" and the "host rock" (Fig. 2). This coarse-grained rock is typically pink, and generally parallels the foliation inherent in the surrounding units. A few areas of discordancy were observed, but this relationship is exceedingly subordinate. Field study revealed numerous pegmatitic veinlets throughout the "host rock" which are also for the most part concordant with foliation. All pegmatites observed exhibit a pronounced banded structure made conspicuous by layers of biotite and the relative variations of quartz admixed with feldspar. Linear and planar elements inherent in the pegmatites are conformable to rock contacts and in most cases to adjacent gneissic banding. Boundaries are both knife-sharp and gradational. Where the contact is sharp it can in most cases be related to faulting. Gradation in mineral size from fine at the borders to coarse within the pegmatites can be observed where the contact is not faulted. There also appears to be a replacement and incorporation of the intruded rock, but in many cases this phenomenon can be detected only upon close megascopic examination.

No detailed field study of the mineral assemblage of the pegmatites was undertaken. Cursory examination revealed pink feldspar constituting the major mineral, with sporadic abundance of mica, quartz, and black tourmaline. Sparse pyrite, magnetite, and molybdenite were also megascopically identified. Samples 5 and 25 were taken from the major pegmatitic seam.

Sample No. 5. Texturally the sample is hypidiomorphic-unequigranular with the variable grain size (0.4—3.2 mm.) averaging 2.1 mm. In thin section the rock consists mainly of feldspar with subordinate quantities of quartz, mica, and magnetite. Traces of zircon, apatite, rutile, and secondary chlorite, epidote, and sericite complete the mineral assemblage (Table II). The chief feldspar is oligoclase, commonly exhibiting a weakly defined albite twin and occurring as large interlocking grains. Granulation at grain boundaries is completely absent. The plagioclase for the most part has undergone extensive alteration to paragonite (Fig. 5), and appears to be one of the earliest formed minerals. Other abundant feldspars are microcline and microperthite. Microcline shows excellent grid twinning and for the most part carries lens-shaped blebs of albite

TABLE II

MODAL ANALYSES OF PEGMATITES

Analysis	Sample	
	No. 5	No. 25
Quartz	10	6
Plagioclase[a] (Ab85·An15)	38	10
Microperthite and/or microantiperthite	27	67
Microcline[a]	12	4
Magnetite and/or martite	4	3
Biotite	6	4
Apatite	tr.	tr.
Epidote	tr.	
Zircon	tr.	tr.
Sericite	tr.	tr.
Paragonite	2	4
Chlorite	tr.	1
Muscovite	tr.	
Rutile	tr.	
Leucoxene		tr.
Total	98	99

[a]The feldspar may be slightly perthitic.

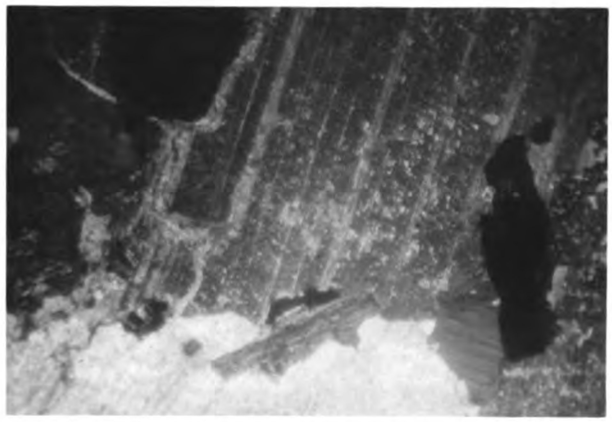

Figure 5. Photomicrograph of sample 5 showing the alteration of plagioclase to paragonite. Crossed nicols, ×32 diameters.

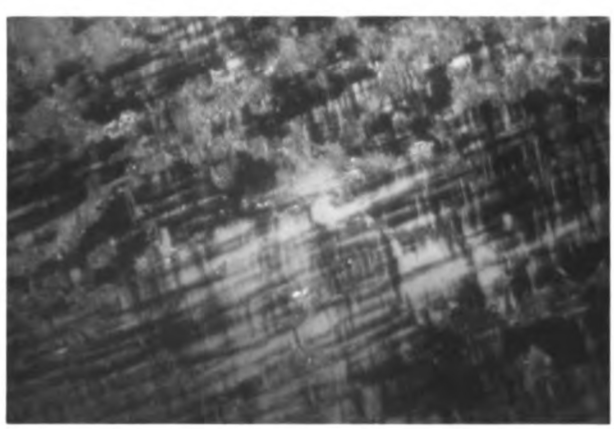

Figure 6. Photomicrograph of sample 5 showing microcline-perthite and extensive alteration of secondary albite to paragonite. Crossed nicols, ×32 diameters.

(Fig. 6). Secondary albite occurs at grain boundaries, and in many cases penetrates into the microcline, forming veins and patches. A few small grains of microcline are free of optically resolvable perthitic intergrowth.

Quartz occurs as late fresh spherical grains penetrating and replacing the feldspar. Undulatory extinction is rare and in most cases perceptible only in larger grains. The chief mica is a strongly pleochroic, greenish-brown biotite. Almost complete alteration to green chlorite and iron oxide is apparent in some plates, but generally chloritization is restricted to cleavage planes. Rare pleochroic halos are associated with small included zircons. Some of the more altered biotite also includes needlelike crystals, probably rutile. Magnetite occurs as a late secondary mineral, and is entirely anhedral; much of it has been oxidized to martite at grain boundaries. Biotite is the preferred host for the replacing magnetite, but restriction to this mineral is not ubiquitous. Sporadic grains of epidote appear as an alteration product, but the conversion was so complete that the pre-existing mineral remains unknown.

Sample No. 25. Mineral types and relationships are much the same as in sample 5 (Table II). The most significant difference is the relative abundance and the type of feldspar. Whereas sodic plagioclase predominated in sample 5, the dominant feldspar in this specimen is microperthite. However, due to the relatively large crystals within the pegmatitic seam these variations may very well be due to sampling and bear little significance.

The microperthite consists of a microcline host and albite guest (Figs. 7 and 8). The perthitic structure has been modified by the addition of secondary albite. Primary plagioclase is again albitic-oligoclose. Almost all the sodic plagioclase exhibits extensive alteration to paragonite in contrast to the potash feldspar which appears relatively fresh. Biotite is, for the most part, altered to chlorite, which also occurs in thin seams cutting all other minerals. Quartz is generally fresh, exhibiting very little undulatory extinction, and it appears to cut and replace feldspar. Anhedral magnetite is almost completely oxidized to martite. Only minor relics of magnetite within the center of martite grains can be observed. Using reflected light, milky-white leucoxene is observed as a sparse constituent associated with the iron oxide, suggesting the original presence of ilmenite.

Petrologic interpretations. Excluding minerals interpreted as secondary, the volumetric percentage of feldspar within the "hanging-wall gneiss" approximates that of the pegmatites. The two units do, however, differ appreciably in the type of feldspar. The pegmatites

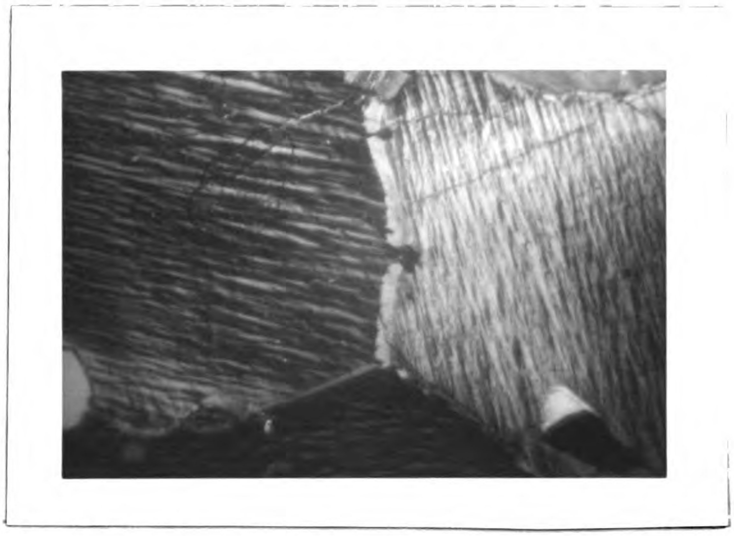

Figure 7. Photomicrograph of sample 25 showing secondary albite rim. Crossed nicols, ×32 diameters.

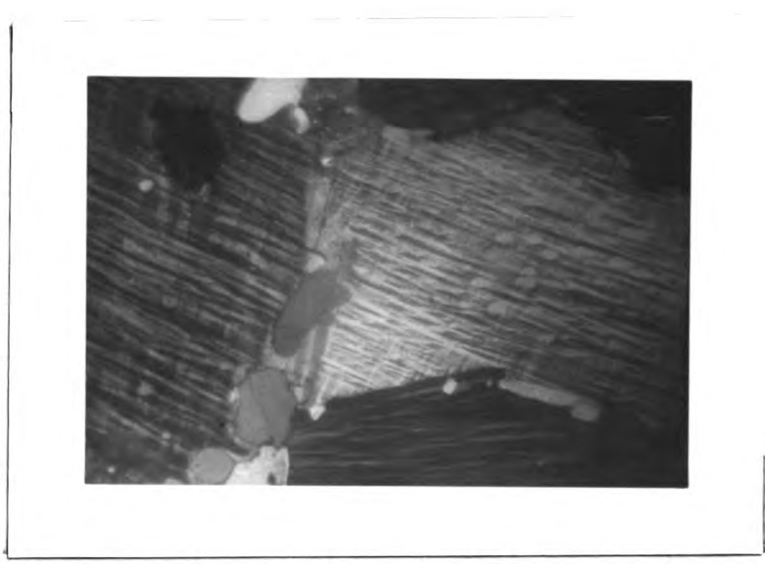

Figure 8. Photomicrograph of sample 25 showing microperthite containing both exsolution and replacement blebs of albite. Crossed nicols, ×32 diameters.

are characterized by typically twinned microcline which was undetected in "hanging-wall gneiss." Host-guest relationships of the perthitic intergrowths are such that, in the pegmatite, microperthite is dominant in contrast to microantiperthite in the "hanging-wall gneiss." The perthites are also complex, exhibiting albitic inclusions typical of both magmatic and replacement origin. This phenomenon is well illustrated and easily detected in observing the large grains, where the replacement type, clearly related to a distinctive ancestry, randomly cuts primary blebs, forming patch and veinlike inclusions. Another interesting phenomenon is the effect of inclusions within the microcline-microperthite. The blebs formed early and related to either exsolution or deuteric processes are abruptly truncated by spherical intrusions of quartz. In contrast, veins of secondary albite are definitely modified and tend to circle the periphery of the inclusion. The varying relationships certainly indicate at least two distinct types of perthitic textures. The primary blebs were undoubtedly formed prior to the introduction of quartz. Explanation for the modification of the blebs is more complex, and there are several possibilities. Alling (1932, p. 59), in describing a similar phenomenon, postulates that differential rates of contraction between inclusion and host create channelways for the albite solutions forming the late perthites. He further suggests that differential contraction is also responsible for many of the vein-type perthites paralleling previous exsolution blebs, and that these are not hydrothermal but deuteric in origin. Alling's hypothesis may be true with respect to parallel blebs, but fails to explain the same modification on veins and patches randomly orientated. The writer feels that these patchlike inclusions of albite are of replacement origin, and the modification by secondary quartz is related to selective receptiveness for the permeating solutions carrying albite. Certainly pre-existing channelways would influence the direction of replacement, but this in itself is not a necessary prerequisite.

Secondary albite can be observed rimming many grains (Figs. 7 and 8). Tuttle (1952, pp. 115-116) suggested that such rims are a product of unmixing. He tested all possible orthoclase-plagioclase-quartz contacts and concluded that nearly all the albite rims lie at orthoclase-plagioclase boundaries. This is thought by Tuttle to substantiate the hypothesis that the potash feldspar was the original source of the late-stage albite. Apparently no optically resolvable perthitic intergrowths were represented in the samples tested. In order to test the possible preference of secondary albite rims to any particular boundary, a similar analysis was undertaken using two sections from sample 25. The major presence of perthite adds four more possible boundary contacts to the six analyzed by Tuttle.

The results clearly indicate a relationship of secondary albite to the original perthites (Table III). Either one or both of the boundaries of the secondary albite are in contact with perthitic grains. This tends to substantiate the hypothesis that the secondary albite originated from pre-existing perthites caused by unmixing. Although the close relationship is evident, and the unmixing hypothesis feasible, the writer has no precedent to refer to nor can he comprehend any reason for segregation at grain boundaries in preference to other portions within the perthites. Strain relationships at grain boundaries may be a partial explanation for rocks of metamorphic ancestry but this fails to explain a similar phenomenon found in magmatic rocks which have been subjected to no appreciable deformation. Sample 25 exhibits a relationship which may be pertinent to the problem of unmixing. Secondary albite is almost always in crystallographic continuity with the albite blebs included in an adjacent grain. No systematic analysis was undertaken to substantiate this, and it is presented merely as a cursory observation.

Much of the sodic plagioclase within the pegmatites has undergone extensive alteration to a fine-grained aggregate of minute flakes believed to be paragonite (Fig. 5). The potash feldspar is generally clear, but occasional evidence of seritization can be detected. Biotite

TABLE III

RELATION BETWEEN ALBITE RIMS ON GRAIN BOUNDARIES

Contact	Total Traversed	With Secondary Albite	Percentage Rimed
Quartz-quartz	12	0	0
Quartz-microcline	10	0	0
Quartz-plagioclase	14	0	0
Quartz-perthite	20	8	40
Plagioclase-perthite	20	18	90
Perthite-perthite	62	55	89
Microcline-perthite	12	10	83
Plagioclase-plagioclase	30	1	3
Plagioclase-microcline	5	0	0
Microcline-microcline	11	0	0
Total	196	92	

is also extensively altered to green chlorite. Certainly the rock has been affected by late igneous or hydrothermal solutions.

Generally, the pegmatites are interpreted as resulting from the modification and alteration of pre-existing pegmatites which represented the youngest unit in the area. They have been subjected to regional deformation but have since been recrystallized. The lack of cataclastic textures could possibly indicate plastic deformation. Another alternative might be the complete obliteration of cataclastic textures by replacement and recrystallization.

"Host Rock"

The "host rock" is a complex of injected, replaced, and metamorphosed gneiss. The general term is used to include all rock types within the area except the pegmatites and "hanging-wall gneiss." The zone includes the major ore body and a small area, locally termed "footwall." The footwall portion, at the western edge of the area, is strictly an assay contact based on economic factors, and is therefore included in this major rock type. Within the Newton Falls Pit the "host rock" includes all the area west of the generally north-south trending pegmatitic contact (Fig. 2). Interpretations relative to ore emplacement are not discussed, and the emphasis here is restricted to the actual host rock. The rock types are extremely variable but field evidence indicates a general zonal distribution of various lithologic units. The individual segments are characterized by extraordinary quantities of certain mineral assemblages. The general outline of the zones roughly parallels the hanging-wall contact forming large bands or lenslike belts. Zones are not separated by any set boundaries, and all contacts are gradational. Field evidence indicates four general zones. Those encountered traversing westward from the hanging-wall contact are (1) "disseminated garnet gneiss," (2) "sillimanite gneiss," (3) "ferro-magnesian gneiss," and (4) "blotchy garnet gneiss." The "blotchy garnet gneiss" generally represents the footwall although as previously mentioned this is an assay contact. The lithologic terms applied are those used locally. The prefix designates the mineral assemblage characteristic to the particular zone, but this in no way infers limits beyond which specified minerals may occur.

For the most part all the rock exhibits a gneissic texture which is generally concordant with the major north-south trend of the hanging-wall contact. Locally there are numerous exceptions, and in certain portions the rock may even appear massive. Banding is made conspicuous by variations in the quantity of iron oxide admixed with quartz and feldspar. Minerals identified megascopically are iron oxide, potash feldspar, sillimanite, garnet, pyroxene, biotite, pyrite, chlorite, calcite, epidote, molybdenite, and serpentine. Sample locations are indicated on Figure 2.

Sample No. 17. In thin section the principal minerals are magnetite and potash feldspar. Also present but less abundant are cordierite, quartz, epidote, clinozoisite, and chlorite. Traces of pyrite, biotite, sillimanite, and sericite complete the mineral assemblage (Table IV). The abundant magnetite replaces all minerals but reflects a definite preference for what appears to have been ferromagnesian minerals. The iron oxide is entirely magnetite, with no evidence of oxidation to martite. By usual flat stage methods the potash feldspar appears to be orthoclase, and in cursory examination could easily be mistaken for quartz due to its clearness and lack of distinguishable cleavage. The feldspar often exhibits a shadowy or undulatory extinction but is never twinned. Unequivocal proof that the untwinned feldspar is microcline, rather than orthoclase, could not be established. Anhedral cordierite containing abundant inclusions is present, exhibiting a positive optic angle. Twinning is for the most part absent, but a few examples of simple sector twin patterns were observed. Quartz is present as a late mineral often found penetrating the feldspars. Clinozoisite and epidote occur as formless masses with noticeable variations in birefringence within

TABLE IV

MODAL ANALYSES OF "HOST ROCK"

Analysis	Sample No. 17	No. 24	No. 12	No. 35	No. 22
Quartz	8	3	11	5	36
Microcline			65		
K-feldspar[a]	21	62		41	7
Magnetite	52	22		8	15
Martite		8	21		
Biotite	tr.			33	12
Apatite			tr.	3	1
Epidote[b]	9	1	tr.	tr.	
Zircon		tr.	tr.		
Sercite	tr.				
Chlorite	2	3	tr.	2	
Garnet			tr.	3	
Saussurite[c]					26
Cordierite	8				2
Sillimanite	tr.		1		
Calcite					tr.
Pyrite		tr.		4	tr.
Leucoxene					tr.
Serpentine		tr.			
Total	100	99	98	99	99

[a]K-feldspar is always untwinned, and commonly exhibits undulatory extinction.

[b]Includes zoisite, clinozoisite, and epidote.

[c]Consists of complex aggregate, including chlorite, epidote, feldspar, zoisite, clinozoisite, sericite, and quartz.

single grains. Most of the clinozoisite exhibits an anomalous rich dark blue interference color. Chlorite rims epidote, clinozoisite, and magnetite at grain boundaries. A few elongate needles of sillimanite are present as a late mineral. For the most part, traces of biotite have been either replaced or completely altered. Minute zircons and garnets occur as inclusions within feldspar and cordierite.

Sample No. 24. The rock is composed almost entirely of iron oxides and potash feldspar (Fig. 9) with a minor amount of quartz, chlorite, and biotite (Table IV). Traces of pyrite, epidote, zircon, and serpentine were also recognized in thin section. The potash feldspar is again untwinned, exhibiting pronounced undulatory extinction. Numerous curved, streaklike inclusions are commonly within the feldspar. The composition of these streaks was undetermined although in part they appear to be a fine aggregate of chlorite. The majority of the iron oxide is magnetite which has been partially oxidized to martite. The habit of quartz is unique in that it is ubiquitously associated with a fine aggregate of green chlorite (Figs. 10 and 11). Several frayed grains within a patch of chlorite are usually in crystallographic continuity. The quartz exhibits no undulatory extinction. Brown tablets of biotite have been almost completely altered to chlorite and epidote. In part they appear

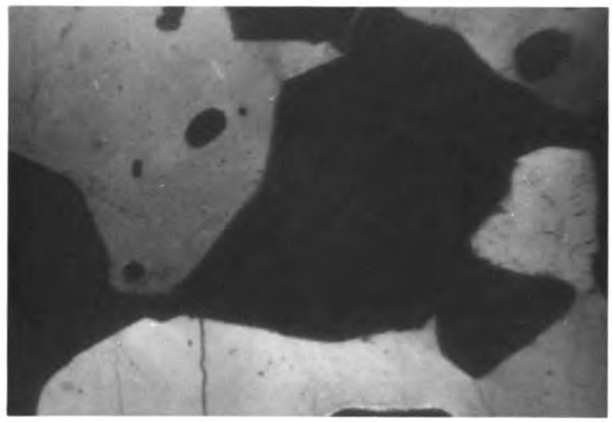

Figure 9. Photomicrograph of sample 24 showing untwinned potash feldspar and replacing magnetite. Crossed nicoles, ×32 diameters.

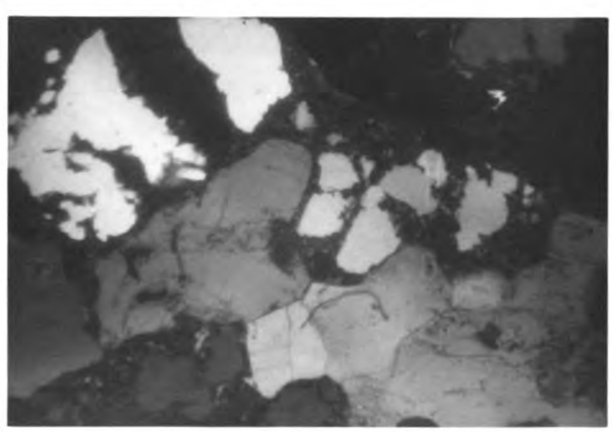

Figure 10. Photomicrograph of sample 24 showing frayed quartz grains, in crystallographic continuity, surrounded by chlorite. Crossed nicols, ×32 diameters.

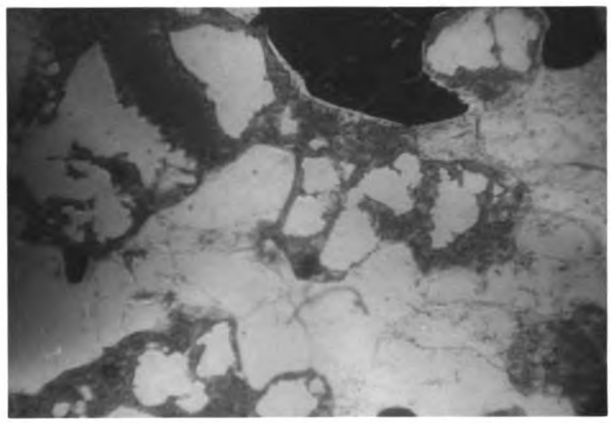

Figure 11. Same as Figure 10, using plain light.

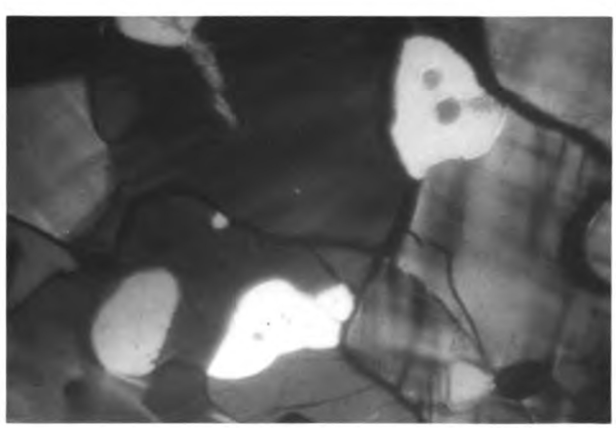

Figure 12. Photomicrograph of sample 12 showing twinned microcline and fractures at grain boundaries. Crossed nicols, ×32 diameters.

massive when included within magnetite. Alteration products within certain grains vary from chlorite in the center to epidote on the edges. Minute zircons are included within the feldspar. Small patches of leucoxene occur as either an alteration or exsolution product of magnetite or ilmenite.

Sample No. 12. In order of decreasing abundance, the rock consists mainly of potash feldspar, iron oxide, and quartz (Table IV). Subordinate sillimanite and traces of apatite, zircon, garnet, and chlorite complete the mineral assemblage. The character of the potash feldspar differs appreciably from that typically inherent to "host rock" in that pronounced grid twinning is exhibited, making possible the positive identification as microcline (Fig. 12). The grains average 1.0 mm., and are extraordinarily clean. All the iron oxide is martite, although identification was based on similarities with other samples. No corroded relics of magnetite or octahedra pseudomorphs could be identified, and therefore, on the basis of this sample, positive classification of the iron oxide was not conclusive. Quartz is present in two habits, most of it forming leaflike masses engulfing and penetrating microcline. This quartz is characterized by planes of liquid inclusions and exhibits undulatory extinction; it is interpreted as being related to a late period of introduction. Early quartz appears sparsely as small, well-rounded grains. Finely fibrous aggregates of sillimanite are present as a minor constituent. Minute zircons and apatites are included in microcline and quartz. Traces of garnet appear partially chloritized. In thin sections as well as hand specimen there is a marked tendency to fracture at grain boundaries, making the rock characteristically friable (Fig. 12).

Sample No. 35. Major constituents consist of feldspar and biotite with subordinate magnetite, quartz, pyrite, apatite, garnet, and chlorite (Table IV). Traces of epidote and leucoxene also appear. The potash feldspar is very similar to the untwinned variety previously described, exhibiting undulatory extinction. Large brown biotite flakes appear extremely clean and unaltered--exhibit subparallel orientation (Fig. 13). The biotite is one of the latest minerals formed, and its presence can be most likely attributed to recrystallization during metamorphism. All the iron oxide present is magnetite, with no evidence of oxidation. Spherical grains of quartz, partially undulant, are enclosed within feldspar. Numerous shreds of pyrite are present, replacing all major constituents except biotite. The majority of the pyrite is intimately associated with green chlorite. Many large apatite crystals measuring 0.5 mm. are everywhere

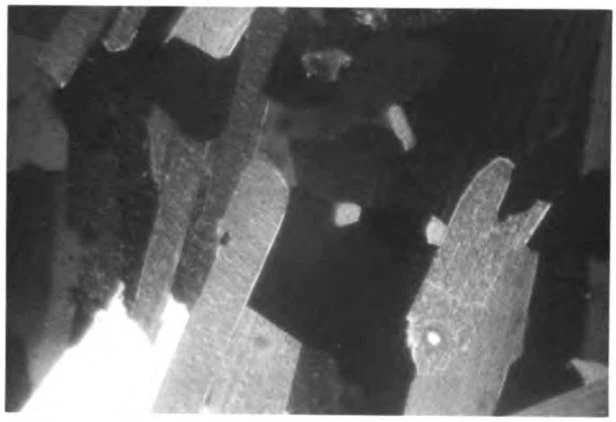

Figure 13. Photomicrograph of sample 35 showing subparallel orientation of large fresh biotite flakes. Crossed nicols, ×32 diameters.

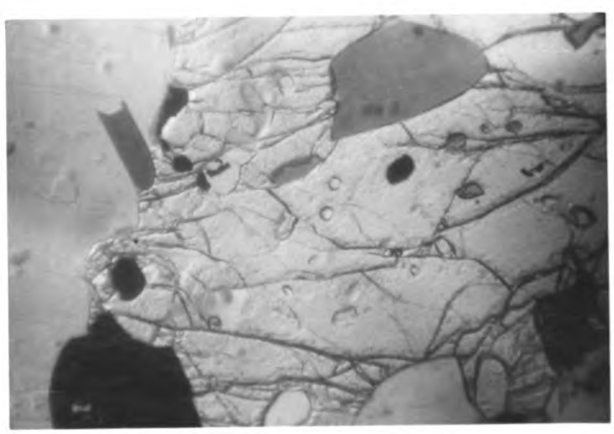

Figure 14. Photomicrograph of sample 35 showing large poikilitic garnet. Plain light, ×32 diameters.

included in other minerals. One apatite crystal is completely surrounded by garnet. Large anhedral garnets are observed including small fragments of quartz and feldspar showing a poikilitic texture (Fig. 14). Other small garnets are partially altered to chlorite. A sparse amount of epidote occurs as formless masses.

Sample No. 22. In thin section this dark greenish rock consists mainly of quartz and a complex aggregate of what resembles saussurite (Table IV). Other abundant minerals are magnetite, biotite, and potash feldspar. Occasional grains of cordierite and apatite and traces of pyrite and calcite were also identified. Quartz grains are characterized by numerous fractures and irregular boundaries, some of which appear frayed. Undulatory extinction is pronounced in some grains and absent in others. The quartz appears cloudy and weathered, caused in part by inclusions. An abundant complex aggregate containing chlorite, epidote, feldspar, zoisite, clinozoisite, sericite, and quartz closely resembles saussurite (Figs. 15 and 16). In part the saussurite pseudomorphically replaces plagioclase, and emphasizes relic bands of what appear to have been simple albite twin planes. The iron oxide is entirely magnetite and replaces all major minerals except biotite. The occurrence of biotite is similar to that described for sample 35; namely, large, fresh, brown

Figure 15. Photomicrograph of sample 22 showing fractured quartz and fine aggregate of saussurite. Crossed nicols, ×32 diameters.

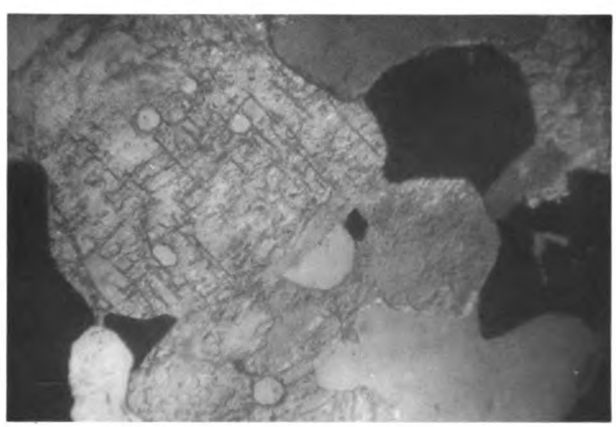

Figure 16. Same as Figure 15, using plain light.

flakes. Potash feldspar is untwinned, and cordierite exhibits simple sector twinning at best. Apatite crystals form relatively large ellipsoids which on cursory examination appear roughly oriented. Traces of pyrite and calcite are attributed to late secondary introduction. Generally the rock exhibits a cataclastic texture which has been obliterated largely by the addition of new minerals and recrystallization.

Petrologic interpretations. A few of the more unique characteristics observed during field and thin section study are discussed with possible implications relative to the history of the "host rock."

With the exception of sample 12, all the potash feldspar observed is untwinned and generally clear and colorless. Within sample 12 the feldspar is pink and definitely twinned as microcline. Field evidence indicates the pink twinned variety is generally related to areas in which the predominant iron oxide is martite. These areas are also characteristically friable, with the degree of friability increasing relative to the increase in nonmagnetic ore (Crump, personal communication). The clear untwinned variety commonly exhibits undulatory extinction, and for the most part cleavage can be detected only at the edges of thin sections. The optic sign is negative with variable angles measuring from 45° to 80°. No unequivocal proof could be determined in order to establish the feldspar as triclinic or monoclinic. The phenomenon of undulatory extinction in untwinned microcline has been interpreted by Laves (1950, p. 553) as resulting from either the relative variation in the deviation from monoclinic symmetry at various positions within the crystal or that the crystal is actually submicroscopically twinned, but the proportion of the right and left twin positions vary resulting in different extinction angles. No precedent can be referred to with reference to environmental conditions producing these phenomena. Very little is known of the stability relationships between microcline and orthoclase. The writer can only suggest that if the original feldspar was microcline it has lost its optically resolvable twinning as a result of metamorphism. However, alteration would tend to produce a more stable form, probably decreasing the planes of symmetry by converting from a monoclinic to a triclinic feldspar. According to Winchell and Winchell (1951, p. 276), shearing stresses favor the inversion of orthoclase to microcline. This might account for the twinned microcline associated with the rock characteristically friable. Assuming the friability was inherent, these areas would favor distortion by shear and therefore either retain the typical twinning or rejuvenate it during later periods of deformation. Certainly a more detailed study of feldspars is required, and when more concise knowledge relative to their stability relationships is known, some pertinent information with respect to environmental conditions during the conversion of the "host rock" might well be revealed.

Extensive permeation of the "host rock" by solutions and emanations was particularly effective in the formation and alteration of many minerals. Secondary quartz appears throughout the entire area, but this addition is subordinate to that observed in the "hanging-wall gneiss." In the west end (samples 22 and 35) there appears a marked increase in the quantity and size of apatite crystals, indicating active phosphate-bearing solutions. This is also closely associated with the occurrence of garnet. Evidently formation of these minerals was closely related as indicated by apatite completely surrounded by garnet.

Alteration of mafic minerals to chlorite and epidote, the presence of saussurite (Figs. 15 and 16) and seritization of feldspar all indicate the extensive reconstitution caused by secondary solutions. In part these may also represent a retrograde metamorphic effect. Heinrich (1956, p. 257) attributes the process of saussuritization in metamorphic rocks to such retrograde processes. He also describes the process as the breakdown of plagioclose into Na and Ca products. Although the Ca constituents could be accounted for in sample 22, no clear albite granules were observed, but these are possibly present in the fine granular aggregate and remained undetected.

There is a noticeable absence of plagioclase within the "host rock." Megascopic plagioclase has been detected west of the assay contact, referred to as footwall. Apparently the plagioclase has been completely altered or replaced within the "host rock." Evidence of the extensive alteration is indicated by the presence of saussurite which in some cases appears to replace plagioclase pseudomorphically.

The extreme complexity and variations in mineral assemblages and textural characteristics induces numerous difficulties in attempting to relate the ancestry of the "host rock." The problem is further enhanced by extensive recrystallization, complex metamorphism, and the addition of solutions and emanations which have for the most part obliterated relic textures.

The structural relationships and compositions indicate the rock was at least in part of sedimentary origin. The tendency for the zonal distribution of minerals such as sillimanite, garnet, and biotite reflect the metamorphic history. The zoning possibly indicates variations in thermal gradients, but a detailed study of the relationships was not undertaken. In all probability the original sediments were of heterogeneous composition, restricting the presence of minerals to areas where the appropriate assemblages existed.

Much of the recrystallization and permeation must have taken place during the final stage or after the major period of disturbance. This is indicated by the absence of cataclastic textures which one certainly would expect to find in rocks subjected to such intense deformation.

STRUCTURAL GEOLOGY

Structural Framework

The structural pattern of the area consists of the eastern limb of a major north-south trending syncline, which is, for the most part, overturned to the west and appears as a fishhook in plan. South of the Newton Falls Pit a large anticline-syncline structure is superimposed on the major syncline. These structures plunge to the south while the major syncline plunges north.

Minor Folds

The Newton Falls Pit is marked by numerous crenulations ranging in amplitude from less than a centimeter to several feet. These small-scale folds are almost entirely isoclinal or overturned, with open folds exceedingly rare. Considering the structure as a whole, field evidence indicates a general parallelism of the axial planes of minor folds with that of the major syncline. When observing restricted localities in more detail there are numerous exceptions to the general rule. The divergent pattern is extremely complicated and predominates at the western portion of the area near the footwall. No consistency was revealed from cursory measurements. The axes of minor folds plunge both to the north and south, with the angle of plunge extremely variable, ranging from nearly horizontal to vertical.

Banding, Lineation, and Foliation

The most prominent structural feature of the area is the banding. With the exception of a few minor localities all the rock types encountered exhibit a gneissic texture. The most common type of banding in the "host rock" is a result of the segregation of iron oxides and feldspar into layers. Banding is made conspicuous in "hanging-wall gneiss" and pegmatites by the relative quantity of quartz admixed with feldspar. The bands range from a few millimeters to several feet in thickness and may be continuous for many yards or pinch out within inches.

The most common type of foliation is the alignment of biotite flakes into subparallel orientation. Although this feature is less prevalent than banding, it locally accentuates the gneissic texture.

Numerous examples of lineations occur, but measurements with reference to trend were restricted to a few pods of sillimanite. These lineations are generally in b when referring to the major fold axis.

Joints and Faults

Joint sets were mapped in detail during the summer of 1955 (Fig. 2). More than 3,775 joint planes were measured throughout the Benson Mines. A concentration of 1,990 planes was encountered at the Newton Falls Pit. To facilitate interpretations, contoured face pole diagrams were prepared on the lower hemisphere of a Schmidt equal-area net referring to the method outlined by Billings (1942, pp. 120-121). "Hanging-wall gneiss" and "host rock" were analyzed individually, and separate diagrams prepared for each (Figs. 17 and 18).

The most prominent set in the "hanging-wall gneiss" ranges in strike from N. 5° E. to N. 20° E., and dips 50°–70° eastward. In the vicinity of sample 19 the planes of this set are less than six inches apart and consist of well-defined parallel fractures. The set occurs throughout the entire "hanging-wall gneiss" but the concentration of planes decreases in adjacent areas. Joints of this set are for the most part subparallel to local banding. They are almost always accompanied by a second set which strikes from N. 70° E. to E.-W. and dips steeply southward, in many places up to 80°. These planes are approximately perpendicular to banding and foliation. The fractures are open and often stained by ferric iron or filled with

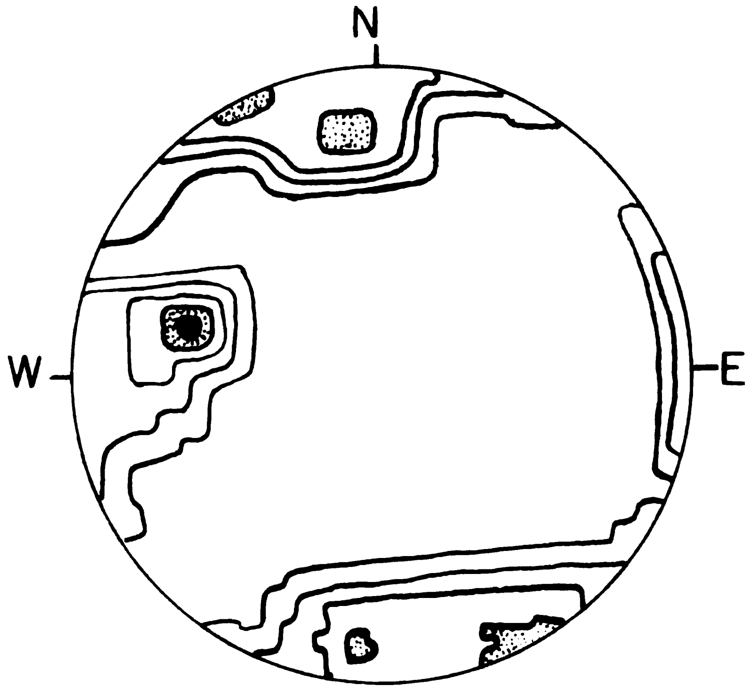

Figure 17. Eight hundred eighty poles to joints of "hanging-wall gneiss." Contours 12-8-5-3-1 percent.

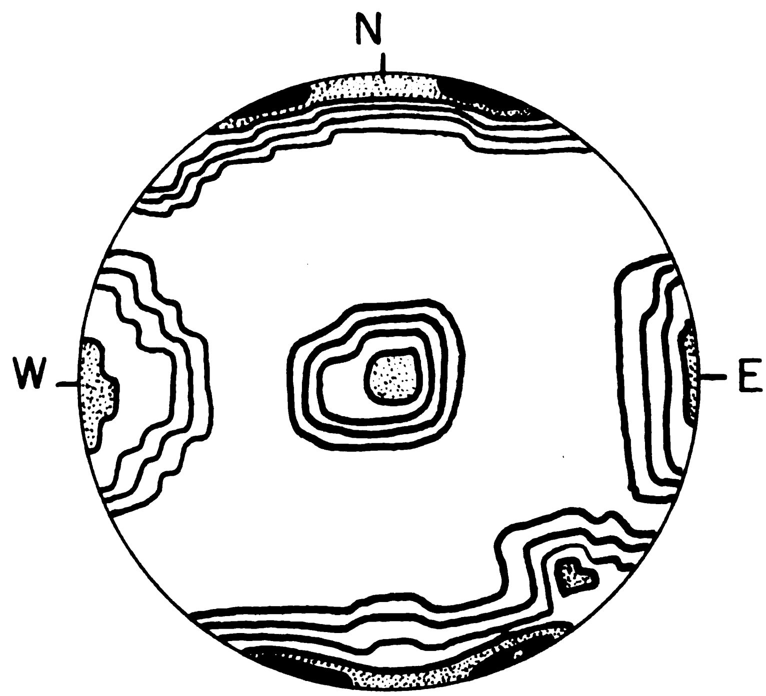

Figure 18. One thousand one hundred poles to joints of "host rock." Contours 12-8-5-3-1 percent.

secondary minerals. These are interpreted as typical ac tension joints. A third and fourth set may be genetically related to these tension joints. The planes are of similar appearance, but they deviate significantly relative to strike and dip. One of these sets is almost always vertical, and strikes approximately N. 65° E. The strike of the second set ranges from N. 85° W. to E.-W., and dips steeply northward (80°—90°). Although two or more planes commonly intersect, no two sets within the "hanging-wall gneiss" could definitely be established as forming a conjugate system.

Similar sets occur within the "host rock" but the equal-area projections (Figs. 17 and 18) illustrate variations in trend and concentration. Two major sets commonly occur together and may represent a conjugate system. One set strikes from N. 65° W. to N. 80° W., while the second ranges from N. 60° E. to N. 75° E., and both vary only slightly from vertical dips. The two planes do not always occur together, and either may individually intersect with some other set. If these planes represent a conjugate system the acute bisectrix lies roughly horizontal in an E.-W. plane. Steeply dipping planes (75°—90°) which strike parallel or subparallel to the foliation and banding constitute a set similar to the one predominating in the "hanging-wall gneiss." A group of nearly horizontal planes (0°—15°) form a set unique to the "host rock." The fractures are for the most part jagged and curved, lying roughly in the bc plane. These are interpreted as representing tension cracks.

A major fault trending N.-S., and dipping steeply (55°—90°) in an easterly direction, roughly parallels the regional structure. This fault is believed to separate the "hanging-wall gneiss" and "host rock" throughout the entire area, but the actual extent of the fault plane was not established. Movement on this fault was likely early in the geologic history of the area. The plane later acted as a channelway for intruding pegmatites which have obliterated evidence of relative movement. Small faults of minor displacement were encountered throughout the area. It was also impossible to ascertain the relative movement on any of these faults.

PETROFABRICS

In order to determine possible relationships between megascopic and microscopic fabric orientations a petrofabric study was undertaken. Twenty-two oriented thin sections were prepared from nine samples. Figure 2 shows the location of the samples studied All samples were oriented in the field relative to true north and a horizontal plane. Intense magnetic attractions necessitated using a sun compass for bearing determinations. Two sections were cut from samples exhibiting a pronounced banding or foliation, one parallel and one perpendicular to the planar element. When no conspicuous fabric element could be observed, three sections were cut respectively parallel to a horizontal, a north-south vertical, and an east-west vertical plane.

Quartz Orientation

A study was made of the orientation of the c-axes of quartz grains. Using a 4-axes Universal Stage, standard orientation procedures were applied, referring to the method outlined by Fairbairn (1954, p. 264). All points were plotted on the lower hemisphere of a Schmidt equal-area net. Diagrams were prepared from fifteen thin sections and then each diagram was rotated to a horizontal plane. To facilitate observations and interpretations, a composite diagram was compiled and contoured for each sample (Figs. 19 to 24).

Figure 19 shows 626 quartz axes plotted from three thin sections from sample 9. The rock exhibits a faint foliation striking N. 2° W. and dipping 60° NE. This was taken as the ab plane, with b assumed nearly horizontal as indicated by the regional fold axis. The quartz-axis diagram is almost isotropic, although a 3 percent maximum occurs. This weak orientation roughly strikes N. 25° E. and plunges 40° SE., apparently independent of regional structures.

Figure 20 represents three sections cut from sample 19. Megascopic banding is weakly defined striking N. 3° E., dipping 80° SE. Orientations of 678 quartz axes shows a concentration of 3 percent per 1 percent area in a small zone near a. This point concentration approximates a similar orientation described by Fairbairn (1949, pp. 118-121) as maximum I of his synoptic quartz-axes diagram, and is believed common because of the numerous possible needle orientations with relation to predictable ruptures in quartz.

A quartz-axes diagram of 436 grains from sample 5 (Fig. 21), representing a pegmatitic rock, shows a 4 percent maximum and a weakly defined incomplete girdle. The incomplete girdle parallels

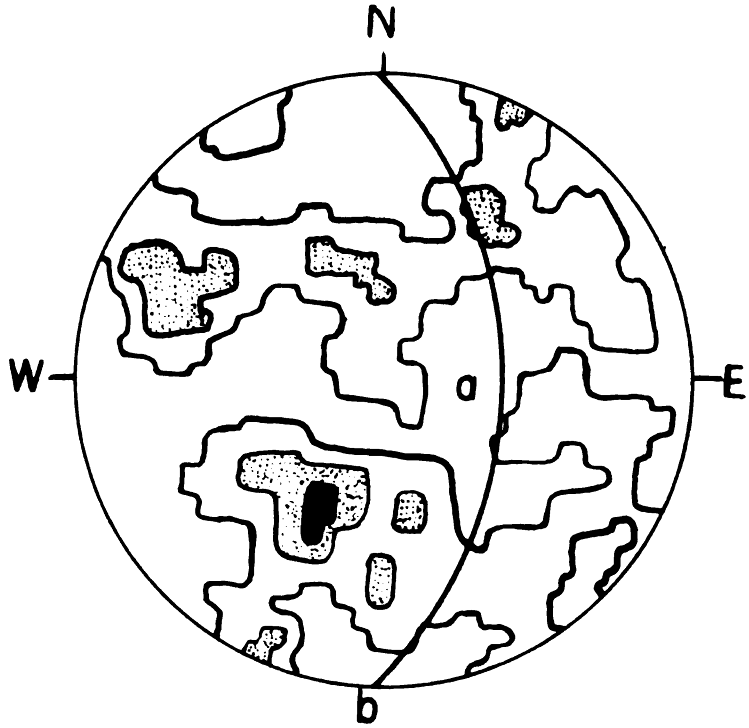

Figure 19. Six hundred twenty-six quartz axes from sample 9. Contours 3-2-1 percent.

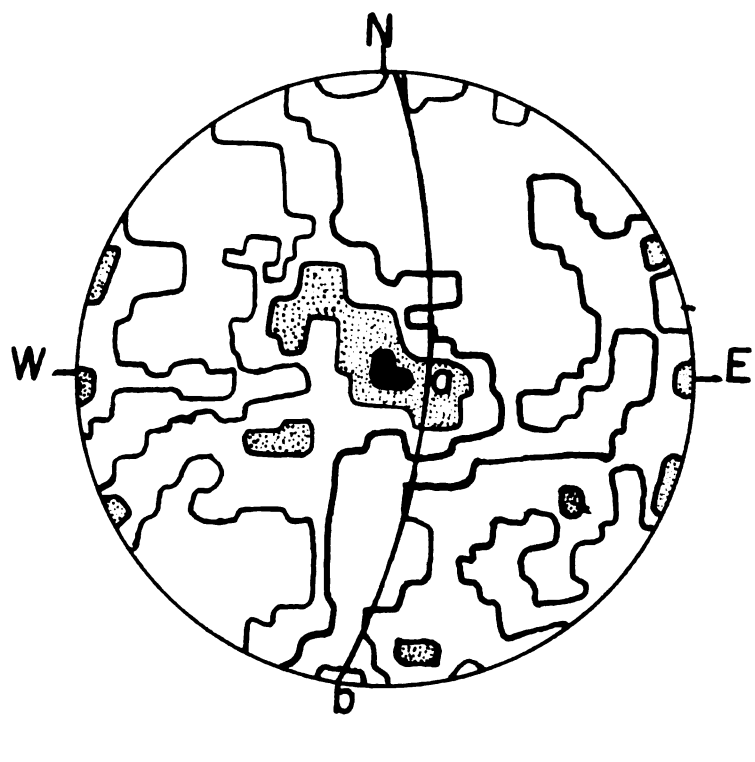

Figure 20. Six hundred seventy-eight quartz axes from sample 19. Contours 3-2-1 percent.

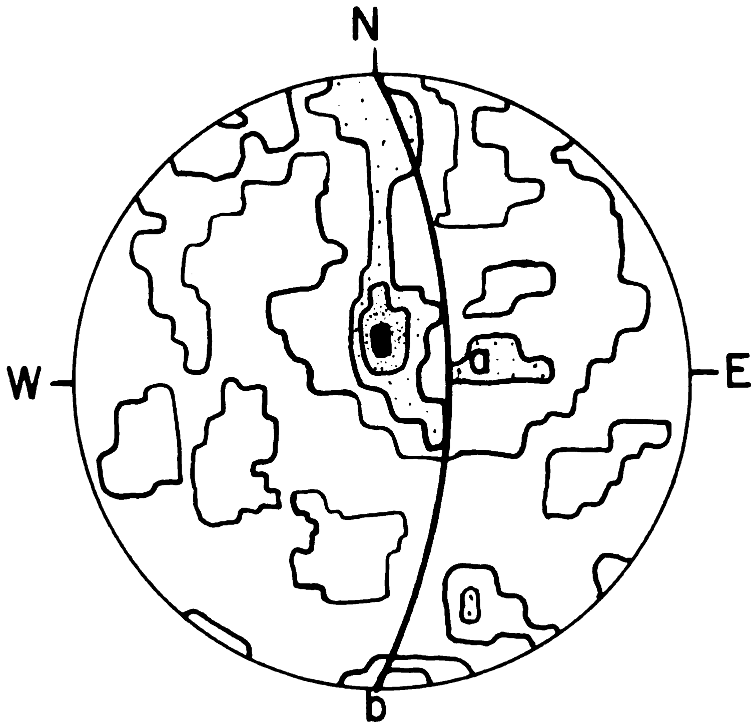

Figure 21. Four hundred thirty-six quartz axes from sample 5. Contours 4-3-2-1 percent.

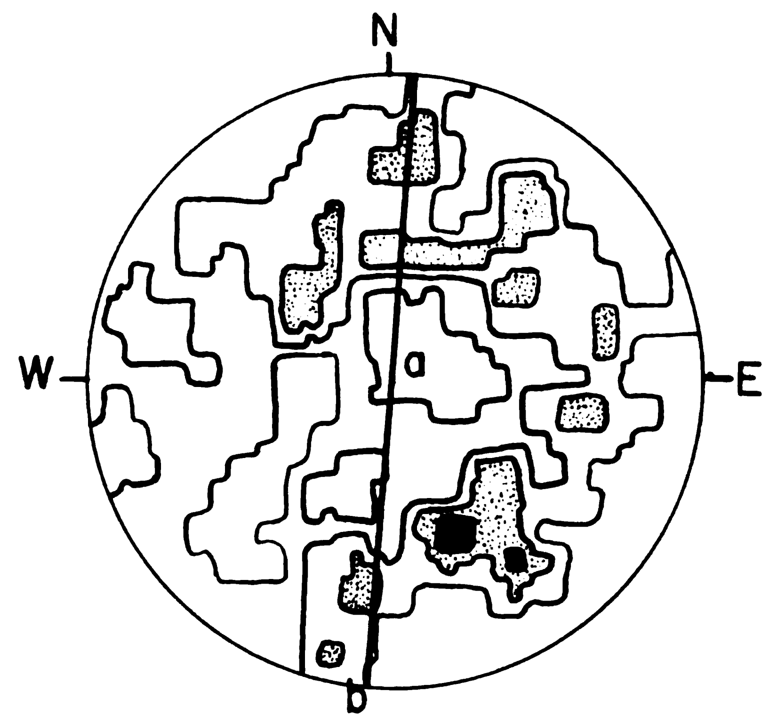

Figure 22. Four hundred forty-three quartz axes from sample 12. Contours 3-2-1 percent.

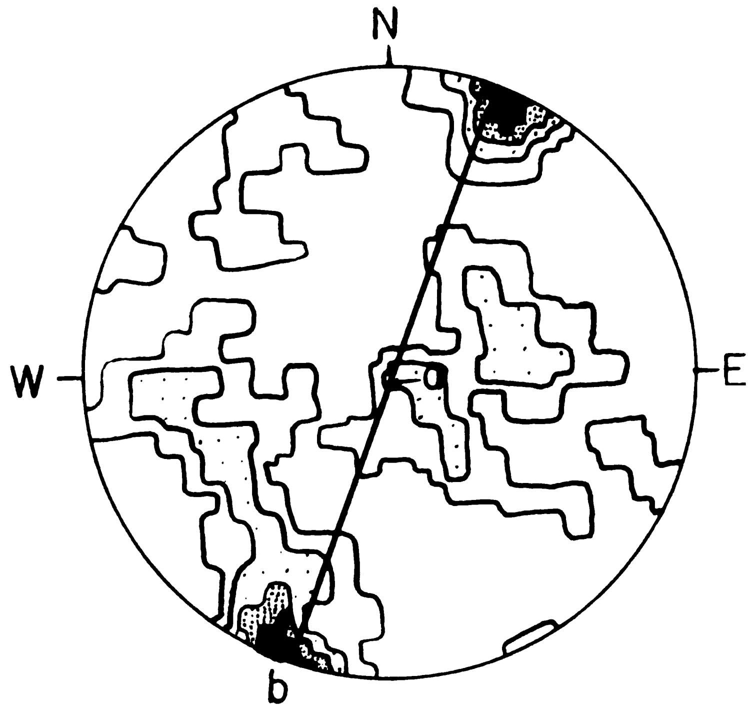

Figure 23. Four hundred sixty-eight quartz axes from sample 35. Contours 4-3-2-1 percent.

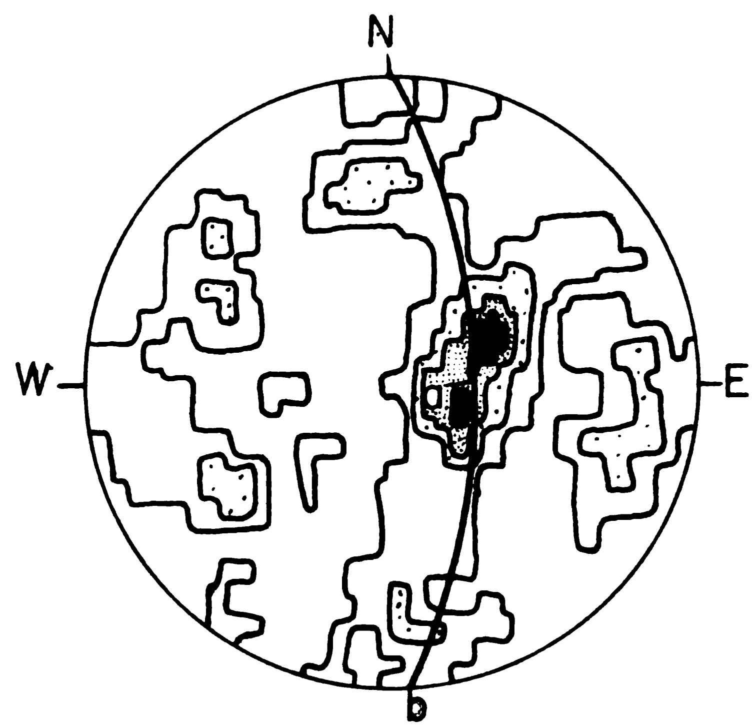

Figure 24. Four hundred seventy quartz axes from sample 22. Contours 4-3-2-1 percent.

the N.-S. strike of a well-defined megascopic foliation. The quartz axes deviate slightly from the ab foliation plane which dips 75° E. The small zone of 4 percent maximum represents axes trending N.-S. and plunging roughly 80° N. The orientation of this poorly defined fabric may be ascribed to a relic fabric induced during the injection of the pegmatite. The original orientation may have been partially retained during later replacement and recrystallization.

The diagram of sample 12 (Fig. 22) again exhibits no positive relationships with the inferred major structural features. Two sections comprising 443 quartz axes present two small zones of 3 percent maxima. The largest of these trends N. 25° W. and plunges on the average of 45° SE. The second maximum strikes near N. 35° W., plunging 30° SE. Megascopic banding is fairly well defined, trending N. 5° E. with a vertical dip. The relatively haphazard fabric pattern may be attributed to the friable nature of the rock. Mechanical rotation of grains at varying degrees obliterate any preferred orientation and the diagram would not represent the true fabric.

The composite diagram of sample 35 represents 463 quartz axes from three thin sections (Fig. 23). Megascopic foliation planes are vertical and trend N. 22° E. A maximum of over 4 percent forms a relatively large zone with the axes paralleling the inferred b axes. This type of concentration is uncommon, and described

by Fairbairn (1949, pp. 118-121) as maximum VIII, which is dependent on needles bounded by a prism plane in ab. In the vicinity of sample 35 the trend of the megascopic foliation is extremely variable. The inferred a and b axes may not represent the true orientation, and it is feasible that these axes could possibly be reversed in portions of this sector.

Figure 24 shows 470 quartz axes plotted from two sections from sample 22. The megascopic foliation, made conspicuous by the subparallel orientation of biotite flakes, strikes N.-S. and dips 80° E. The inferred a axis lies between two 4 percent maxima and is completely bounded by a zone representing a concentration exceeding 3 percent. The quartz grains within the sample are elongate, and cursory measurements indicated a close relationship between grain shape and lattice orientation. The quartz grains are in part fractured, showing some granulation. Generally the habit of these quartz grains appears older than those previously mentioned. The writer believes that fragmentation took place during an early stage of granulation and that orientation occurred later according to form.

The general lack of any definite girdles and the appearance of only weak point maxima indicates to the writer that postdeformational replacement and recrystallization has for the most part obliterated any preferred orientation of quartz. The almost isotropic quartz fabric of all the samples analyzed also substantiates the petrologic interpretation referring to a late period of quartz introduction. The weak maxima may be a result of the retention of a pre-existing fabric by replacing solutions.

Biotite Orientation

Biotite orientation was investigated in six samples consisting of fifteen thin sections. The analysis consisted of orienting face poles to the 001 cleavage planes while treating the mineral as uniaxial and employing the standard procedures described by Fairbairn (1949, pp. 262-266). Composite contour diagrams were compiled (Figs. 25-30) and megascopic ab planes were plotted with reference to the inherent foliation and banding.

All the samples analyzed show a strong concentration of poles around c, the flakes being parallel to ab with a tendency to spread both on ac and bc. Sample 35 (Fig. 29) shows a second concentration between a and c. A petrologic study of the sample revealed numerous biotite flakes related to a late period of formation. The second concentration, apparently unrelated to megascopic foliation, may be a result of neocrystallization. This is a process of recrystallization involving the development of new minerals among a pre-existing fabric element.

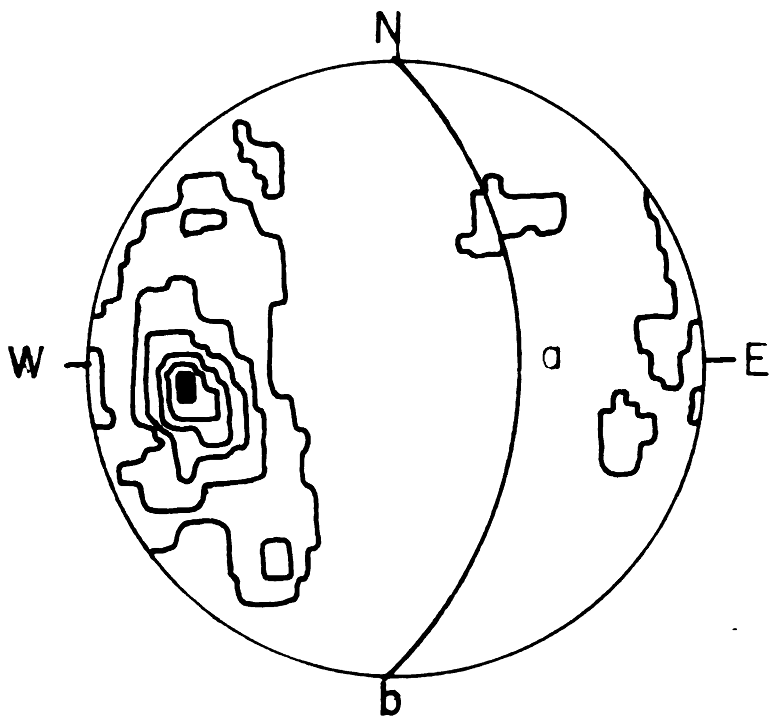

Figure 25. Four hundred ninety-six poles to (001) cleavage in biotite from sample 9. Contours 11-7-5-3-1 percent.

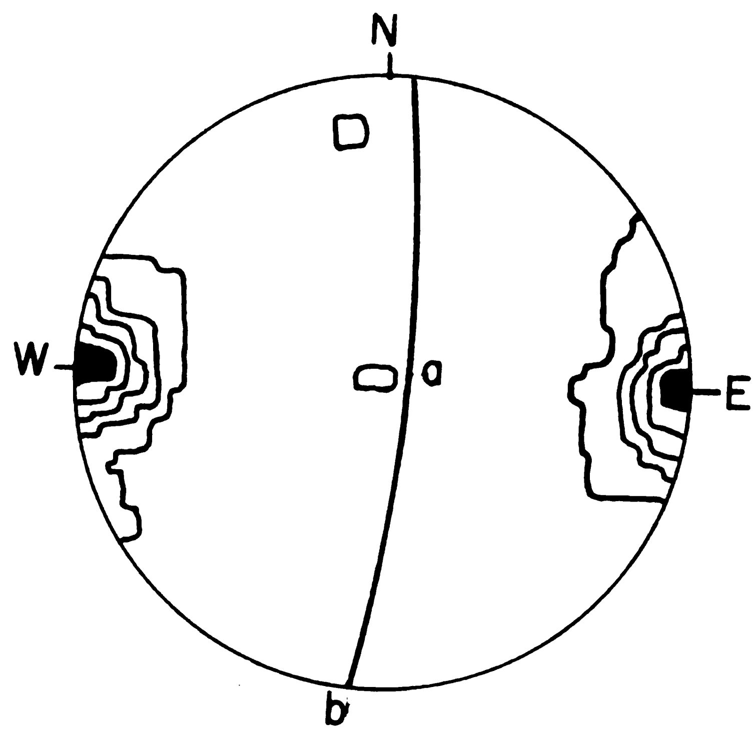

Figure 26. Four hundred ten poles to (001) cleavage in biotite from sample 19. Contours 16-10-7-4-1 percent.

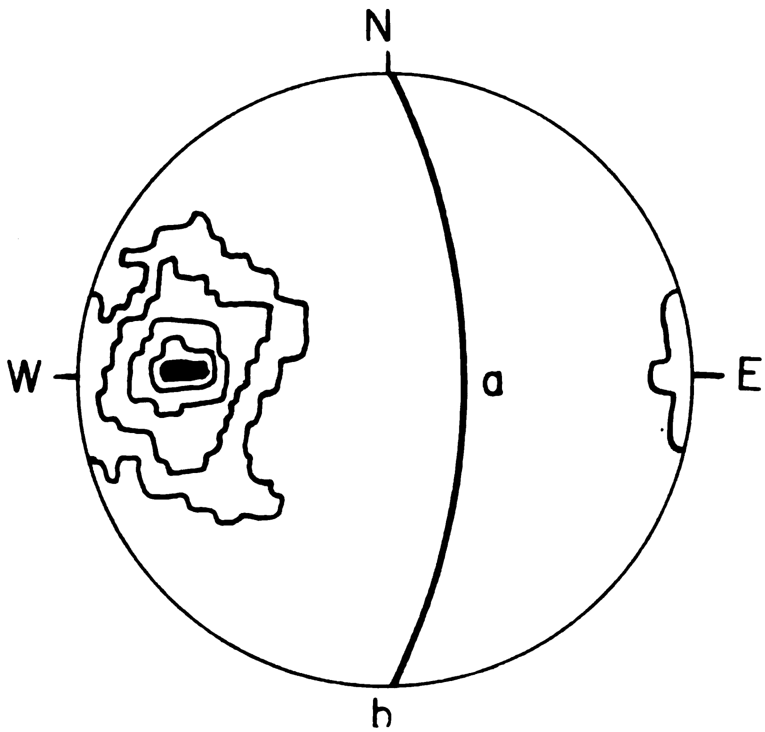

Figure 27. Two hundred sixty-four poles to (001) cleavage in biotite from sample 5. Contours 19-16-10-4-1 percent.

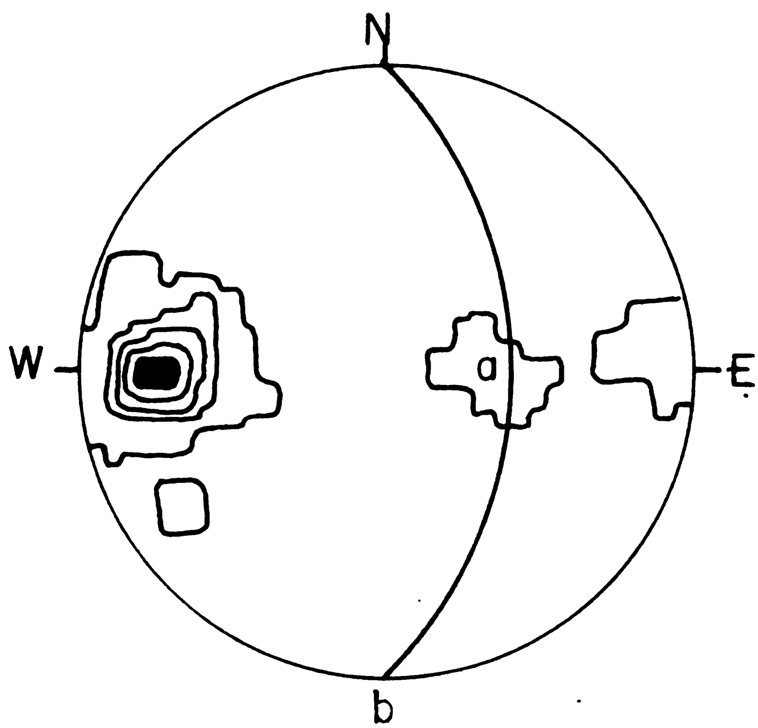

Figure 28. One hundred seventy-one poles to (001) cleavage in biotite from sample 25. Contours 25-19-13-7-1 percent.

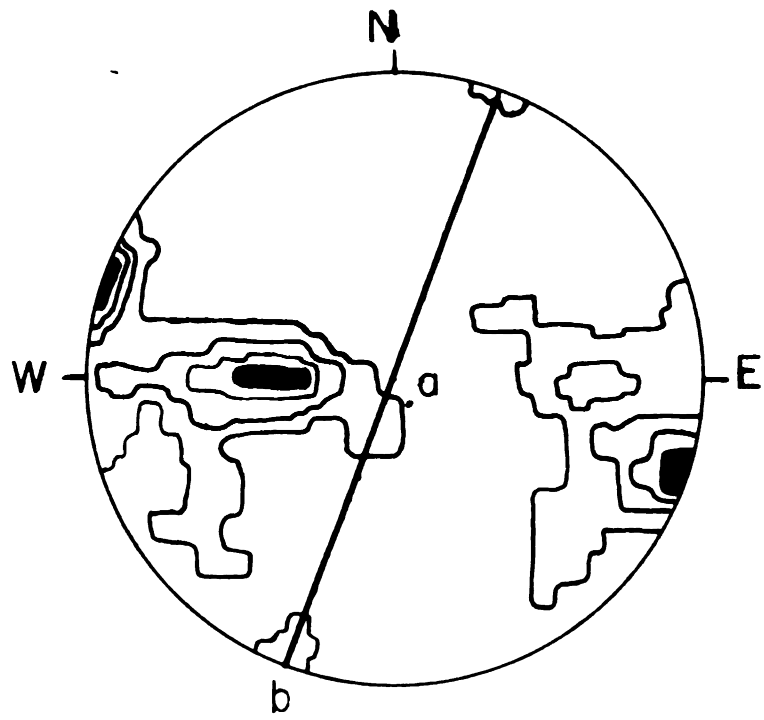

Figure 29. Four hundred thirty-one poles to (001) cleavage in biotite from sample 35. Contours 7-5-3-1 percent.

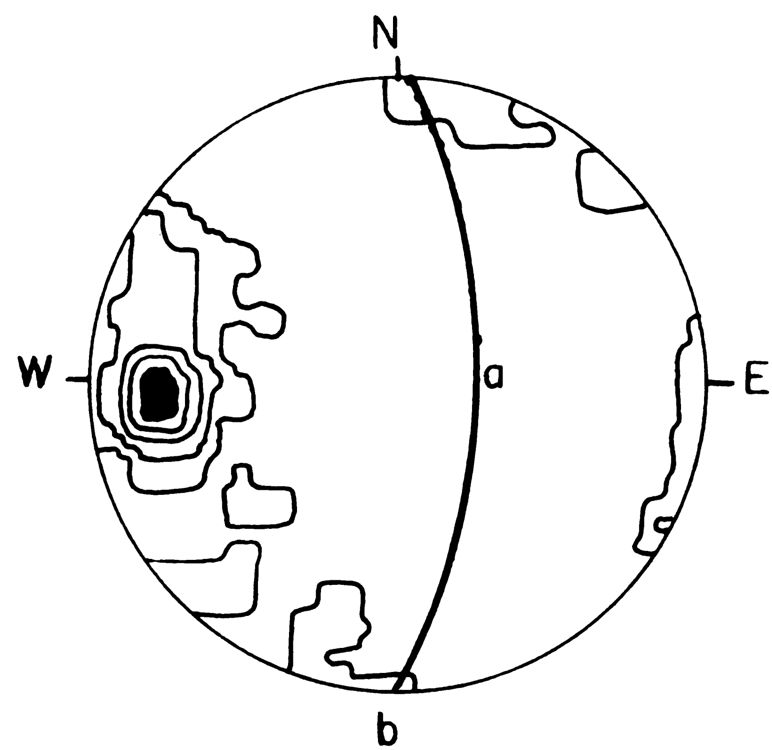

Figure 30. One hundred eighty-two poles to (001) cleavage in biotite from sample 22. Contours 22-16-10-4-1 percent.

Generally the petrofabric analysis of biotite served mainly to substantiate the position of the inferred ab foliation plane.

CONCLUSIONS

The data accumulated during the field and laboratory study present certain implications relative to the geologic ancestry of the area. The writer has found no single hypothesis conclusive enough to warrant definite endorsement.

The rocks comprising the area are believed to be of variable origins and have been distinguished as three major units: (1) "hanging-wall gneiss," (2) pegmatites, and (3) "host rock."

The "host rock," interpreted as the oldest unit, consists of textures, compositions, and structural relationships indicative of a sedimentary origin, at least in part. Almost all the mineral assemblages have evolved in conjunction with extensive injection and soaking of the metasediments by magmatic fluids, emanations, and solutions. The fluids and associated metamorphism undoubtedly introduced gradients of temperature and composition. Moreover, there are indications of a phase change in the initial feldspar. Comparison of mineral assemblages (Table IV) suggests a parent sediment of variable composition. Differential effects of metamorphism and replacement were undoubtedly in part responsible, but this seems hardly tenable as a sole explanation for variations within such a restricted locality.

From the evidences observed, the writer favors a magmatic origin for the ''hanging-wall gneiss.'' This unit is believed younger than the ''host rock'' but older than the pegmatites. The rock has undergone extensive postmagmatic alteration with the abundance of silica and soda interpreted as a product of secondary introduction.

The pegmatites represent the youngest unit. No criteria for genetically relating their origin to a magmatic sources similar to that forming the ''hanging-wall gneiss'' could be determined. Certainly the injection of the pegmatites took place after the ''hanging-wall gneiss'' was for the most part solidified. This is indicated by the appearance of the major pegmatitic seam within a fault which displaces the ''hanging-wall gneiss.''

Both metasedimentary and igneous rocks have been subjected to intense metamorphism and deformation. Folds are predominantly isoclinal and overturned, reflecting the intensity of deformation. The general structural pattern reveals parallelism of foliation, banding, lineation, and rock contacts. Local discordancies complicate the pattern and imply the existence of at least two periods of deformation with forces acting from different directions.

Postdeformational replacement and recrystallization obliterated much of the original microscopic fabric. Quartz axes reflect only weak maxima which appear unrelated to the megascopic structural features. These weak maxima may be ascribed to the retention of a pre-existing fabric. Late solutions or emanations were introduced along foliation planes and therefore for the most part preserved the gneissic texture. Evidence of granulation has been almost completely obliterated by these postdeformational alterations.

The iron oxides are of replacement origin, possibly high temperature hydrothermal. Magnetite was introduced after the major deformation of the area. The nonmagnetic ore is largely a product of the oxidation of magnetite, and therefore may be referred to as martite. Magnetite replaces all minerals, but indicates a preference for biotite and other ferro-magnesium minerals. The localization of the ore was probably controlled both by structural and stratigraphic relationships.

The solutions which introduced magnetite and other late minerals have reflected many retrograde effects on the mineral assemblages.

SUGGESTIONS FOR FURTHER STUDY

Certain problems worthy of further research have become apparent from this preliminary study. The following are likely to be the most fruitful for future study.

1. Implications relative to the process of albitization might be revealed from a detailed petrographic study of the perthitic intergrowths. The variable abundance of secondary albite with relation to the composition of the primary plagioclase would provide initial data on the alteration effect of sodic impregnation.

2. The possible relationship between pegmatitic intrusions and ore localization should be studied in detail. The abundance and type of iron oxide adjacent to the immediate area of the pegmatites would throw more light on the problem of ore genesis.

3. Pertinent information on the stability relationships of certain potash feldspars might be revealed by determining the exact composition and crystal structure of the untwinned variety in the "host rock." Substantiation of the implied association of typically twinned microcline with friable "host rock" and untwinned potash feldspar with coherent "host rock" could provide the initial framework on the effect of stress and strain.

4. A detailed petrographic study of the simple and complex twin patterns inherent to the plagioclase in the "hanging-wall gneiss" and pegmatites could provide additional data relative to the ancestry of these units.

5. Mineral orientations beyond the footwall and hanging-wall may better indicate the time, nature, and complexity of deformational periods. In these areas secondary mineralization and recrystallization may not have obliterated relic fabric elements.

6. A systematic study of lineations and their relationships to the major structural elements might augment derivation of the structural pattern.

7. A petrofabric analysis of the planes of liquid inclusions inherent to the quartz within the "hanging-wall gneiss" might provide an additional fabric element. Such a study could also conceivably supplement the sparse knowledge related to this poorly understood phenomenon.

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