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Petrographic Analysis of an Early Cenozoic Breccia from the Tinton Area, Northern Black Hills, South Dakota

Timothy M. Lockrem

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PETROGRAPHIC ANALYSIS OF AN EARLY CENOZOIC? BRECCIA FROM
THE TINTON AREA, NORTHERN BLACK HILLS, SOUTH DAKOTA

by
Timothy M. Lockrem

A Senior Thesis
submitted in partial fulfillment of
the requirements for the degree of
Bachelor of Science
in Geology
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Abstract

The Tinton area breccia crops out in two areas in the northern Black Hills just northwest of Tinton, South Dakota, in an area of Precambrian metamorphic rocks, pegmatites, and Tertiary intrusives. The outcrops are fairly circular, the smaller measuring 150 meters and the larger measuring 400 meters. Located nearby is the Mineral Hill alkalic ring dike complex, with which this breccia is thought to be associated.

The breccia contains clasts of diverse rock types set in a fine-grained igneous matrix with a chemistry in the quartz latite to rhyodacite range. The rock types present within the clasts are, in order of decreasing abundance: pegmatite, amphibolite, monzonite porphyry, metamorphosed anorthosite, quartz latite, muscovite-biotite? schist?, graphite schist, and a separate category of highly altered clasts. The clasts are 0.1 to 10 cm in diameter; they are well mixed and many are rounded. Both clasts and matrix are hydrothermally altered and fractured, and small-scale faulting is common with deposition of sulfides in many fractures.

Four possibilities for an origin of this breccia are: igneous intrusion breccia, pyroclastic volcanic breccia, meteorite impact breccia, and breccia pipe. The presence of well mixed, rounded clasts of diverse lithology and size that are highly altered and fractured point to a probable breccia pipe origin. As an inferred stock of magma at depth cooled, it probably evolved gases which initiated a breccia pipe sequence to the surface.
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Microscope photographs of the Tinton area breccia clast rock types and matrix appear on the following pages: 5,7,9,11,13.
The Tinton area breccia is one of several breccias associated with Tertiary intrusives which crop out in the northern Black Hills. Some of these areas of Tertiary intrusives have been studied by several people (Berg 1940, Welch 1974, Ray 1979), but do not include detailed studies of the Tinton area breccia. This breccia crops out in two locations just northwest of the town of Tinton, South Dakota (Figure 1), 20 kilometers west of Deadwood on the South Dakota-Wyoming border. Surrounding the breccia are Precambrian schists and amphibolites, pegmatites, and monzonite porphyry.

In the Tinton District, the pegmatites appear to be associated with the intrusion of the Harney Peak Granite about 1.6 billion years ago, and with the related metamorphism of the Precambrian rocks in this area. Following this intrusion, the Cambrian Deadwood Sandstone was deposited along with later shallow marine sequences of limestone and dolomite. Igneous activity occurred again in Tertiary time, with the intrusion of vertical sills of monzonite porphyry in the rocks of the Tinton District. These vertical sills coalesce into an inferred stock at depth (Ray, 1979). The Tinton area breccia was formed in association with this monzonite porphyry.

I studied the Tinton area breccia in an attempt to categorize the rock types found within the breccia clasts, and to determine the composition of the matrix. From these and other characteristics, I hoped to select the mode of origin which best fits this breccia from the following possibilities: igneous intrusion breccia; pyroclastic volcanic breccia; meteorite impact breccia; and breccia pipe. The characteristics that I used to differentiate between these four types are (Figure 13): breccia
FIGURE 1
GEOLOGIC MAP OF THE TINTON AREA (Ray 1979)

Tinton area breccia
monzonite porphyry
pegmatite
Precambrian schists, amphibolites

LOCATION OF TINTON AREA

Montana
South Dakota
Wyoming

Tinton area

0  20  40
scale in km

0  200  400  600
scale in meters
clast diversity in size and rock type, presence or absence of rounding and mixing of the clasts, type of matrix, and outcrop size, shape, and occurrence.

Of the two outcrops shown on the map (Figure 1), I sampled the smaller one. The samples were taken from several rock piles which had most likely been dug up during exploration for sulfides in the area. These rock piles provided good access to a large number of unweathered breccia samples, and since surface exposure of the breccia was poor, these were the areas I chose to sample.

I made 20 thin sections of the breccia for microscope analysis. From the thin-section work I was able to divide the breccia clasts into 8 rock types (Figure 2). The clasts are set in a fine-grained matrix, and range in size from 0.1 to 10 cm. A large number are subrounded, nearly all show some alteration, and many are fractured and faulted. Those clast rock types which crop out locally are, in order of decreasing abundance: pegmatite, amphibolite, and monzonite porphyry. Those which do not crop out locally are, in order of decreasing abundance: metamorphosed anorthosite, quartz latite, muscovite-biotite? schist?, and graphite schist. Highly altered clasts are grouped into a separate category. A detailed description of each rock type follows.

PEGMATITE

These clasts were very abundant, subrounded to angular, greyish-white in color, and ranged from 0.2 to 5 cm in diameter. They consist of very coarse crystals of feldspar and quartz. The feldspar is mainly plagioclase crystals up to several centimeters across that show very obscure twinning due to alteration (Figure 3). Many plagioclase crystals show
**ROCK TYPES FOUND WITHIN THE BRECCIA CLASTS**

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Physical Description</th>
<th>Abundance</th>
<th>Mineralogy</th>
</tr>
</thead>
<tbody>
<tr>
<td>pegmatite</td>
<td>subrounded to tabular clasts, 0.2 - 5 cm, white to pale lavender</td>
<td>very abundant</td>
<td>altered feldspar (largely plagioclase), quartz, both as coarse crystals up to 2 cm</td>
</tr>
<tr>
<td>amphibolite</td>
<td>subrounded clasts, 0.5 - 10 cm, dark green to black</td>
<td>abundant</td>
<td>medium to fine-grained hornblende (75-90%), plagioclase (10-25%), magnetite (2%)</td>
</tr>
<tr>
<td>monzonite</td>
<td>subrounded clasts 1 - 3 cm, lavender grey</td>
<td>frequent</td>
<td>aphanitic matrix of orthoclase, zoned plagioclase phenocrysts</td>
</tr>
<tr>
<td>porphyry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>metamorphosed anorthosite</td>
<td>angular to subrounded clasts 0.1 - 3 cm, white to whitish-grey</td>
<td>frequent</td>
<td>nearly 100% medium to fine-grained mostly untwinned plagioclase, alkali feldspar uncommon, tourmaline and cassiterite as accessory minerals</td>
</tr>
<tr>
<td>quartz latite</td>
<td>rounded to subrounded clasts, 0.2 - 1 cm, greyish-brown</td>
<td>frequent to uncommon</td>
<td>altered feldspar (40-60%), quartz (20-40%), biotite (10-25%), all fine-grained</td>
</tr>
<tr>
<td>muscovite-biotite? schist?</td>
<td>subangular to subrounded clasts 0.2 - 3 cm, greyish-yellow</td>
<td>uncommon</td>
<td>medium-grained elongate muscovite (40-60%), biotite? (30-40%), quartz (10-15%)</td>
</tr>
<tr>
<td>graphite schist</td>
<td>angular to subangular clasts 0.1 - 2 cm, shiny black</td>
<td>uncommon</td>
<td>alternating lenses of graphite and muscovite, banded appearance in thin section</td>
</tr>
<tr>
<td>highly altered clasts</td>
<td>subrounded, 0.5 - 4 cm, greyish-brown</td>
<td>frequent</td>
<td>fine-grained brownish alteration minerals, few relict quartz crystals</td>
</tr>
</tbody>
</table>

(See appendix for a description of 3 thin sections which together contain all eight rock types)
FIGURE 3  Typical plagioclase pegmatite crystal showing obscure twinning due to alteration.  60X  Crossed Polars

FIGURE 4  Fibrous clast with composition similar to a sodium-potassium feldspar.  50X  Uncrossed Polars
90 to 100% alteration to a very fine-grained brownish alteration product, often with a small area in the center which remains unaltered and shows some albite twinning. The twinning was too obscure to determine the An-Ab ratio optically. Most crystals are fractured, and often contain calcite in the fractures. The presence of alkali feldspar is inferred, but because of the alteration I could not distinguish it optically from the plagioclase. Quartz is abundant, both as large single crystals and as clusters of crystals. There are occasional areas consisting of elongate parallel fibers (Figure 4) with a composition similar to a sodium-potassium feldspar.

Some of the areas within these pegmatite clasts are of a finer grain size than what is normally considered a pegmatite. Areas such as these are also found in the pegmatite that crops out in the Tinton area, so I still consider these areas as part of the pegmatite.

Occasionally the pegmatite clasts occur as parallel tabular clasts separated by small amounts of breccia matrix. This indicates that these particular clasts probably have not been subjected to much turbulent action within the breccia because they have not been transported far.

**AMPHIBOLITE**

These are abundant clasts, dark green in color, subrounded to angular, and range from 0.5 to 10 cm across. They contain 75 to 90% deep green hornblende crystals with strong pleochroism (dark to light green) and moderate birefringence. The hornblende is medium to fine-grained and shows a very weak foliation (Figure 5). Plagioclase makes up 10 to 25% of the clasts and is nearly all untwinned. It resembles quartz in thin section, but unlike quartz shows well-developed extinction zoning. Magnetite makes up less than 2% of the clasts. Quartz veins occur within the amphibolite.
FIGURE 5  Amphibolite clast showing hornblende (dark), plagioclase (clear), and magnetite (black).  50X Uncrossed Polars

FIGURE 6  Groundmass of orthoclase, zoned plagioclase phenocrysts (clear area). Clast of Monzonite Porphyry.  20X Uncrossed Polars
Alteration is uncommon, but many clasts are fractured and faulted with pyrite filling the cracks.

**MONZONITE PORPHYRY**

This rock type is common within the breccia as subrounded unaltered clasts 1 to 3 cm in size and lavender in color. They consist of zoned plagioclase phenocrysts set in an aphanitic groundmass (Figure 6). The groundmass consists primarily of orthoclase, and the phenocrysts are predominantly zoned plagioclase of composition $An_{44}$ which exhibit both albite and carlsbad twinning. Also present as phenocrysts are hornblende, biotite, and quartz.

**METAMORPHOSED ANORTHOSITE**

These clasts are abundant, subrounded to angular, and are 0.1 to 3 cm in size. They are white to greyish-white in color and consist of nearly 100% plagioclase. The plagioclase is medium to fine-grained, fairly equigranular, slightly elongate, and aligned in a distinct foliation (Figure 7). 80% of the plagioclase is untwinned; the remaining 20% shows albite and occasional carlsbad twinning. The untwinned plagioclase can be separated from quartz by its well developed extinction zoning. From the twinned plagioclase, the composition was determined to be $A_b 65-70$. Alkali feldspar is uncommon.

Cassiterite and tourmaline are both present as accessory minerals. The cassiterite occurs as small euhedral crystals, strongly pleochroic (clear to red-brown), and highly birefringent. Occasionally these crystals are found within alteration zones which parallel the foliation, indicating association with the metamorphism. Deep blue tourmaline (schorl) is commonly found in bands paralleling the foliation, and consists of pleochroic (dark to light blue) longitudinal crystal sections, and non-pleo-
FIGURE 7  Metamorphosed anorthosite clast showing foliation of plagioclase crystals.  50X  Crossed Polars

FIGURE 8  Quartz latite clast showing quartz (clear), altered feldspar (grey), and biotite (elongate crystals).  70X  Uncrossed Polars
chroic deep blue basal crystal sections.

Quite commonly within these anorthosite clasts there are areas of very coarse plagioclase crystals. These show albite twinning and are often bent or fractured, but show no foliation like the finer grained plagioclase. Perhaps the presence of these coarse crystals associated with the anorthosite clasts as well as the presence of cassiterite and tourmaline within the anorthosite (these minerals are typically found in granitic pegmatites), indicate a relationship between the metamorphosed anorthosite and the pegmatite.

QUARTZ LATITE

These clasts are common, rounded to subrounded, greyish-brown, and occur from 0.2 to 1 cm in diameter. Due to the variations in the percentages of the minerals and the variations in the alignment of the biotite crystals, there is quite a lot of variability in the appearance of these clasts. Feldspar is the main mineral constituent, making up 40 to 70% of the clasts. It occurs as fine-grained crystals altered to brown in color. No twinning is present so it resembles alkali feldspar, but the alteration makes it hard to separate it optically from untwinned plagioclase. Quartz occurs from 20 to 40% as fine-grained crystals and occasionally as veins within the clasts.

The biotite which is present is found as elongate parallel crystals in some clasts, and as unaligned crystals or clumps of crystals in other clasts. The biotite makes up 10 to 25% of the clasts and usually shows moderate pleochroism (dark to light brown). (Figure 8)

Alteration is quite common, with a few of the more altered clasts containing up to 20% limonite.
FIGURE 9 Muscovite-biotite? schist? clast showing fibrous muscovite, altered biotite? (dark grey), and quartz (clear). 60X Uncrossed Polars

FIGURE 10 Graphite schist clast showing alternating lenses of graphite and muscovite. 60X Crossed Polars
MUSCOVITE-BIOTITE? SCHIST?

These clasts occur uncommonly; they are greyish-yellow in color, subrounded, and 0.2 to 3 cm in diameter. They consist of 45 to 65% elongate colorless crystals of muscovite (Figure 9), with no distinct foliation. Biotite? is found up to 40% as anhedral crystals with moderate pleochroism (dark to light brown), but also no preferred orientation. I am calling it biotite because of its pleochroism and its association with muscovite. Quartz occurs up to 10% as single crystals scattered throughout the clasts, and chlorite and magnetite are both present at less than 5%.

Occasional crystals of mica show a very anhedral, ragged crystal form, but I believe these are muscovite because of the sweeping extinction and the negative BXA interference figures obtained from them.

GRAPHITE SCHIST

Uncommon clasts of graphite schist occur as shiny black angular to subangular fragments 0.1 to 2 cm in size. The clasts consist of alternating lenses of graphite and muscovite, giving them a banded appearance in thin section (Figure 10). Most clasts show signs of deformation; displacements along fractures and frequent bending of the clasts. Alteration to a bluish mineral (in doubly polarized light) occurs at the edges of some clasts.

HIGHLY ALTERED CLASTS

This category was made because of the presence of a number of clasts which are so highly altered that they cannot be placed in any of the previous seven categories. Most of these clasts are subrounded, greyish-brown, and range from 0.5 to 4 cm in diameter. They consist of very fine-grained brownish clay-like alteration minerals with very few relict crystals of quartz visible in some of the clasts (Figure 11). The appearance of the
FIGURE 11  Highly altered clast showing fine-grained brownish alteration minerals with no relict structures. 60X Uncrossed Polars

FIGURE 12  Breccia matrix showing aphanitic texture, alteration minerals (dark), and quartz (clear). 60X Crossed Polars
clasts is quite variable, some are uniform greyish-brown and some are blotchy in color (dark and light brown).

**BRECCIA MATRIX**

The matrix was difficult to analyze in thin section because of its very fine-grained texture. It ranges from greenish-grey to brownish-grey, and in most places contains abundant quartz. Much of the matrix appears altered to very fine-grained clay-like areas of feldspar and chlorite (Figure 12). Pyrite and other opaques are quite common.

Microprobe analyses of the matrix show a high percentage of quartz, along with areas similar in composition to albite, biotite, chlorite, and potassium feldspar; so chemically it appears to be in the quartz latite, rhyodacite range.

There are a variety of microstructures within the Tinton area breccia. Some small scale faulting with displacements of less than 1 cm are common, often with deposition of pyrite in the fractures. A few clasts are rimmed by pyrite. Many are bent without actually being fractured. Most of the breccia shows partial or complete alteration of the feldspars and micas. Sometimes altered and unaltered clasts of the same rock type occur together within the breccia.

The clasts are of a wide variety of rock types and sizes quite thoroughly mixed within the breccia. Ray (1979) found clasts of Deadwood Sandstone and lamprophyre, which are not present in my samples. The Tinton area breccia shows a number of distinguishing characteristics that can be used to determine which of the four modes of formation (Figure 13) best fit this breccia.

An igneous intrusion breccia forms when a magma intrudes country. As the magma moves forward, pieces of the country rock are stoped off and
FIGURE 13

COMPARISON OF CHARACTERISTICS OF TINTON AREA BRECCIA WITH FOUR POSSIBLE MODES OF ORIGIN

<table>
<thead>
<tr>
<th>Breccia</th>
<th>Clast Rock Types</th>
<th>Diversity</th>
<th>Mixing</th>
<th>Clast Size</th>
<th>Rounding</th>
<th>Structures</th>
<th>Geologic Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tinton area breccia</td>
<td>metamorphic igneous</td>
<td>eight rock types</td>
<td>well mixed</td>
<td>0.1-10 cm</td>
<td>subrounded to subangular</td>
<td>small-scale faulting and fracturing, alteration</td>
<td>nearly circular outcrop pattern</td>
</tr>
<tr>
<td>igneous intrusion breccia</td>
<td>igneous metamorphic</td>
<td>few rock types</td>
<td>poorly mixed</td>
<td>few small clasts</td>
<td>mostly angular</td>
<td>reaction rims on clasts</td>
<td>wide range of outcrop shapes</td>
</tr>
<tr>
<td>pyroclastic volcanic breccia</td>
<td>mostly volcanic</td>
<td>few rock types</td>
<td>well mixed</td>
<td>wide size range</td>
<td>mostly angular</td>
<td>abundant glass shards and pumice fragments</td>
<td>possible circular outcrop shape</td>
</tr>
<tr>
<td>meteorite impact breccia</td>
<td>igneous metamorphic</td>
<td>few to many rock types</td>
<td>well mixed</td>
<td>wide size range</td>
<td>subrounded to angular</td>
<td>possible fracturing and faulting</td>
<td>relict crater lone occurrence circular outcrop</td>
</tr>
<tr>
<td>breccia pipe</td>
<td>igneous metamorphic</td>
<td>few to many rock types</td>
<td>well mixed</td>
<td>wide size range</td>
<td>subrounded to angular</td>
<td>fracturing, hydrothermal alteration</td>
<td>circular outcrop pattern</td>
</tr>
</tbody>
</table>


incorporated into the magma, along with pieces of chilled magma which are broken off the edges of the magma by friction with the moving liquid. Little mixing or grinding of the clasts takes place as the magma moves along. A breccia formed in this manner would contain few different rock types found as angular clasts which exhibit little sign of mixing or grinding to a fine size. Many clasts would show reaction rims. In the Tinton area breccia, the presence of subrounded and well mixed clasts of diverse lithology and size, and the lack of reaction rims on the clasts indicate that it did not form as an igneous intrusion breccia.

A pyroclastic volcanic breccia forms from a magma chamber below the surface of the earth which, due to the heat and pressure of magma and evolving gases, erupts when an opening to the surface is found. As the gas and magma rush to the surface, fragments of chilled magma, glass shards, pumice fragments, and some fragments of country rock form a welded ash flow breccia on the surface. A breccia formed in this way would contain mostly volcanic fragments (glass shards and pumice fragments), and would have a fragmental matrix. The presence of numerous metamorphic rock types as fragments within the Tinton area breccia as well as the fine-grained igneous matrix indicate that it did not form as a pyroclastic volcanic breccia.

A meteorite impact breccia forms when a meteorite impacts the surface of the earth. The force of the impact drives a wedge of rock down into the earth, which then rebounds as the pressure subsides. As it rebounds, a column of breccia is formed at the center of the meteorite crater. Beds of rock on both sides of the crater are overturned, and shock metamorphism affects the rocks in the area. A breccia formed in this way could have rounded to angular clasts of diverse lithology and size well mixed within
the breccia. On these petrographic characteristics alone it would be hard to discard this as a possible method of formation for the Tinton area breccia. However, the fact that no relict crater or overturned beds are found in the Tinton District, as well as the fact that there are other similar breccias in the area indicate that this method of formation for the Tinton area breccia is unlikely.

A breccia pipe, as described by Gates (1959), is formed when there is a rising cupola of magma at depth which evolves volatiles as it rises and crystallizes. The magma is probably preceded by an aureole of gas. The pressure of the magma and gas open cracks overhead, and the gas rushes into these and tears loose fragments of rock which become incorporated into the magma. Magma rushes into other cracks, quickly chills and evolves more gas which further brecciates the rocks. Conversion of included water to steam may add to the brecciation. As the magma and rock fragments rise, a conduit is formed which becomes filled with the breccia. If the gas or magma eventually finds access to the surface, an explosive eruption follows which perhaps forms a small crater. Once the pressure diminishes, subsidence occurs and more rock fragments are incorporated into the magma. As the magma then begins to cool, more gas is evolved and another cycle of eruption, brecciation, and subsidence increases the amount of breccia, grinds the fragments to a smaller size, and rounds and thoroughly mixes the fragments. The breccia pipe is then solidified by silicification, devitrification, and alteration. A breccia formed in this way would have clasts of diverse rock types and sizes which are well mixed, rounded, altered, and set in a fine-grained igneous matrix. These characteristics match very well with those of the Tinton area breccia. The outcrop shape is also what would be expected from a breccia pipe.
Considering all these factors, a breccia pipe is the most logical mode of origin for the Tinton area breccia.

The Mineral Hill alkalic ring dike complex crops out several kilometers southwest of Tinton, and contains a feldspathic breccia at its core. This area was studied by Welch(1974). He describes this feldspathic breccia as fragments of light and dark foidal syenite, pyroxene-rich pseudoleucite porphyry, lamprophyre, pyroxenite, and many fragments of unknown source set in a matrix of potassium feldspar, nephelene, and pyroxene. Alteration of the breccia is extensive, and weathering has obscured most detail in surface samples. Welch(1974) states that the central distribution and large size of this breccia as well as its petrographic characteristics strongly suggest that it has been intruded from depth. The similar petrographic characteristics and the proximity of this breccia to the Tinton area breccia point to a similar mode of origin for both.

In his work on the Tinton District, Ray(1979) states that the monzonite porphyry was intruded as a series of vertical sills from an inferred stock at depth. The stock caused doming and fracturing of the rocks in the area. This study suggests that after the intrusion of these monzonite porphyry sills, the magma stock cooled and evolved gases which initiated a breccia pipe sequence to the surface. As it progressed upward, the breccia incorporated fragments of the rock types below the Tinton District.

The small-scale faulting, fracturing, and alteration of the Tinton area breccia suggest a late stage hydrothermal event. Hydrothermal fluids under high pressure must have fractured and faulted the breccia after solidification, producing widespread alteration and deposition of sulfides in many of the fractures. Johnson and Lowell(1961), in their discussion of the breccia pipes in the Copper Basin district in Arizona, suggest that
breccia pipes act as main channelways for ore depositing solutions.

Breccia pipes are associated with porphyry copper deposits in many areas of the world. Ray (1979) concluded that the chemistry, fabric, age, geometry, and alteration of the rocks in the Tinton District conforms to the porphyry copper environment, and that they have an apparent consonance with the Mineral Hill alkalic ring dike complex. All of this points to a probable breccia pipe origin for the Tinton area breccia.

Breccia pipes act as sampling probes for rock types below an area, and can also give information about magma generation at depth. By studying the clasts and matrix of the Tinton area breccia, I believe that much can be learned about the rock types and magmatic processes below the Tinton District.

For future study, I recommend a sampling of this breccia to show variations within the outcrop area to help determine movements that take place within a breccia pipe. And the proposed method of breccia pipe origin (Gates 1959) should be evaluated, and other possibilities considered. Also, a geochemical study of the clasts and matrix could help determine temperature of formation of the breccia magma and temperatures and possible reactions as the clasts were incorporated.
APPENDIX

Detailed Thin Section Descriptions

From Original Data
#1 Clasts consisting of 70-85% greenish pleochroic hornblende crystals showing poor foliation (as in a schist), 15-25% untwinned plagioclase crystals, and up to 5% magnetite. Hornblende shows moderate birefringence; plagioclase resembles quartz except for concentric extinction.

#2 Medium to coarse crystals of quartz, as in a quartzite. This appears to be a quartz vein within the hornblende-rich clast (amphibolite). Displacement along a small-scale fault is evident.

#3 Large crystal of pyrite

#4 Clast which contains elongate parallel fibers with parallel extinction and moderate birefringence. The fibers are mostly colorless to grey. A few outer fibers are pleochroic (light to dark brown). Often occurs associated with the pegmatites. Microprobe analysis shows chemistry similar to sodium-potassium feldspar.

#5 Clast of an aphanitic groundmass of somewhat altered alkali feldspar, brownish-grey, with phenocrysts of zoned plagioclase, biotite, and quartz.

#6 Large phenocryst of plagioclase feldspar showing zoning and good albite twinning.

#7 Very coarse crystals of plagioclase feldspar with very narrow albite twinning, but no zoning or alteration.

#8 Fine grained matrix, dirty brown in color. Abundant quartz crystals, high degree of alteration to very fine-grained clay-like minerals. Occasional clinopyroxene crystals present.
APPENDIX

THIN SECTION DESCRIPTION FROM RAW DATA

#1 Large clast consisting of almost entirely fine-grained plagioclase. 80% of the plagioclase is untwinned, but shows good concentric extinction; the other 20% show both albite and carlsbad twinning. Composition determined to be Ab$_{65-70}$. Good foliation is present throughout the clast. Dark band of deep blue tourmaline parallels the foliation. Consists of crystals of schorl, some pleochroic (longitudinal crystal sections, light-dark blue), and some showing no pleochroism (basal crystal sections, deep blue). Euhedral crystals of cassiterite present throughout the clast. Pleochroic (clear-reddish-brown) and highly birefringent.

#2 Clast of parallel elongate fibers with high first order interference colors and parallel extinction. Mostly greyish in color. Similar to clast #4, thin section #7.

#3 Clast of highly altered minerals. Dirty grey in color and mottled. Cannot determine original mineral content.

#4 Clasts of 40% altered alkali feldspar, 40% quartz, and 20% biotite. Fine grained, greyish-brown in color. Biotite found as both lineated and unlineated crystals, showing moderate pleochroism (light to dark brown).
THIN SECTION DESCRIPTION FROM RAW DATA

#1, 2, 3, 4 - Clasts of medium to fine-grained crystals of altered alkali feldspar (40%), quartz (40%), and biotite (20%). Greyish-brown in color. Biotite found as both lineated and unlineated crystals, showing moderate pleochroism (dark to light brown). Alteration is common.

#5 Alternating lenses of black graphite and clear muscovite, forming a graphite schist. Banded appearance in thin section. The edges show some alteration to a bluish (in doubly polarized light) mineral, possibly chlorite.

#6 Clast of highly altered minerals. Greyish-brown in color. A few small unaltered crystals of quartz are found within this clast. Original composition possibly was a large amount of feldspar, but this is difficult to tell.

#7 Coarse pegmatitic crystals of quartz.

#8, 9 - Clear, elongate crystals of muscovite (60%), and which show parallel extinction. Biotite makes up 30% of the clast, with quartz present at 10%. No foliation is seen. A few of the muscovite crystals have a shredded appearance and very low interference colors. They give centered RXA interference figures with low 2V and a negative sign. The extinction is sweeping.
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REFERENCES


