Reviewed by Terry Swor July, 2003

Geology of the Kensington Rune Stone

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Introduction

This report presents the results of an investigation into the geologic aspects of a stone slab artifact called the Kensington Rune Stone or KRS. In addition to documenting the physical features of the stone ~~we have made an attempt to quantify~~ the age of the inscription. The investigation began on July 3, 2000, and included both field and laboratory work. The field work consisted first of a site visit to where the stone was discovered on a farm near Kensington, Minnesota, in 1898 and the collection of chip samples from tombstones in the Hallowell Cemetery in Hallowell, Maine. Laboratory analysis was performed at American Petrographic Services Inc. in St. Paul, Minnesota, and at the Materials Laboratory at Iowa State University in Ames, Iowa. We also performed research into the history of the KRS at the Minnesota Historical Society (MHS). Where appropriate, portions of relevant documents are reproduced in this report.

Conclusions

Based on our observations, test results, research and past experience the following conclusions are appropriate:

1. The KRS is a tabular shaped, dark gray, meta-graywacke glacial erratic boulder. The back side of the stone exhibits very pronounced, roughly parallel, glacial striations.

2. Several curved fractures along one edge of the stone were produced by purposeful man-made impact. The previously larger-sized stone was shaped, or "dressed," prior to the entire inscription being carved.

3. Approximately 95% of the inscription was cleaned out with a nail shortly after its discovery. This "retooling" removed weathering features from the bottom of the carved grooves and crushed the constituent minerals which turned these surfaces white. This "fresh" appearance of the inscription has led to confusion and miss-interpretation of the relative age of the inscription. Several man-made characters in the last three lines of the inscription on the side of the stone were not retooled and exhibit original weathering features.

4. The glacial back side of the KRS exhibits two, approximately ½" wide, white, undulating and branching lineations. These lineations were likely produced by young tree roots leaching nutrients from minerals in the stone. The pattern of the lineations closely matches the description by witnesses of the roots that tightly gripped the KRS when it was discovered.

5. Based on comparison with the still actively oxidizing pyrite crystals within the AVM Stone inscription, the completely oxidized pyrite pits observed in the original KRS inscription took longer than 18 years of weathering to develop.

6. Based on comparison of chip samples obtained from slate tombstones, the biotite mica that was exposed at the time of the original inscription on the KRS took longer than 200 years to completely weather away.

General Description of the Physical Features

The laboratory work performed is essentially the same as what a pathologist does when performing an autopsy. The only difference is that the "body" in this case ~~was~~ a 202-pound slab of very hard stone. During the course of the examination ~~we "start big and work small."~~ In other words, we consider the large scale features first and progressively examine increasingly smaller scale features through microscopy. We began by recording basic parameters of the stone.

Approximate Dimensions	**Weight, lbs.**
31" x 16" x 5 ½" thick	202

Overall view of the "face" side of the KRS that contains the first nine lines of the inscription.

The stone is tabular in shape and is roughly the size of a common tombstone. Its overall angular shape was produced by roughly-parallel fracture planes that developed while the stone was still ~~in the bedrock.~~ Intense pressure and stress from deep within the earth over millions of years produced these orderly fractures called **joints**. A few of these joint fractures cut across the face of the KRS and are parallel to each other.

A prominent joint fracture runs across the face side of the stone at a shallow angle.

The flat and elongate stone exhibits three distinct types of surfaces. The first is bluish-gray in color and does not exhibit any observable glacial striations. The first nine lines of the inscription are carved into this surface. For discussion purposes we'll call this surface the "face" side. The face side also exhibits a second set of smaller scale fracture planes called **cleavage**, that exhibit a repeatable, sub-parallel orientation. These fracture planes are produced by intense pressure from within the earth that aligned micas and other elongate minerals. Five distinct cleavage planes are visible on the face side of the KRS.

Sunlight at a low angle highlights five distinct cleavage planes that step upward along the "face" of the stone. The long vertical step between two cleavage planes cuts across six lines of the inscription at a high angle.

Cleavage played an interesting role during the original carving of the inscription that caused the carver to change plans as he went along. The first line of the inscription begins at the far upper left side of the stone. The second line is indented about 3" and begins on the upper side of the step between two cleavage planes. Close inspection of this area reveals where a character was carved that appears to have caused a piece of the rock to spall off when it was stuck. Presumably, the carver began the second line at the far left edge but lost part of the first word when the rock broke off along the cleavage plane below. I like to call this the "Oh Shoot" area. The carver was apparently nervous about more spalling and started the third line on the upper area. Confidence in the stability of the rock was restored and the fourth line was started at the far left edge.

colloquial?

you can't speak to this!

A relatively large piece of rock spalled off along the lower cleavage plane as the second line of the inscription was being carved.

Whoever carved the inscription definitely had to be mindful of the unpredictable nature of fractures and spalling caused by the inherent aspect of cleavage in the stone.

A pit was created when two runes were carved in the area between two cleavage planes.

Another prominent feature on the face is the white triangular shaped area in the lower left side of the stone. This very thin layer (1-2 mm thick) is comprised of a coarse-grained calcite ($CaCO_3$) that was deposited by solutions that moved along the joint fracture system parallel to the face side of the stone. The calcite was deposited in the crack and exhibits a preferred orientation of elongate chlorite $[(Mg, Fe, Al)_6 (Al, Si)_4 O_{10} (OH)_8]$ minerals that run parallel to the long axis of the stone. This calcite was probably deposited millions of years ago when the KRS was still part of the bedrock.

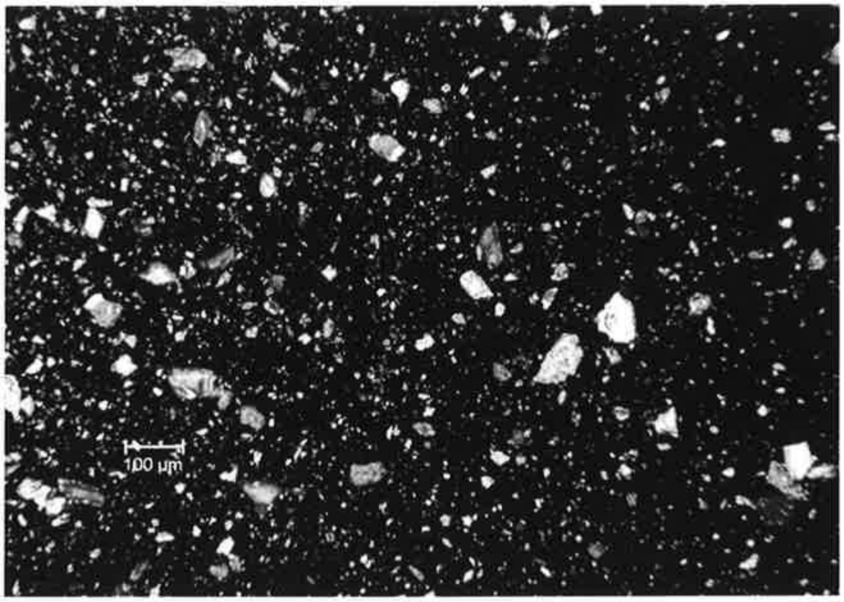
mass
larger

crystalline

The white triangle shaped area is hydrothermal calcite. This calcite was deposited by hot solutions that moved along the joint fracture system when the stone was still in the bedrock.

The hydrothermal calcite is important because several characters were carved into this area. The weathering of calcite, a relatively soft mineral (3 ~~out of 10~~ on the Mohs hardness scale), is much different than the rest of the rock which is considerably harder. Microscopic examination using reflected light revealed little difference between the texture and apparent weathering of the calcite both around and within the carved characters. Further study of the weathering of the characters within the calcite area is strongly recommended. ?

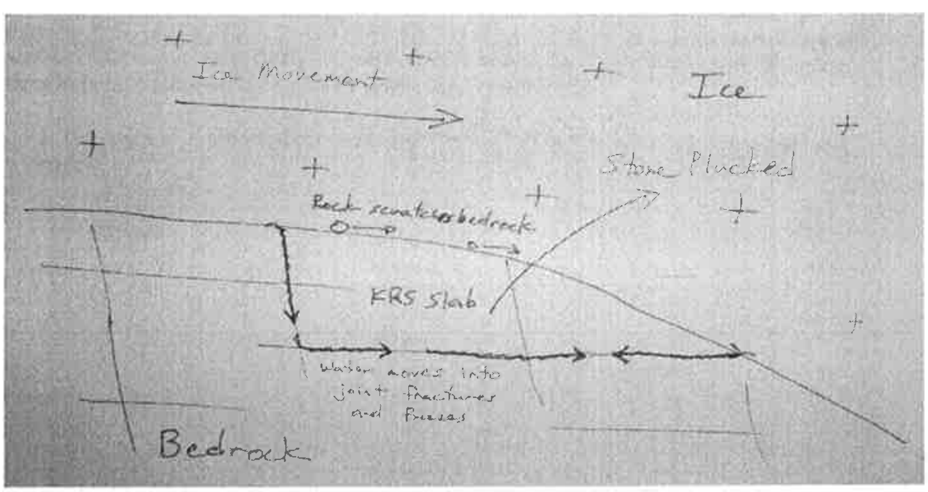
which ranges from 1 to 10..



A sample of the hydrothermal calcite was scraped off from the white triangular shaped area on the face side of the stone. The relatively coarse-sized, angular grains exhibit 3rd order birefringence colors when reviewed under cross polarized light.

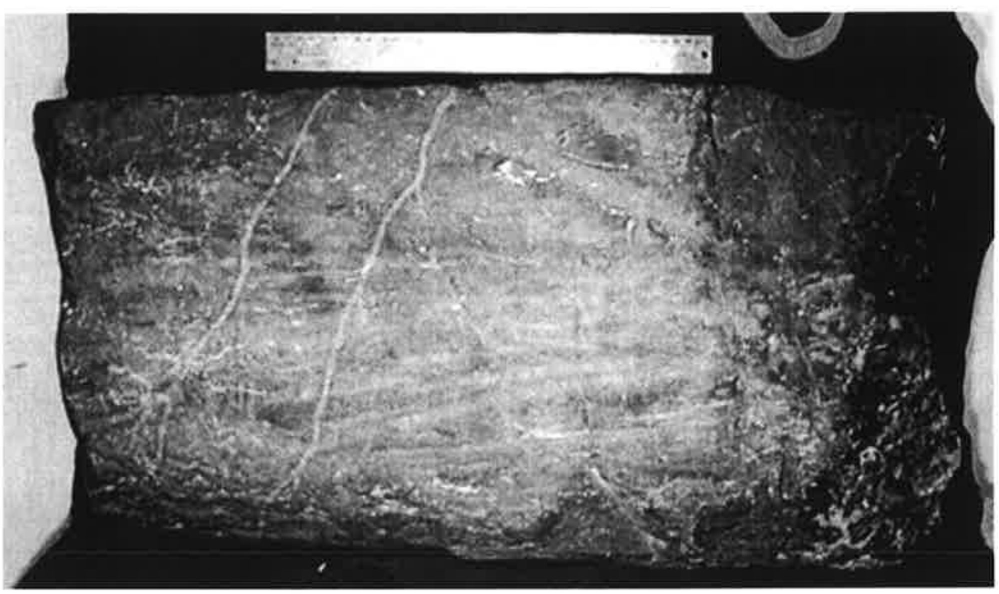
When the stone was flipped over, the back side exhibited some very interesting features. A fiber-optic light source was directed at a very low angle across the back side of the stone. What immediately became apparent were relatively deep (1 to 5 mm) glacial striations that run roughly parallel to the long axis of the stone. Since all other sides of the KRS do not exhibit striations, it appears that the scratches were made while the stone was still a part of the bedrock. The glacier likely dragged rocks frozen at the base of the ice over the bedrock creating the striations. At some point, water under great pressure moved into joint fractures within the bedrock where it refroze. This then allowed the tabular-shaped stone to be dislodged from the bedrock and incorporated within the body of glacial ice. The stone was then transported, presumably into the Kensington area, and then deposited when the glacial ice melted roughly 12 to 15 thousand years ago.

before the stone was dislodged/plucked from the bedrock mass



The relatively deep glacial striations are highlighted by low angle fiber-optic light.

When the overhead lights were turned back on, two peculiar white lines were observed running across the glacial surface. These lineations were roughly parallel, undulating and branched off at three locations. They were not geologic in origin and appeared be derived by organic processes. They looked as if they could like be tree roots. The lineations extend from the sharpest edge of the stone and gradually thin as they traverse the glacial side at roughly a 50 degree angle. The white lineation closest to the middle of the stone turns downward over the relatively steep and rounded opposite side.

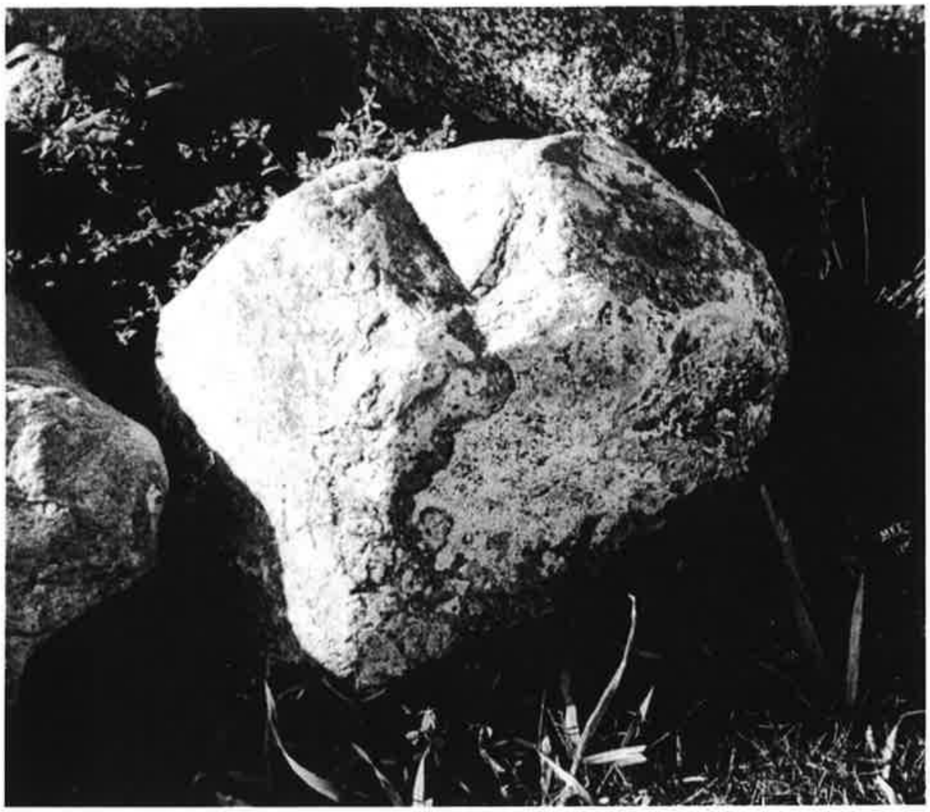


Two white, roughly parallel, undulating and branching lineations run across the glacial surface and then down the opposite side.

One lineation runs vertically down and apparently would have continued beyond the bottom edge of the stone (in this orientation). This pattern is consistent with the growth behavior of tree roots.

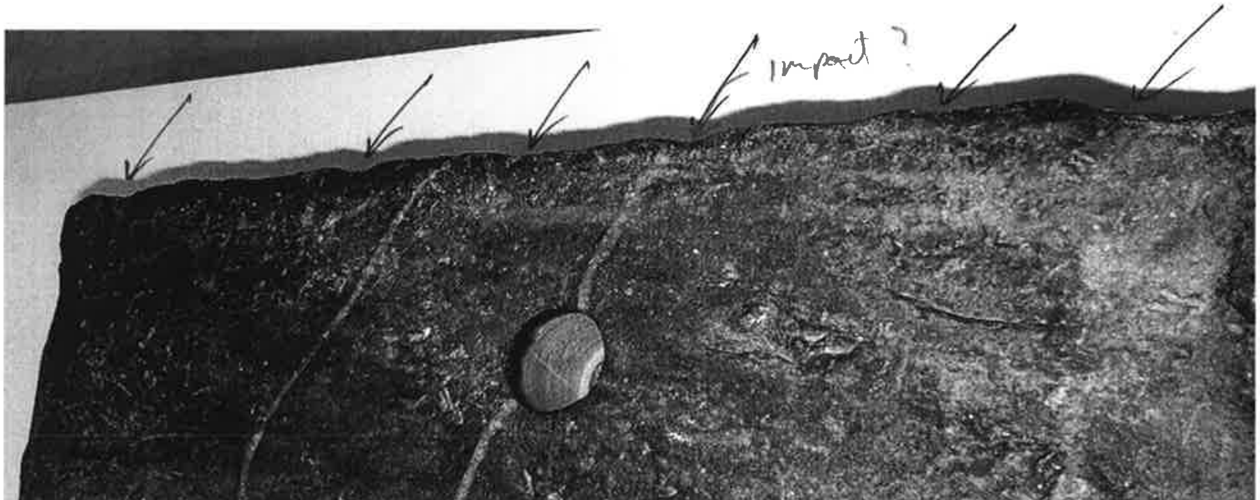
On the sharp, tapered end of the glacial side are intermittent areas of yellowish-white coatings of secondary calcite. This calcite is much finer-grained than the hydrothermal calcite on the face side. After the glacier melted away (approximately 12 thousand years ago), percolating groundwater deposited secondary calcite on the surface of the stone. Numerous sand grains are bound within the coatings which are commonly found on glacial erratics.

Yellowish-white, secondary calcite coatings speckle the tapered end of the glacial side of the stone. After being deposited by the glacier, percolating groundwater deposited the coatings.



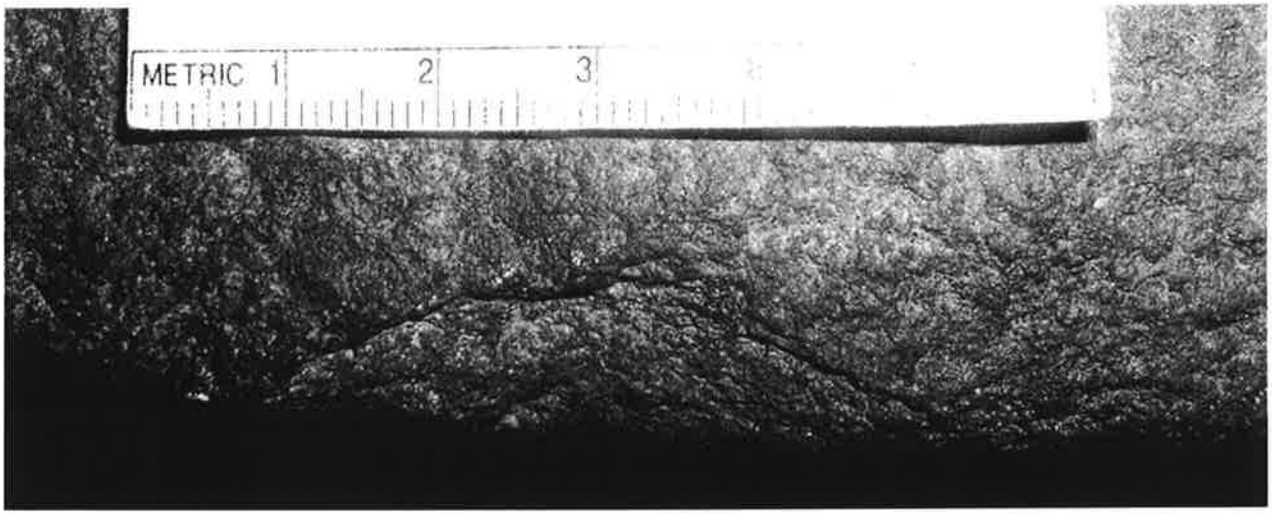
A heavy calcite coating on a granite glacial boulder was found next to a flagpole at Rune Stone Park in Kensington, Minnesota. Many glacial erratics with calcite coatings were observed near the site where the KRS was discovered.

Close examination of the sharpest edge, where the glacial side and the side containing the last three lines of the inscription meet, reveals at least six indentations. These rounded, conchoidal fracture-like areas appear to be related to purposeful impact.



At least six indentations along the sharpest edge appear to be related to purposeful impact.

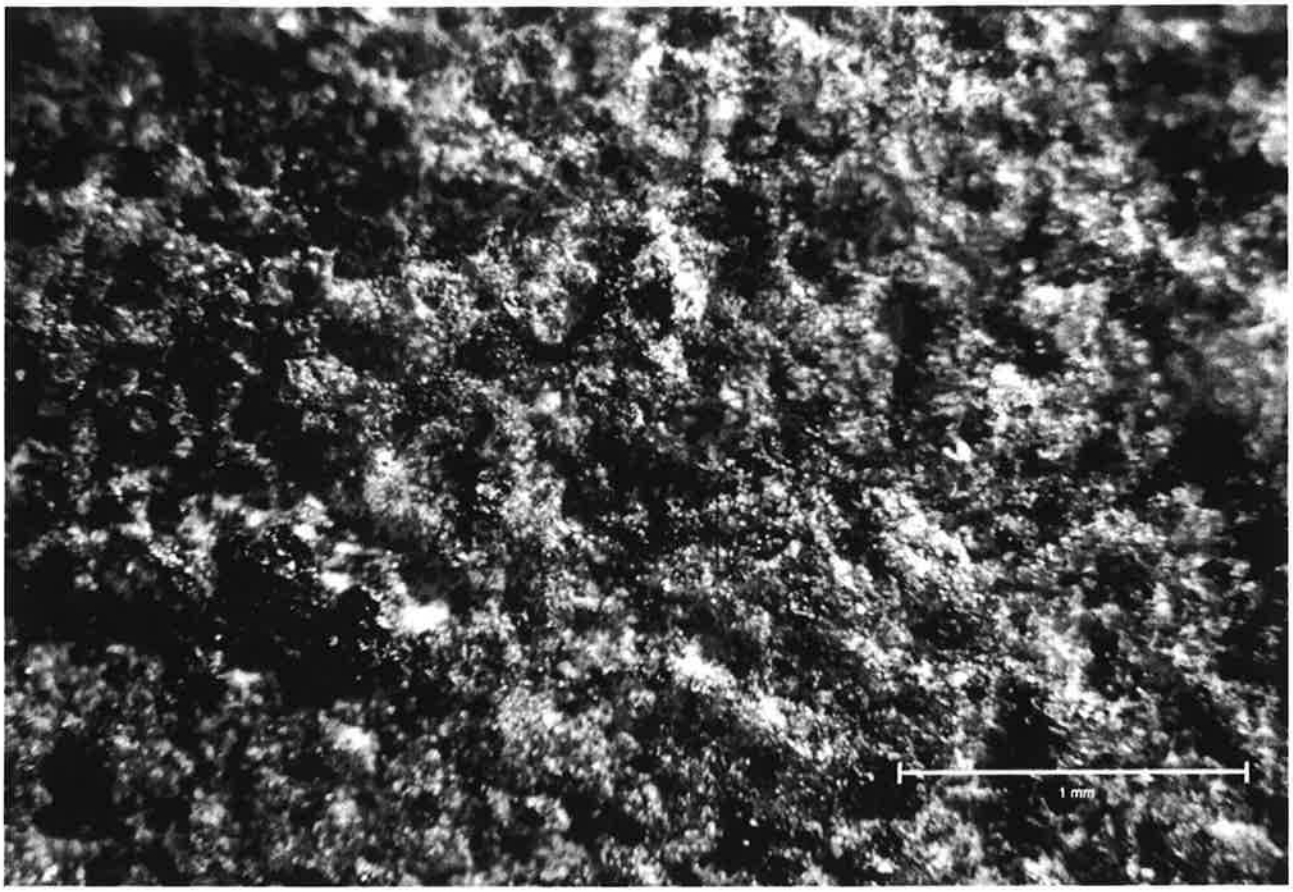
core hole?



This rounded, conchoidal-like fracture along the sharpest edge of the stone was produced by purposeful impact. based on what

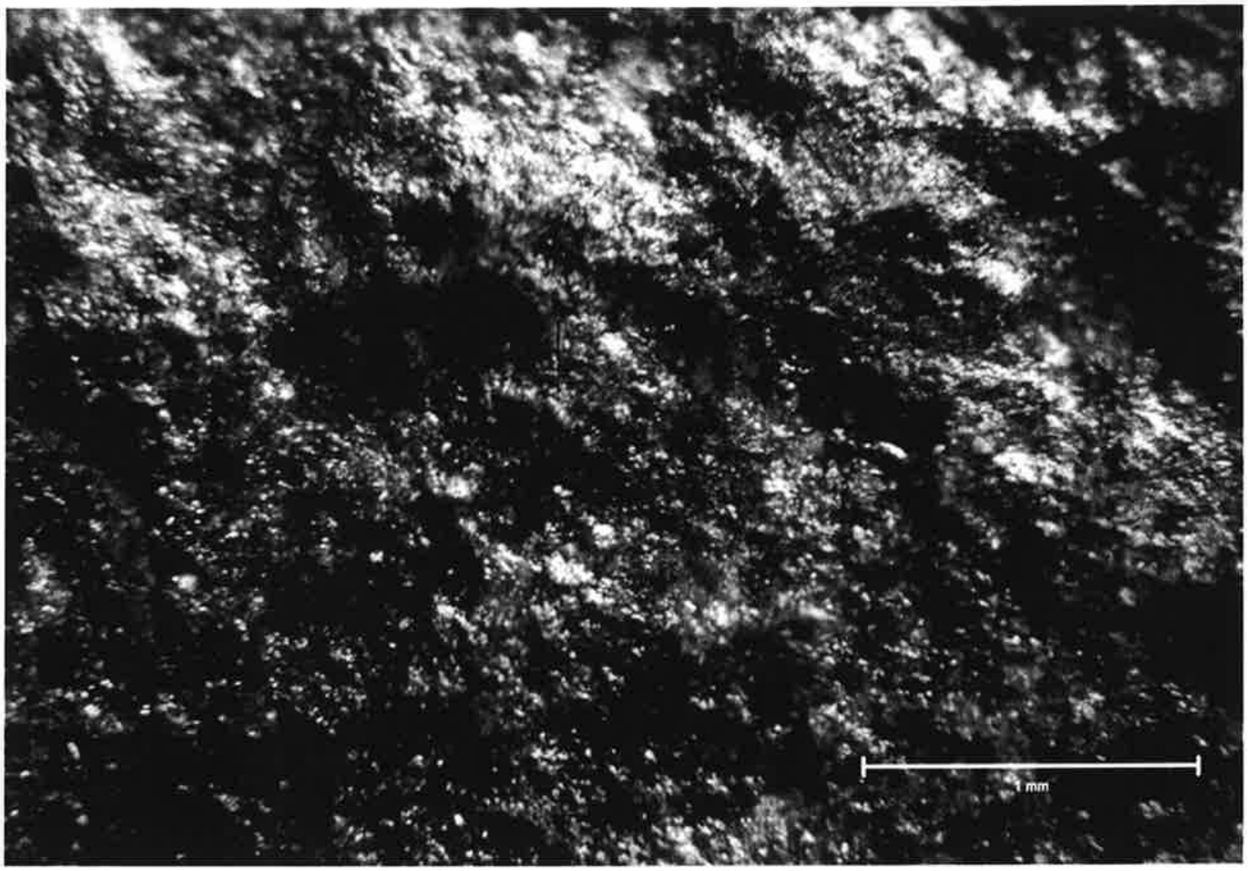
The side of the stone containing the last three lines of the inscription has an appearance that is different than all the other surfaces of the stone. The color of this surface is a slightly darker bluish-gray and has a rougher overall texture. It appears that the stone was purposefully shaped, or "dressed," prior to the inscription being carved since seven of the nine lines on the face side begin immediate adjacent to the left edge. We have identified this surface as the "split" side. In December of 2000, a professional letter carver named Janey Westin; was asked to examine the KRS. She agreed that the conchoidal fractures along the edge were consistent with purposeful impact and that the entire split side had been dressed prior to carving the last three lines of the inscription.

An important aspect of the stone is the weathering characteristics of the different surfaces. All of the surfaces that have been weathering since being transported and then deposited by glaciers have a similar appearance. These surfaces have a light bluish-gray color with noticeable small-scale pitting. The pitting is caused by complete dissolution of the softer and less stable minerals (micas, pyrite and calcite in this case). These surfaces have been exposed to weathering for at least 12,000 years. The split side surface has a darker overall gray color and does not exhibit the prominent pitting observed on the glacial surfaces. This surface appears to have been exposed to weathering for a significantly shorter length of time.



The glacial surfaces of the stone exhibit a lighter overall blue-gray color with noticeable pitting (50x). This surface represents at least 12,000 years of weathering.

The split side of the stone which contains the last three lines of the inscription and the Holand "H." The dark gray color and rougher texture of this surface is different than all the other glacial-aged weathered surfaces.



The split side surface is a darker gray color and does not exhibit the prominent pitting of the glacial surfaces (50x). This surface represents a weathered appearance that developed over a much shorter period of time than the other surfaces of the stone.

The Inscription

There are twelve lines in the original inscription that are comprised of 287 individual carved characters. The first thing that jumps out when examining the inscription is the relatively fresh appearance of the carved characters. The deepest parts of the grooves were re-cut with a sharp instrument with sufficient force to remove all weathering products that were previously present. In addition, the **retooling** crushed the constituent minerals in the stone which turned white and thereby created the fresh appearance. This gives the casual viewer the impression that the inscription was carved recently. However, close examination reveals an obvious difference in the color and texture of the areas adjacent to the deepest part of the grooves. These surfaces have the same darker gray color as the split side of the stone and represent where flakes of rock spalled off immediately adjacent to the main grooves at the time the stone was originally carved. This **flaking** is observed to some degree on nearly every character on the face side.

The deepest parts of the grooves on the face side have been re-cut with a sharp instrument. This retooling has crushed the insipient minerals which then turned white giving the inscription a fresh appearance. The darker gray colored areas adjacent to the retooling were produced by pieces of rock that flaked off when the original inscription was carved. These flaked are have the same properties as the entire split side which indicates that they were created at the same time.

All of the original rune-form grooves on the face side and approximately 75% of the rune-forms on the split side have been lightly scratched or completely retooled. The retooling on the face side appears to have been done with greater force than the split side. This is perhaps due to easier access to the face side. The retooling apparently occurred shortly after its reported discovery in November of 1898. There are three pieces of evidence that strongly support this assertion:

1. On March 3, 1899, after having studied the KRS for two days Professor George Curme of Northwestern University was quoted in the Chicago newspaper The Skandinavien, "Wherever the characters of the inscription have not been disturbed, they have precisely the same color as the general surface of the stone."

2. Close inspection of photographs taken of the KRS in March of 1899 appears to show the retooling was present at that time. The Steward photographs clearly show that the runes had already been cleaned at that time.

Retooling of the split side of the inscription is apparent in this photograph taken by John F. Steward in March of 1899.

3. On page 19 of Professor Winchell's April 19, 1910 report, he writes, "This difference was said to be due to the fact that the runes on the edge had been filled with mud and had been cleaned out with a nail."

4. W. O. Hotchkiss reports in an April 4, 1910 letter that the runes were scratched shortly after its discovery.

~~sedimentary rock not easily weathered.~~ Most of the characters were unfortunately scratched - evidently recently, and, according to Mr. Holand, in cleaning the dirt out at the time the stone was discovered. Some of the characters

W. O. Hotchkiss letter to Upham dated April 4, 1910

There is one other character on the stone that was carved relatively recently. An "H" was reportedly carved on the split side, toward the bottom end of the stone, by Hjalmer Holand in 1907. This character does not exhibit any observable weathering features.

Roughly a dozen characters on the top end of the split side of the stone do not appear to have been retooled at all. A few other characters on the split side appear to have been weakly but weathering of stone for old dates carving dates

retooled. What becomes apparent is that these original characters have the same color, texture and weathering features as entire side they were carved into. This similarity is consistent with the dressing of the side, and the original carving of the characters having been performed at about the same time. These characters are important because they exhibit weathering features such as iron oxide deposits. Iron oxide deposits developed from the decomposition of the mineral pyrite (FeS_2). These deposits were observed within the original carved runes that were not retooled and speckled intermittently throughout the entire split side surface. Also observed within some of the original grooves are small (~ 0.5 mm), iron-oxide coated pits that represent pyrite crystals that have completely weathered away. The timing of these weathered pyrite pits was unknown until a fortuitous control sample was discovered in May of 2001.

Rust-colored iron oxide deposits within an original character on the split side.

Weathered pyrite pits (red arrows) with halos of iron oxide on the split side.

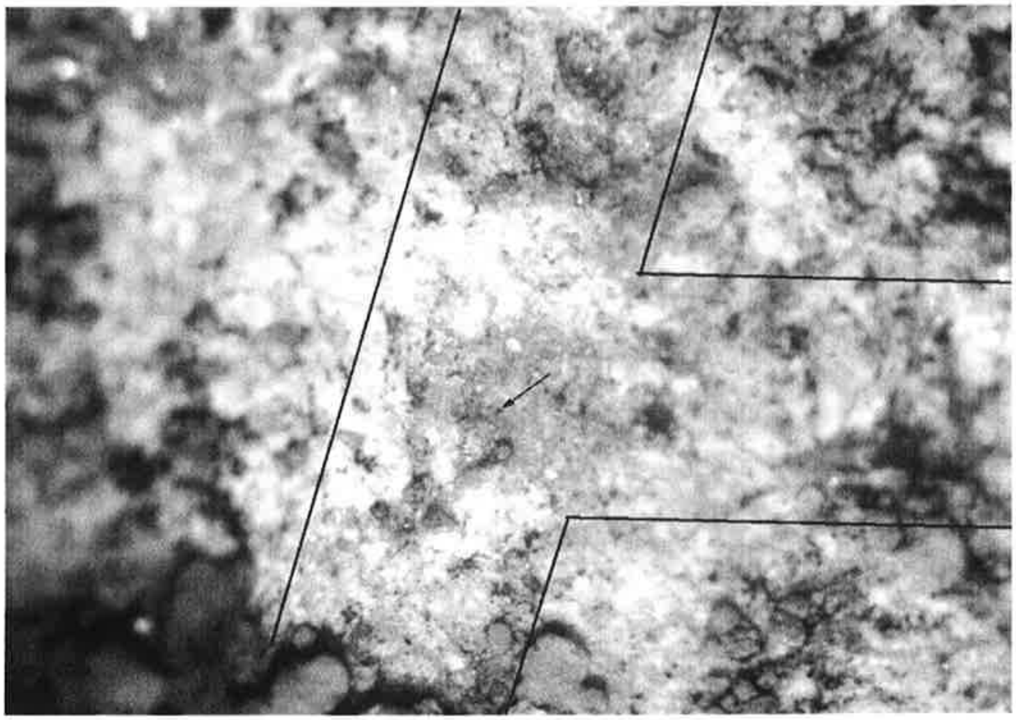
A large, approximately 2500 pound, granite gneiss glacial erratic was discovered in a pile a field-cleared boulders that had an inscription on the top side. The stone was found within a few hundred yards from the discovery site of the Kensington Rune Stone and was initially thought to be related to it. The message contained 13 carved characters including the letters "AVM."

The AVM Stone inscription was carved on granite gneiss glacial erratic boulder. The dark gray, roughly 2 ½" wide band of biotite-rich schist is nearly white in color and appears to have been made recently.

The so-called "AVM Stone" was examined in the APS laboratory in August of 2001. Close inspection of the carved characters in the lighter colored, granitic areas revealed conspicuous rust-colored halos around actively oxidizing exposed pyrite crystals. None of these decomposing pyrite crystals were observed on the glacial aged surfaces of the stone.

The actively oxidizing pyrites within the original carved surfaces of the AVM Stone were in stark contrast to the pyrite pits observed on the KRS. This discrepancy became clear when a group of five individuals came forward in September of 2001 claiming responsibility for carving the inscription in the spring of 1985. Their Rune Stone "hoax" suddenly became an important control sample that exhibited weathering of an inscription in rock comprised of essentially the same minerals as the KRS. Further, both inscriptions were exposed to the same weathering conditions with one important difference. The KRS was found buried in the ground whereas the AVM Stone was exposed to an exterior weathering environment. The rate of weathering in an exterior environment would be expected to be greater and more severe than a below grade environment. Several additional factors would impact the rate of weathering at the surface that would not be present in the ground. These items include numerous wetting and drying events, multiple cycles of freezing and thawing, ultra-violet light exposure, ventification (wind polishing), and acid attack derived from decomposing plant material, animal feces and lichen.

You are comparing a meta graywacke to a granite gneiss yet call them similar



A rust-colored iron oxide stain formed from a decomposing pyrite grain within a carved character in the lighter-colored granitic area of the glacial erratic boulder (20X).

An actively corroding pyrite crystal (red arrow) creates a pronounced halo of iron oxide within a carved character on the AVM Stone (60x).

It should be noted that the KRS was found in the soil horizon of a limey glacial till that has a pH of 7.5 which is on the alkaline side of neutral. This relatively stable environment would tend to slow the rate of pyrite oxidation relative to the above grade environment. These factors all contribute to a reasonable and conservative comparison of the relative rate of pyrite decomposition between the two inscribed stones. One must also remember that the layout of the inscription on the KRS suggests the stone was likely set upright into the ground. Therefore, the inscription would have been exposed to an unknown period of exterior weathering. Regardless of whether the KRS was buried by humans or natural processes, the pyrite weathering comparison is still valid.

In 2002, the AVM Stone was returned to the farmer on whose property the stone was discovered. It was requested that the stone be left out to continue weathering and periodic observations of the weathering of the stone are ongoing. The most recent examination was performed on April 25th of 2003. Active oxidation of the pyrite grains within the inscription was still occurring. Since the pyrite crystals are still actively corroding within the AVM Stone inscription after 18 years of weathering, the pyrite crystals on the original man-made surfaces of the KRS clearly took longer than 18 years to completely decompose.

Photo-library of the Inscription

On December 11 thru 13, 2002, a digital photo-library was generated of all 287 characters that comprise the inscription on the Kensington Rune Stone. At least two photos were taken of each character using reflected light at both high and low angles at magnification ranging from 3.75 to 64 times. These images were generated to gain a better understanding of the physical characteristics of the inscription as well as provide a detailed data base that can be used in the future for research, educational and security purposes.

A photograph taken with low-angle light reflected light that revealed a previously unknown split at the bottom of this rune-form (Line 4). This character is believed to be an intentional combination of two runes called a "bind rune."

Core Sampling

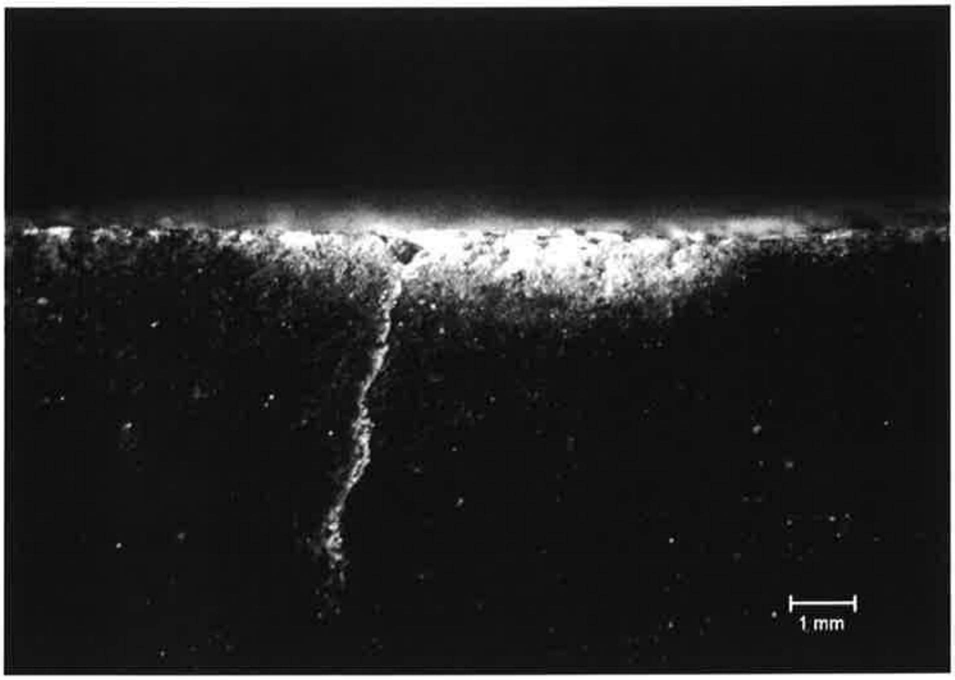
The next phase of the analysis involved obtaining a core sample from the stone. Several test specimens were generated that enabled precise mineral identification and more detailed study of the various weathered surfaces. We selected an area on the glacial back side that included a branching portion of the white root lineations and an apparent joint fracture. On October 3, 2000, a water-cooled, diamond studded coring bit was used to cut a 1-¼" diameter by 2" long core sample. Upon completion of the coring it was decided to not patch the core hole at that time. The museum board believed the open core hole would give the impression that a serious investigation had occurred.

The core sample location on the glacial back side of the stone.

The 1-1/4" diameter diamond studded coring bit being positioned on October 3, 2000.

The 2" long sample after coring.

The top ½" of the core was cut off first. This top portion, or puck, was then cut perpendicular to the top surface and across the white lineation to create a cross-sectional profile. Examination of the polished profile revealed that the white lineation penetrated the rock to a depth of 1.5 mm. The whitened color was produced by chemical leaching of iron and magnesium elements from biotite minerals in the stone. The organic-based origin of the lineations suggests prolonged contact with tree roots in the ground.

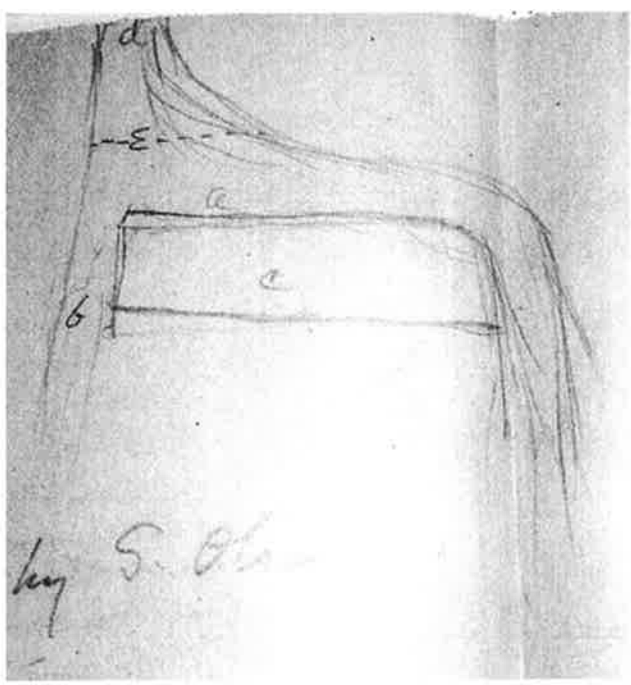


A cut and polished cross-sectional profile of a white lineation on the glacial back side of the stone. Chemical leaching of iron and magnesium elements from biotite minerals through prolonged contact with tree roots in the ground produced the white color. A yellowish colored fracture runs sub-vertically from the top surface.

The curious pattern of the root leaching is eerily similar to the testimony and hand-drawn sketches of the witnesses who saw and described the roots that tightly gripped the stone when it was discovered. Olof Ohman, his son Edward, neighbor Nils Flaten, and Kensington residents Roald Bentson and Samuel Olson all described the root as being about 3" in diameter and flattened to conform to the stone. There is an obvious discrepancy in the much larger size of the flattened root described by the witnesses and the ½" maximum width of the white lineations. This was because the leaching occurred when the roots where relatively young and smaller in size. The highly active immature ends of the roots seek out nutrients through chemical reactions (Recent research suggests that ectomycorrhizal fungi mobilize essential plant nutrients directly from minerals through the excretion of organic acids). As the leading ends of the roots grow downward into the ground, the nutrient seeking phase of that part of the root ends. A bark then grows gradually around the root and its diameter increases with age.

who says?

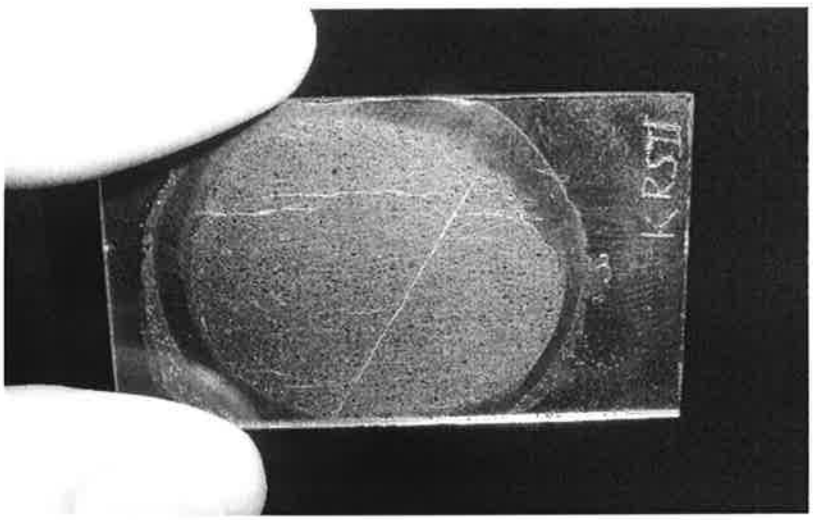
Olof Ohman's December 9, 1909 letter with the sketch of the tree roots gripping the stone. Ohman labels the sketch with the inscription side of the stone facing down.



Sam Olson's drawing of the roots over the back side of the stone which appears in Newton Winchell's field notebook, March, 1910.

Thin Section Analysis

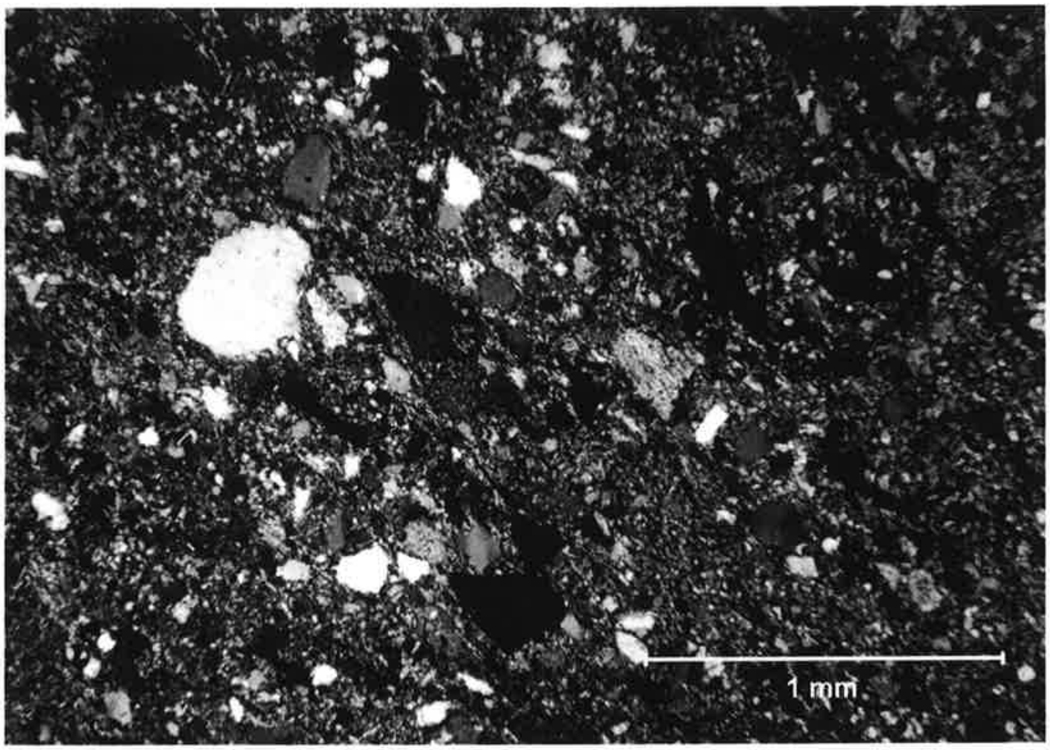
Thin sections were cut from the core sample to properly identify the constituents of the stone. A glass slide was epoxied to the polished surface of the core at the ½" depth. The core was then cut off and the slice of rock attached to the slide was ground down to a thickness of approximately 25 microns. The section was placed under a polarized light microscope and examined under polarized transmitted light.



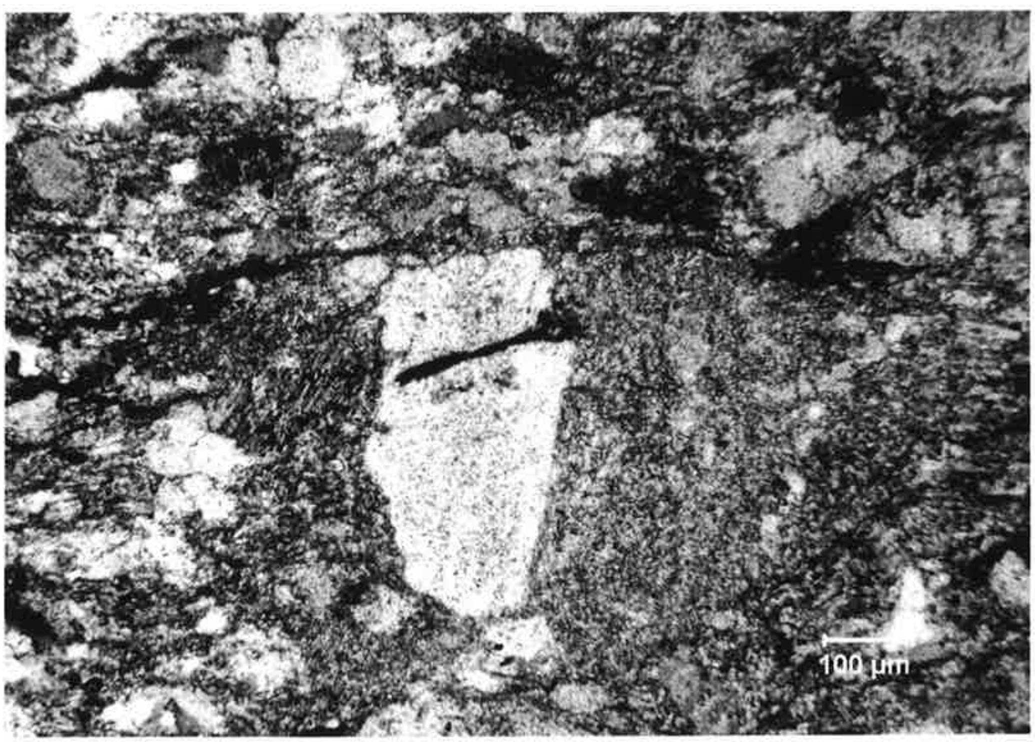
A thin section was made by cutting a slice of rock from the core sample. The sample was examined for identification of the constituent minerals.

The mineralogy was documented by reviewing three individual thin sections cut from the core sample and consisted of the following:

Mineral	Estimated Percentage
1. Quartz	25
2. Rock Fragments	20— ?
3. Chlorite	15
4. Biotite	15
5. Muscovite	10
6. Orthoclase	5
7. Plagioclase	5
8. Pyrite	3
9. Quartzite	2
10. Calcite	1
Total	100



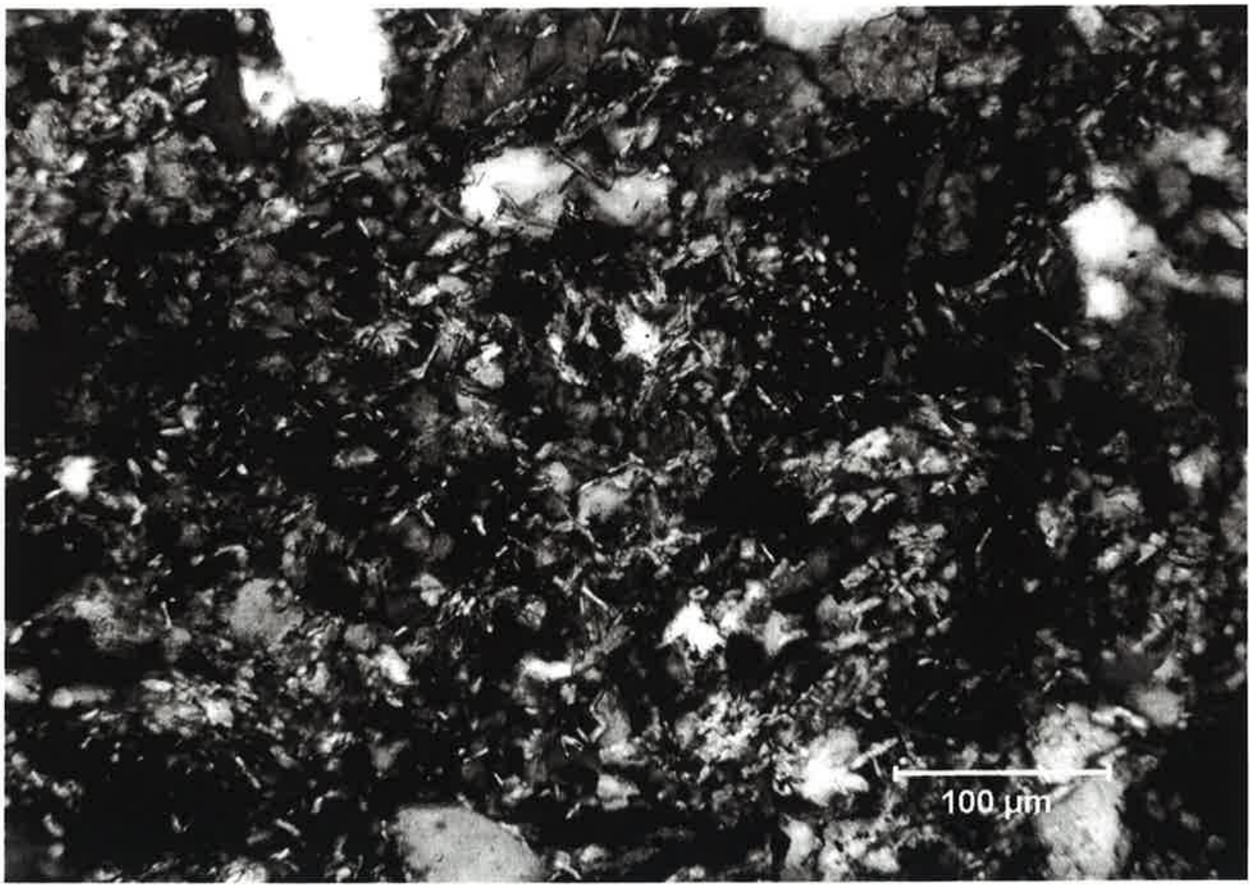
Mostly angular quartz, orthoclase and plagioclase feldspar sand grains are visible under cross polarized light.



Rock fragments, like this granite clast under cross polarized light, comprise roughly 15% of the KRS.

20%?

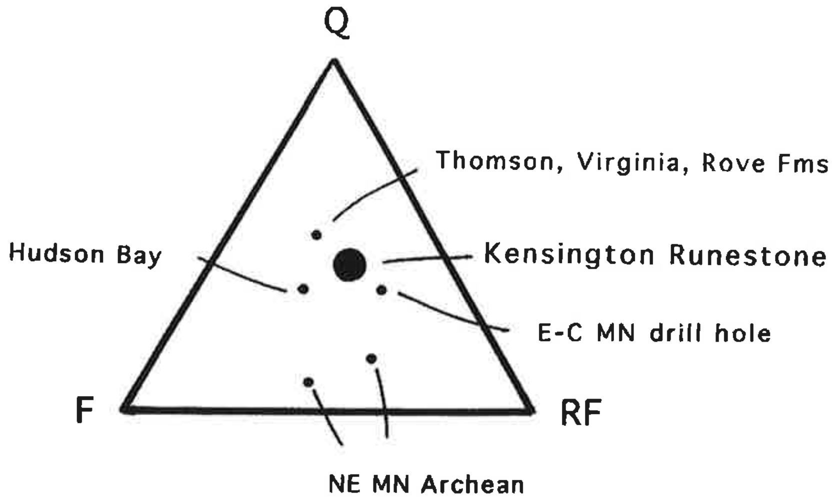
Thin section analysis reveals that the KRS is fine-grained meta-sedimentary rock called a meta-greywacke. The stone exhibited a strong preferred orientation of very fine-grained mica minerals (biotite, muscovite and chlorite). A second, less obvious preferred orientation of micas suggests the stone was subjected to two difference metamorphic events. This two-directional foliation of the mica minerals is a unique and diagnostic feature of the KRS greywacke.



Elongate muscovite mica grains under cross polarized light are aligned in two directions at roughly 90 degrees to each other indicating two metamorphic events that are unique to the KRS meta-greywacke.

In the spring of 2003, Dr. Richard Ojakangas, Professor emeritus of geology from the University of Minnesota Duluth, examined thin sections of the KRS and compared them with samples of other meta-graywackes in an attempt to identify the likely bedrock source. Professor Ojakangas generated a triangle diagram where he plotted the percentages of quartz, feldspar and rock fragments of the KRS and compared it with other possible, well-studied meta-graywackes sources. His conclusion was that "The source of the meta-graywacke upon which the runes were carved probably is the Paleoproterozoic Animikie basin of East-Central Minnesota (1.85 to 2.1 billion years)."

Is the source still
of final location?



A triangle diagram that plots the relative quantities of feldspar (F), quartz (Q) and rock fragments (RF). The KRS plots close to meta-graywackes from the Paleoproterozoic Animikie basin in East-Central Minnesota.

Split Side Chip Sample

To gain a better understanding of the weathering features of the original inscription an additional sample was required for analysis. Since the entire split side of the stone was created at the same time as the original inscription this surface has experienced the same period of weathering. Therefore, a sample taken from anywhere along this surface should yield similar weathering information. On October 21, 2000, a ½" x ¼" x 1/8" thick chip sample was obtained from the split side of the KRS using a two-pound hammer and steel chisel.

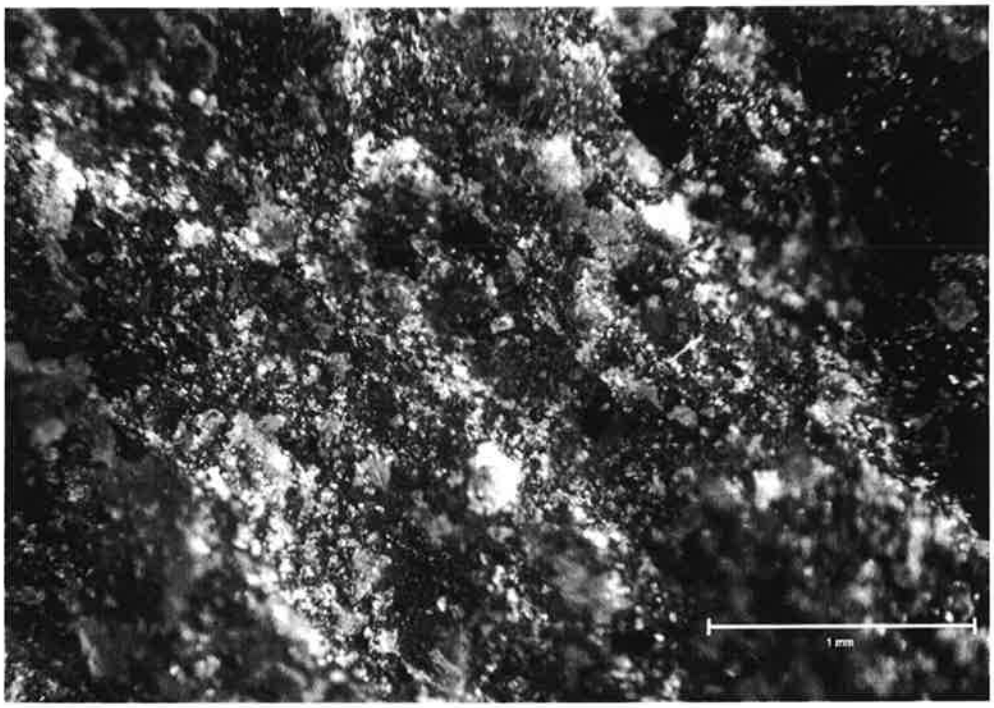
The chip sample captured from the split side.

Location of the chip sample obtained from the split side on October 21, 2000.

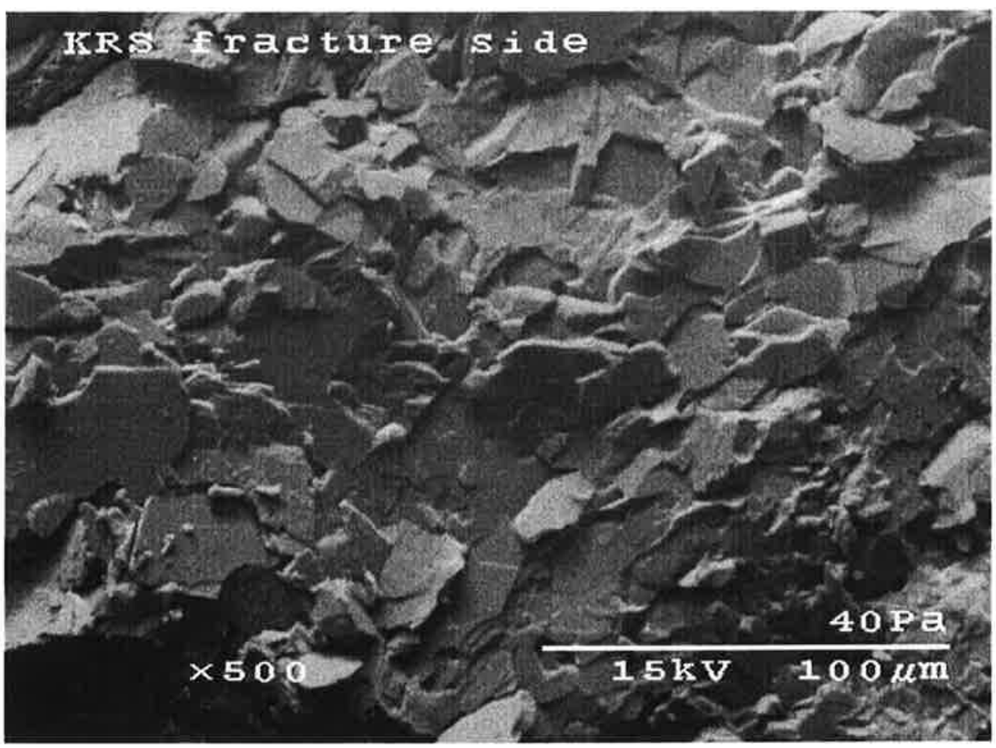
Scanning Electron Microscopy

The next phase of the testing program involved reviewing the core and chip samples using scanning electron microscopy (SEM) and energy-dispersive x-ray microanalysis (EDX). The equipment used was located in the Materials Laboratory at Iowa State University in Ames, Iowa. This microscope has low vacuum capabilities and does not require the use of a gold, carbon or nickel coating of the samples. The samples were put directly into the chamber and analyzed. The first surfaces analyzed were the bottom of the core and the back side of the chip where they had been broken off the stone. These freshly fractured surfaces exhibited clean and un-weathered minerals that also represent the original man-made surfaces at the time they were carved.

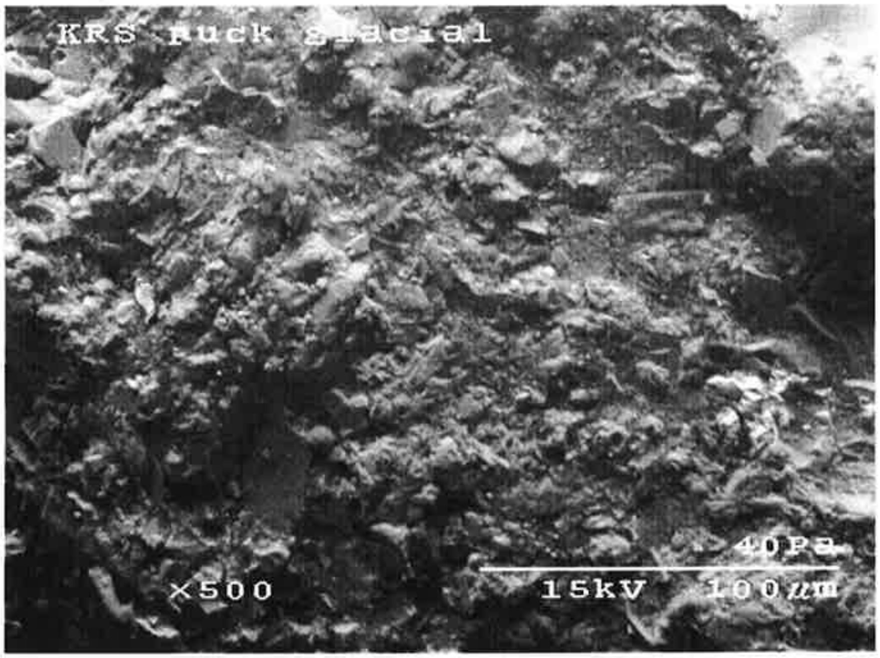
The top of the core sample was then examined in the areas adjacent to the white root leaching. These surfaces represent a glacial aged surface that has experienced at least 12,000 years of weathering. These surfaces exhibit fine-grained, uneven pitting with angular projections of exposed quartz and feldspar grains. Noticeably absent were any of the bladed micas grains which have long since weathered away. This advanced stage of weathering is in sharp contrast to the mica-rich freshly fractured surfaces.



The freshly fractured surface on the bottom of the core sample shows two white clusters of crushed minerals under reflected light.

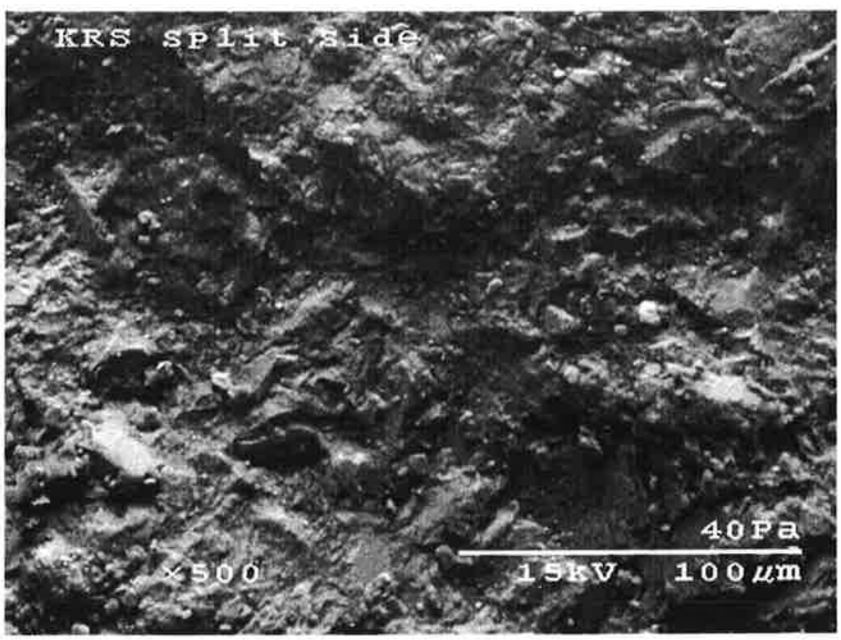


An SEM photograph shows numerous bladed-shaped biotite and muscovite mica minerals on the freshly fractured surface on the back side of the chip sample.



SEM photograph of the glacial top surface of the core that has experienced at least 12,000 years of weathering. The bladed mica minerals have long since weathered away.

Lastly, the chip sample was examined with particular attention paid to the state of the mica minerals that were exposed when the split side of the stone was made. Surprisingly, the mica minerals were not observed on the surface of the chip indicating that they had also weathered away completely.



SEM photograph of the split side of the KRS where the mica minerals have also completely weathered away.

The important question is how long did it take for the micas minerals to weather away? One way to try and answer the question was to analyze samples containing micas that have been weathering for a known period of time. The results of such a study would put a time-line on the decomposition of these minerals. The best way we could think of was to obtain samples from tombstones of various ages that contain the important mica minerals.

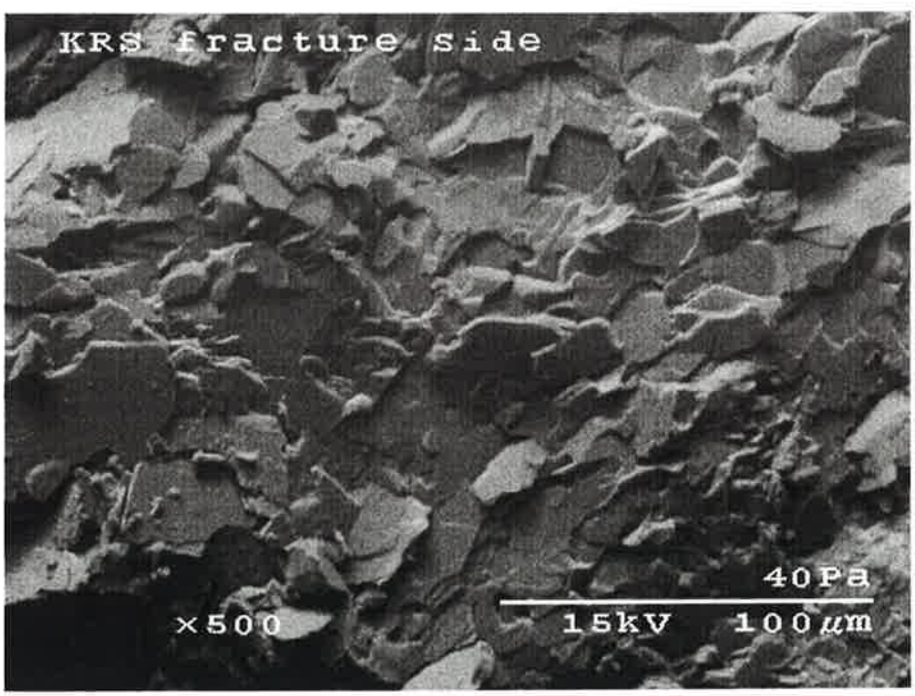
The Tombstone Study

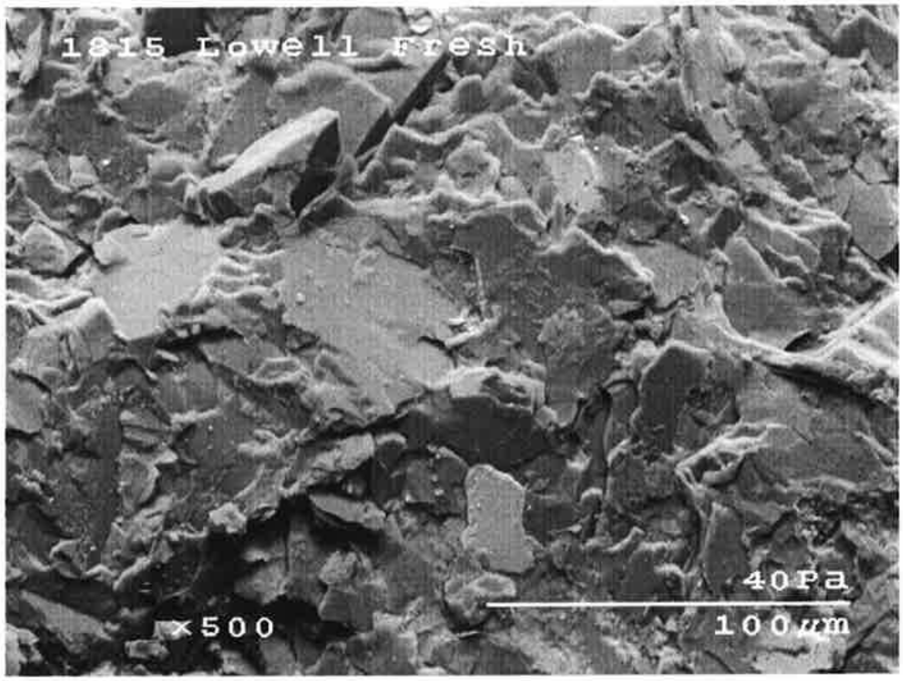
On March 6, 2003, I was able to collect 23 chip samples from slate tombstones in the Hallowell Cemetery in Hallowell, Maine. The tombstone death dates ranged from 1796 to 1865. This gave a range of 138 to 203 years that the slate tombstones had weathered. We outlined what we thought was an important list of criteria for the testing program to give the most meaningful data and includes the following:

1. In general, if all other conditions are the same, the smaller the size of the mineral, the faster the weathering rate. The micas minerals in the slate tombstones must have the same average grain size as the KRS micas. 3 of the 23 samples obtained had comparable mica grain size. The samples were identified as follows:

Sample Number	Decedent	Death Date	Age of Weathering
1	Richard Dummer	1806	197 Years
3	Gorham Dummer	1805	198 Years
22	Abner Lowell	1815	207 Years

The average age of weathering of the three samples was 200 years.





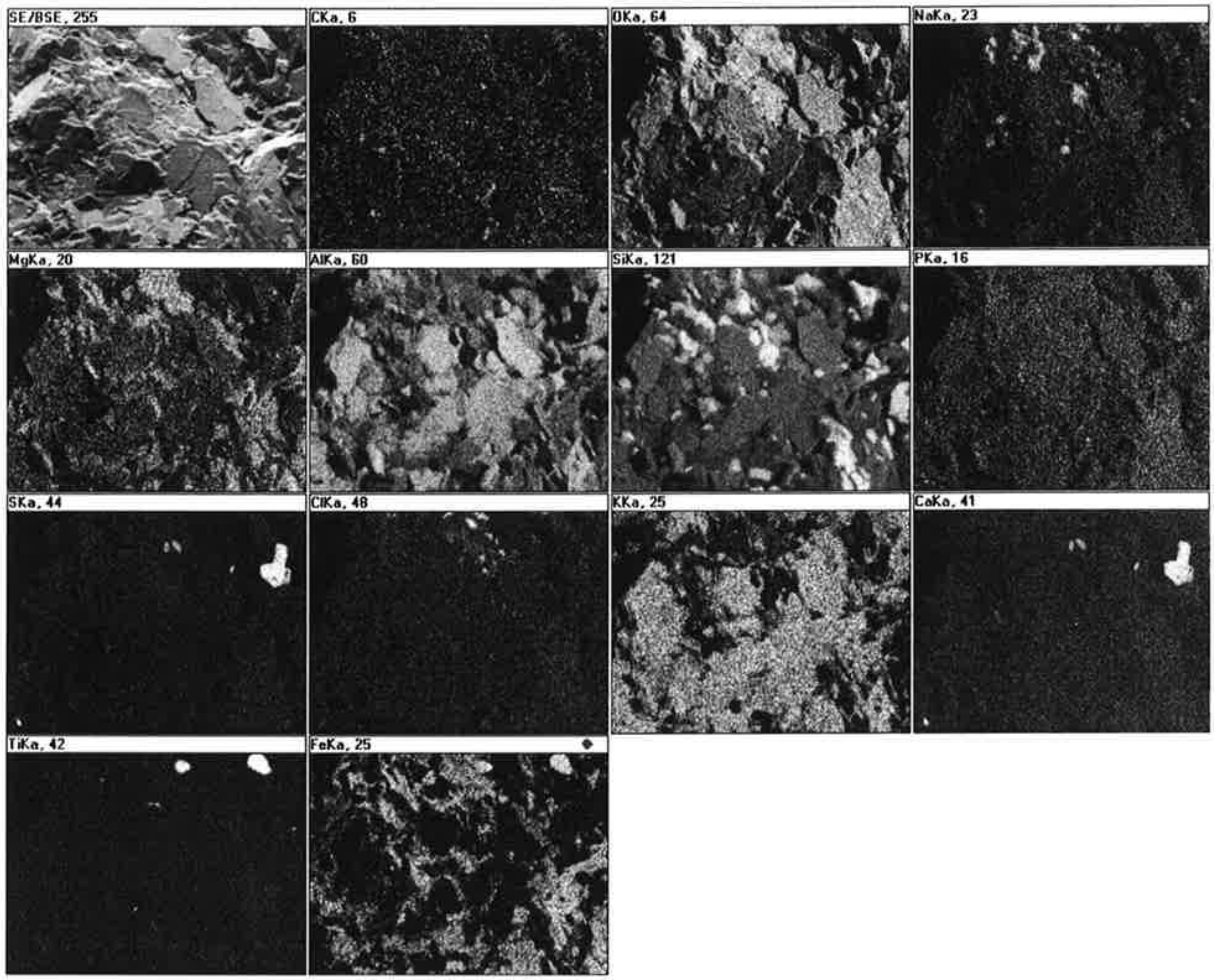
SEM images of the KRS micas (biotite and muscovite) above and the Lowell tombstone mica (biotite) below. The mineral grain size in the two samples is about the same size.

2. The weathering environment where the test samples were obtained must be comparable to the environment where the KRS was found. The climate in Hallowell, Maine is quite similar to the climate in the Kensington, Minnesota area.

3. The samples should be obtained from both above and below grade. Only above grade samples were collected because the ground was frozen and covered with a foot of snow.

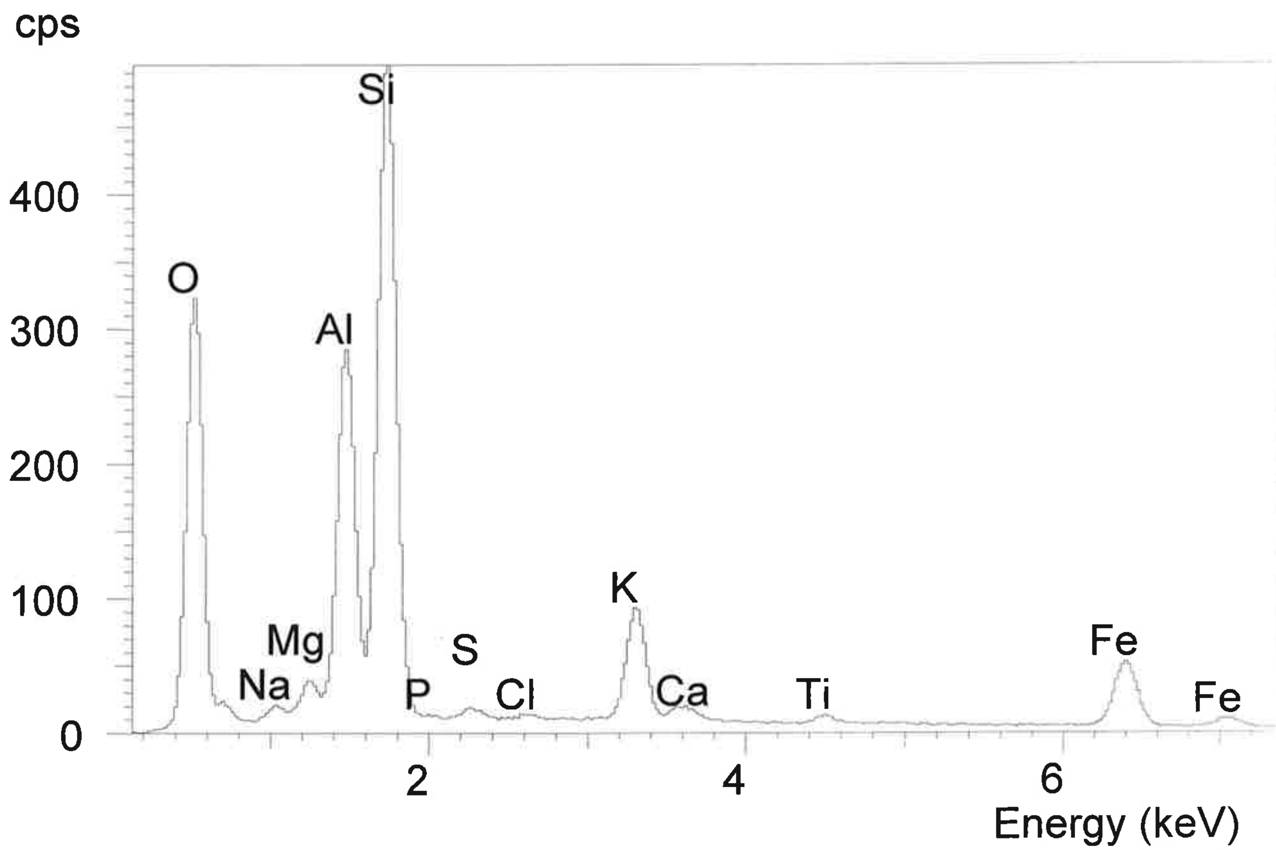
4. The chip samples were examined using both reflected light microscopy and SEM at magnification up to 5000x.

5. The geo-chemistry of the samples was documented using elemental mapping and X-ray diffraction analysis.



1815 Lowell Fresh Surface at 500X

An elemental map highlights the selected elements of a freshly fractured surface of a tombstone chip sample. The back-scatter image being mapped is in the upper left-hand corner. The relative brightness of areas in each panel is impacted by the relative quantity of a given element as well as its atomic weight. The elements selected for this particular map were Carbon (C), Oxygen (O), Sodium (Na), Magnesium (Mg), Aluminum (Al), Silicon (Si), Phosphorous (P), Sulfur (S), Chlorine (Cl), Potassium (K), Calcium (Ca), Titanium (Ti), and Iron (Fe).



1815 Lowell Fresh at 500X

An X-ray diffraction analysis spectra for the mineral biotite obtained from a tombstone chip sample.

The Theresa Stratton tombstone (1802) and the equipment used in sampling. The climate in Hallowell, Maine is comparable to Kensington, Minnesota. Because of the snow and frozen ground only above grade samples were obtained.

Tombstone chip samples #1, 2, 3 and 22 being loaded into the SEM sample chamber.

In general, the individual letters, numbers and images of the inscriptions looked very sharp and exhibited very little visual weathering overall. However, of the approximately 100 slate tombstones reviewed that ranged from about 150 to 200 years (based on the death dates), the weathering features of the slabs overall, consisted of the following:

1. Delamination along cleavage planes aligned sub-parallel to the face of the tombstones.

2. Roughly parallel, linear fractures at various orientations across the tombstone face.

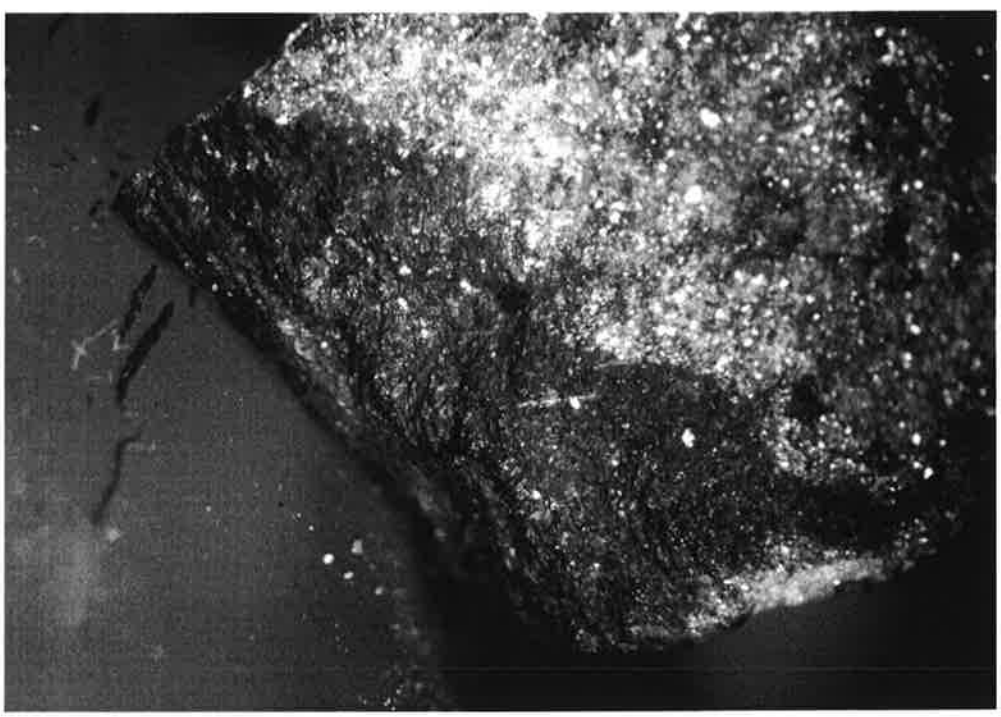
3. Exudation of secondary minerals from within the fractures.

White colored secondary deposits exuding from sub-horizontal fractures traversing the face of a slate tombstone.

4. Intermittent iron oxide staining on exposed surfaces.

Microscopic review of the slate chip samples under reflected light revealed a considerable difference in color between the freshly fractured areas as opposed to the weathered surfaces. The weathered surfaces were dark gray in color and had a somewhat smoother texture.

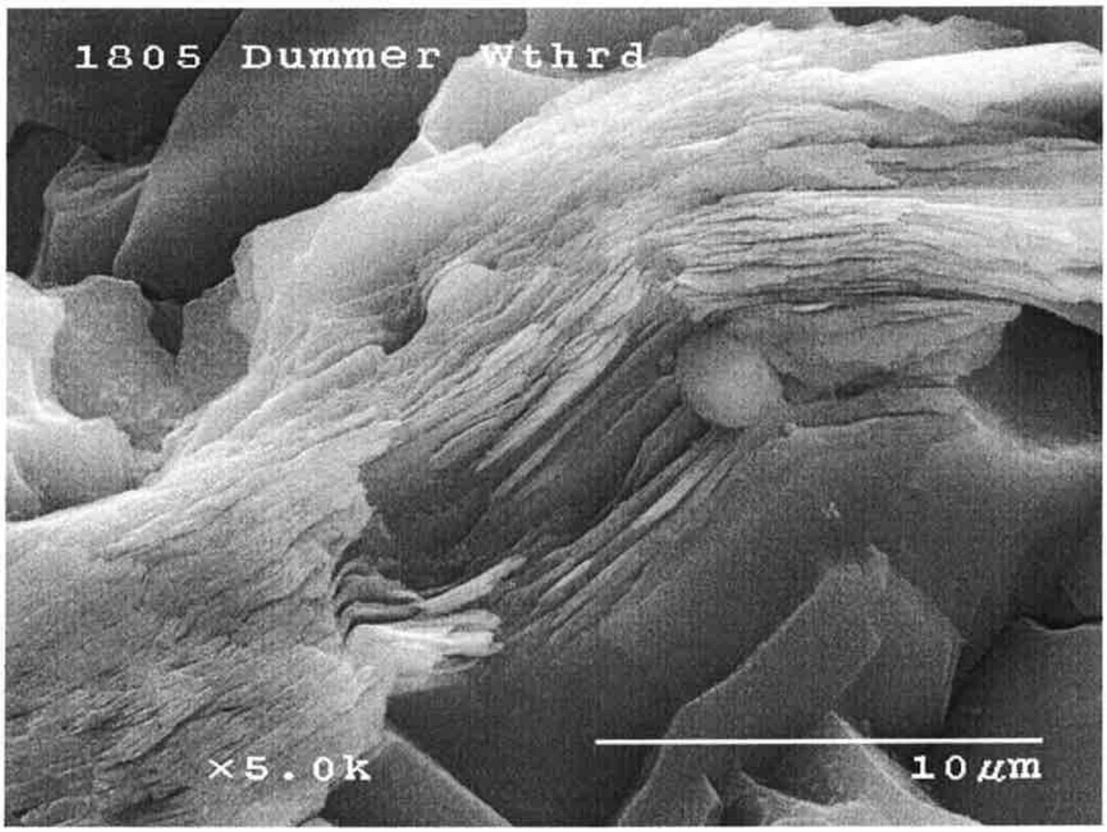
Sub-parallel fractures and rust colored iron oxide deposits on the face side of the Richard Dummer (1806) tombstone.



The Abner Lowell (1815) chip sample showing the dark gray weathered area at left, and the light gray colored freshly fractured area to the right.

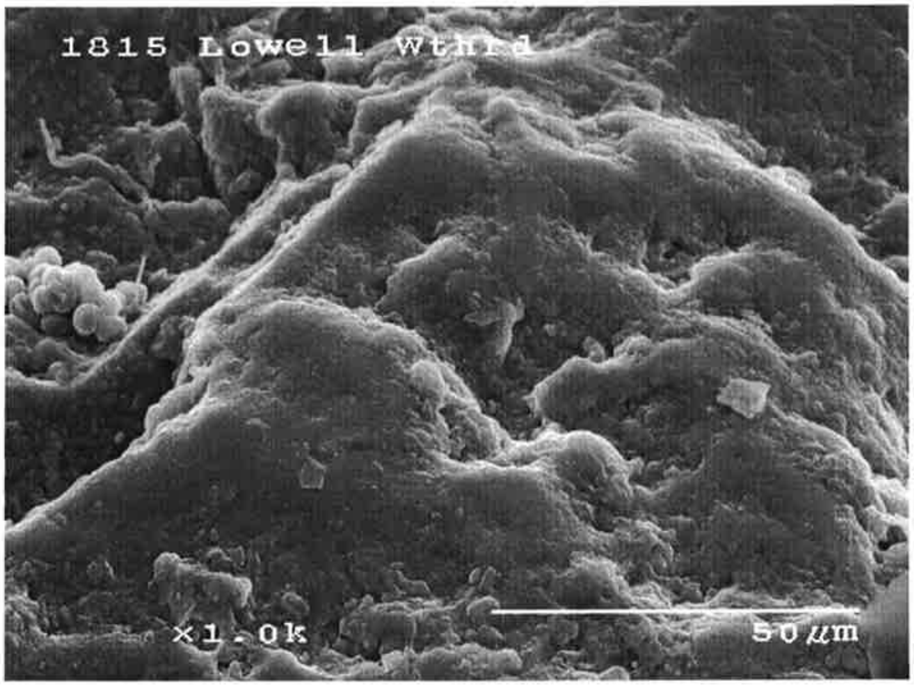
The weathered surfaces of the three chip samples when examined in the SEM exhibited several features that were consistent with decomposition of the insipient biotite mica. In general, the biotite grains exhibited both chemical and physical degradation. It appears that before the biotite completely weather to vermiculite, individual sheets exfoliate off the surface of the stone. In roughly 200 years of weathered biotite minerals exhibited the following characteristics:

1. The edges of multiple sheet clusters or "books" of biotite mica begin to expand and separate.



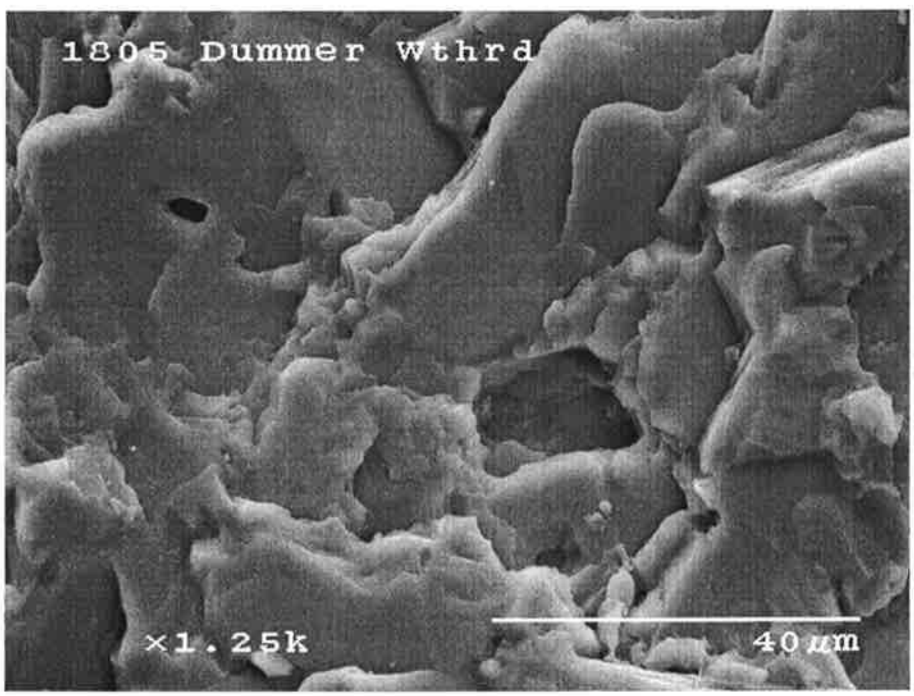
The edges of individual sheets of clustered biotite begin to expand and separate on the weathered surface of a slate tombstone after 200 years.

2. Individual mineral edges become rounded and frayed.



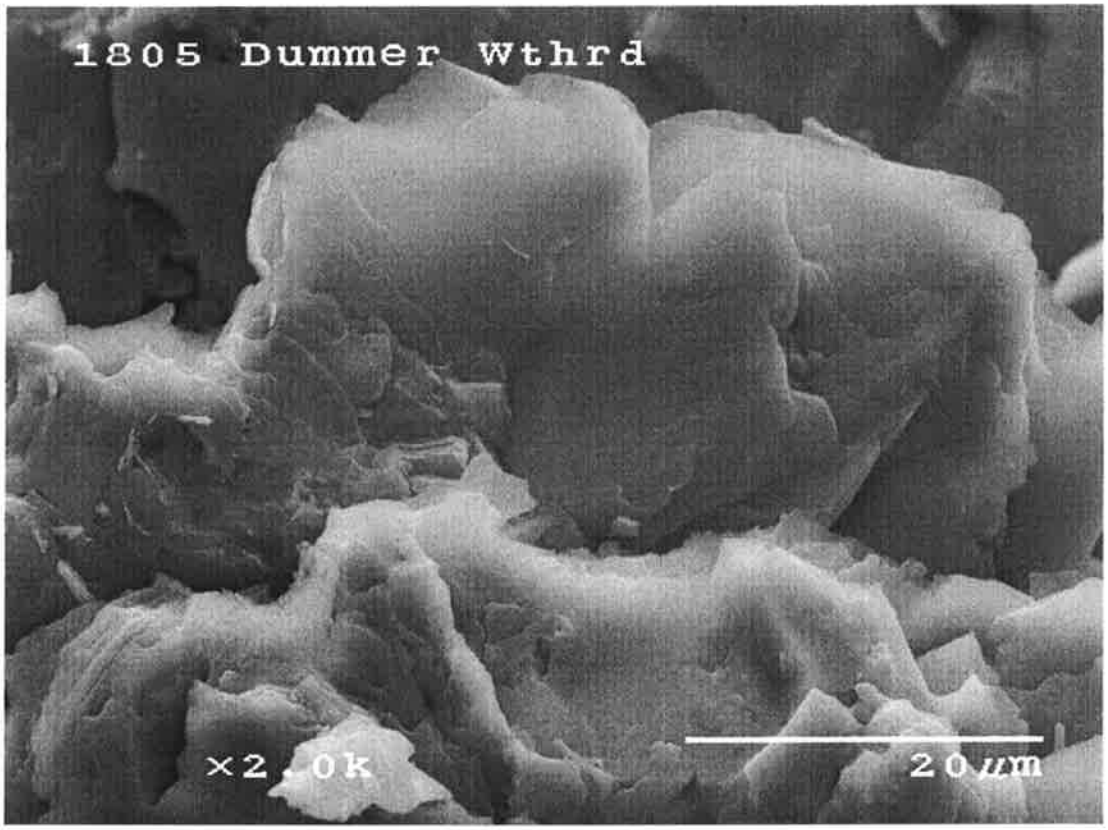
Rounded and frayed edges of biotite mica grains on the weathered surface.

4. Pitting develops on the basal surfaces.



Large and small scale pitting was observed on the basal surfaces of weathered biotite minerals.

4. Individual sheets of biotite begin to exfoliate off the weathered surface of the slate tombstone.

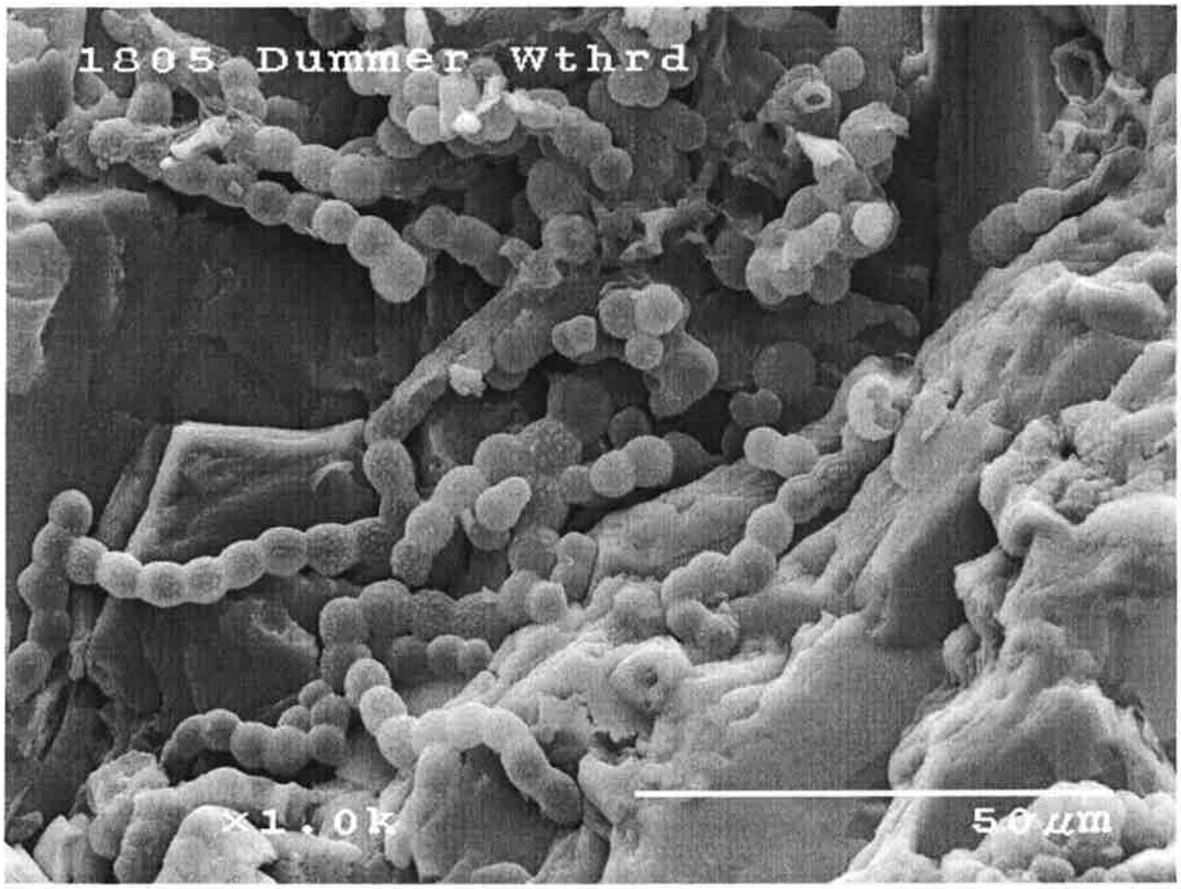


Individual sheets of biotite exfoliate off the weathered surface of the slate tombstone.

5. Acid produced by lichen on the surface of the tombstones accelerates dissolution of biotite grains by an unknown rate. The amount of lichen development on slate tombstones is an important parameter in understanding the rate of weathering.

Another factor of weathering that we need to be mindful of is that the Hallowell cemetery is located within a few yards of the railroad. Localized acid rain conditions were produced by the exhaust from the sulfur-laden coal of the steam engines. This would certainly accelerate the weathering of all of the tombstones in the cemetery. Ironically, the slate tombstones are closest to the railroad. Even though we observed exfoliation of some biotite grains after 200 years of weathering, the vast majority of the minerals were still intact. When we compare the tombstone data with the weathering of the original man-made surfaces on the KRS, a statement about the relative age of the inscription is possible. Based on the results of this initial round of tombstone sample testing, the weathering features of the original man-made surfaces on the Kensington Rune Stone took longer than 200 years to develop.

including the Runes?



Tiny worm-like beads of lichen partially cover the surface of a slate tombstone. Acid produced by the lichen accelerates the weathering rate of biotite mica.

It should be noted that although the dissolution of sheet silicates including biotite, have been studied for decades there are numerous new research opportunities. It is hoped that this ongoing tombstone research will add to the understanding of the weathering characteristics of not only micas, but other minerals as well.