Scanning Electron Microscopy of a Stratigraphic Section of Lavas from Success Cleaver, Mt. Rainier Volcano, Washington State

Aaron Wisher

University of Puget Sound

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Acknowledgments

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Abstract

All of the rocks examined are vesicular andesitic porphyrites. The phenocrysts are predominately mid-range plagioclase and pyroxene, with 1-2% iron-titanium oxides, and small amounts of apatite. The matrix is partially glassy but does contain microlites of oxides, tridymite, and pyroxenes. The plagioclase ranges from An65 to An80. Some of the crystals are zoned with a core of An75 and a rim of An90. The pyroxenes are calcium-iron-magnesium-silicates which mainly vary in the calcium content (hi-cal/lo-cal). Many of the pyroxene crystals contain oxide inclusions. All of the opaques are iron-titanium oxides, and they occur as pure grains or as complex intermixtures of two compounds, usually titaniferous magnetite and illmenite. The glassy matrix appears to be very uniform and similar in composition to the plagioclase but has less silicon and contains potassium, an element not detected in any of the phenocrysts. Small variations in the chemical composition of the phenocrysts, especially the pyroxenes and plagioclase, and the variation in the microlite/glass ratio provide a way to characterize the individual rock flows in the stratigraphic sequence.

Introduction

Mt. Rainier is perhaps the most recognizable peak in the Cascade volcanic chain. At 14,410 feet above sea-level, Rainier is the highest point in Washington state. Other notable volcanic peaks that make up the Cascades are Mt. Shasta, Mt. Hood, Mt. Adams, and Mt. Saint Helens located to the south of Rainier and Glacier Peak and Mount Baker located to the north. Mt. Rainier is built upon the Tatoosh Pluton and Stevens Ridge Formation. These lavas cover 100 square miles and range from 6000 feet to 14,410 feet above sea- level. Past violent eruptions, landslides, and glacial erosion characterized Rainier, which is visited by millions every summer.

Project Objectives

In 1995 C. Kerrick collected a series of rocks from the lavas exposed at Success Cleaver on Mt. Rainier, and subjected these samples to whole-rock analysis. This current study examines those same rocks using backscattered imaging by Scanning Electron Microscope (S.E.M.) supplemented by light microscope petrography and x-ray microanalysis (EDS). Variations detected in whole-rock analysis will hopefully be evident on the microcrystilline level using the S.E.M. and EDS. Microcrystilline variations and variation between different flows should enable the porphyritic flows at the Success Cleaver to be grouped into different eruptive events. This study along with those of Keuhn, Hooper, Eggers, and Kerrick will help us grasp the dynamics of Mt. Rainier's Magma chamber and how it has changed over time.

Previous Studies

The first geologists to study Mt. Rainier were primarily interested in studying and describing the salient features of the mountain. The lavas of Mt. Rainier were initially studied petrographically and chemically by Hague and Iddings (1883). In 1896 I.C. Russell published a paper describing the major glaciers found on the mountain at that time. In 1900 Smith studied the lavas of Mt. Rainier Optically. Howard Coombs (1932,1936) was the next Geologists to do large-scale scientific research on Rainier. In his acclaimed report entitled: The Geology of Mt. Rainier National Park, Coombs described the different rock units present in the area largely by microscopical properties of the lavas, and the extent to which they traveled from the mountain. Fisk (1963) expanded on Coombs research and went on to describe in more detain the constituent formations in the park and the park's geomorphic features. Condie and Swenson (1973) were the first to study the lavas of Mt. Rainier geochemically. Over 100 samples were retrieved from the cone area of the mountain and classified them into to five different eruptive groups. In 1992, Steve Keuhn did 82 whole rock analysis on samples from the low to middle elevations on the cone. His findings showed systematic compositional variations that could not be explained by fractionation and were interpreted to represent magma mixing or assimilation of zenoliths. Swanson (1993) studied the 2.200 year-old C-ash deposit. Chemical analysis and electron microprobe analysis from 9 different sample sites show that the C-ash eruption event was the result of magma mixing. Condie and Swenson (1974) sampled 12 flows from 6640 feet to 10,200 feet on the Success Cleaver. Whole rock XRF analysis were obtained from each of the 12 flows then were averaged to define a distinct compositional group (Kerrick, 1995). Keuhn and Kerrick (1995) sampled 5 flows on the cleaver, the sample sites ranged from 7170 feet to 9500 feet elevations. Keuhn also re-analyzed Condie and Swenson's samples. Kerrick (1995) studied the flows in the success cleaver above 9,500 feet, thus completing the Success Cleaver Section. The flows were determined to have been derived from at least two magma types. Whole rock analysis and petrographic microscopy were used in this study. This magma mixing event is thought to be the cause of the eruptions that deposited the lavas.

Methodology, Procedures, Imaging.

Several techniques were used to gather images directly from the S.E.M. and petrographic microscopes. A coordinate system was established which allowed direct correlation between specific crystals. This coordinate system allowed preliminary work done by Chris Kerrick (1995) and work done by the author with the petrographic microscope to be correlated to the same sample areas that could be located on the S.E.M. An Area of interest seen under polarized light could be recognized using the back-scatter detector, and then analyzed with the EDS detector, which produced a spectrum of the region. Images were gathered from the petrographic microscope by frame capture directly into a Power Macintosh and/or by means of hard copy onto film through a camera. Images acquired on the S.E.M. could be recorded on film and/or computer hard disk. Images can be photographed directly from the S.E.M. via a high resolution photographic CRT, which supports various formats of film and cameras. Images taken directly into the Tracor Northern (spectrum analysis and image processing computer) could be manipulated, colorized, and replayed to both its CRT or the hi-res photo CRT on the S.E.M. Images stored on the Tracor Northern hard disk could then be transferred via cable to a Macintosh computer, where they could be analyzed and manipulated in NIH Image or Adobe Photoshop. These images could then be printed on a high quality printer and used as "crystal maps" when locating other areas or as tools in stereology. Images collected on film could be scanned directly into the Macintosh computer at a much higher resolution as well.

Stereology

Stereology was performed on polished thin sections using back-scatter detection in the S.E.M. When acquiring an image in this manner the crystals with higher atomic number show up as a higher or brighter gray value. Vista, a program on the Tracor Northern computer, allows gray levels to be divided into "bins" or groupings of gray levels. These bins in turn could be colorized, which allowed specific gray levels or crystals to be colored. Pixels can be counted for a given color in the histogram, which could be calculated as a percent of the whole. This process allows a very accurate indication of the percent mineral in a particular region. This stereological technique varies from more standard techniques in that it involves all of the available pixel information rather than a random sample. The question of reliable statistics is thus virtually eliminated. One area of concern this author's method is the magnification of the sample area. It is common to find as the magnification increased that the matrix contained many crystals that were a miniature of the larger area. This problem was handled by taking several different areas at different magnifications and averaging the results.

Spectral Analysis

Spectral analysis of polished thin section sample was used to analyze the chemical make-up of crystals and matrix in the andesite. A spectrum gathered on the Tracor Northern computer could be analyzed in several different ways including standardless analysis and analysis with standards. Both methods are similar in function. Both fit known curves to the curve that is being analyzed. Standardless analysis uses chemical standards built into the program at the time of programming, and then periodically updated as new software is developed. Analysis with standards involves using minerals of known composition which are similar to those that you anticipate analyzing such as plagioclase or pyroxene and acquiring a spectrum from these prior to running the unknown. This method gives the most accurate and consistent results because all the samples and standards were run at the same time. A chi-squared analysis of the curves measures how well the unknown curve fits the curve produced by combining the standards. Chi-squares of 1 means that it is a perfect fit. The chi-squares obtained in standardless analysis were on average much lower than those acquired while using standards. This seemed reversed from what we had expected, but when we compared the weight percent and oxide percent between the two methods there was no discernible difference. It followed that when acquisitions were made overnight or for many hours the preferred method of analysis was standardless. A second method for analyzing spectra was in the Macintosh computer. Spectra collected in the Tracor Northern computer could be transferred via cable to the Macintosh where they could be analyzed with D.T.S.A. (Desk Top Spectrum Analyzer). Although the author has not gone into great detail with this program, an attempt has been made to correlate the findings at the Tracor Northern computer with those gathered from D.T.S.A. The results of this are not altogether clear at this point but do seem to suggest comparable data. There were several methods used to acquire the data points used in generating these spectra. First was the "random-point-of-interest" method which involved finding something interesting in the slide, landing on it, and taking a spectrum. Second, line-scans were used to analyze individual crystals or small groups of crystals at high magnification. A crystal, ranging in size from 30 to 130 NM could contain a linear string of points collected as in picture 1. Third, a low magnification region could be 15 selected where up to 99 points could be set up to gather spectra for several hours at a time.(map 8)

Analysis of Data/Spectra

The following picture (map 8) is a typical area of spectra collection, the numbers represent points at which spectra were acquired. In general the samples were acquired at 18kV for 200 seconds (live-time), unless otherwise noted. Spectra were compared between spots within a single crystal (#'s 46-50), spots on several different crystals (#'s 48,10,84,etc), and spots on crystals from different flows. Spectra 1 is an overlay of two spectra (#'s 2 and 10) in sample MTR11008. You can see from this the variations in chemistry. Spectra 2 is an example of different crystals within the same sample (MTR11008, #'s 2 and 48), again you can see differences in composition. Differences in percent calcium are easily identified using backscatter detection (MTR11011). In map 12 you can see the different gray levels which correspond to differences in atomic number. Variations within individual grains is common throughout all of the samples. Spectra 3 shows how hi-cal spectra overlap with those of lo-cal. Note also the variations in magnesium and aluminum. Spectrum 4 and spectrum 5 show variations in the oxides related to the ratio of titanium and iron. From the spectra the composition of individual crystals can be obtained.

Chemical Analysis

The following section of graph show variations within various samples, variations within individual crystals, and variations between different samples. Triangle plot A shows the chemical composition of ferromagnesian crystal in all the flows. From this plot the hi-cal/lo-cal varieties of crystals can easily be identified as a region separated from the main area near the edge. There is also evidence of weak differentiation between flows (see diagram). The differentiation is not as evident in any of the other plots, and is not as pronounced as in early studies. Triangle plot B shows the primary chemistry of plagioclase in the different flows. Again the differentiation is weak and not as evident as in previous studies. In general there tends to be a reduction in sodium and an increase in calcium toward the top of Success Cleaver. The third triangle plot (C) is an analysis of the matrix, which has little if any differentiation. Graphs 1 through 4 immediately following the triangle plots show chemical variations within individual crystals. These graphs clearly show variations within these crystals, which is common in all of the flows. Typically a drop or rise in the amount of calcium (graphs 1 and 2) would be countered by a rise or drop in the amount of sodium and calcium respectively in the plagioclase crystals. In graph 3 the ferromagnesian crystals behave in a similar fashion. When a change in the amount of calcium occurs there is an inverse reaction to both iron and aluminum. Graph 4 shows matrix composition, and here a change in the amount of magnesium is near perfectly inversely mirrored by a change in the amount of iron, and to a lesser degree the amount of calcium.

Petrographic microscopy

The polished thin sections used in the S.E.M. work were also used as thin sections in petrographic studies. Mainly the petrographic microscope was used to locate unusual areas of interest. One area of interest was the ground-mass. Under polarized light some areas of the groundmass appeared clotty and much darker than other areas. Further inspection of these areas under the S.E.M. revealed that the lighter areas in the groundmass consisted of a concentration of microlitic laths of plagioclase and pyroxene. The darker areas or clots were found to contain far fewer laths, and consist of much finer material. Under back scatter detection and petrographic microscopy the plagioclase crystals are strongly zoned (maps 2 and 11). Chemical variations are also common within the ferromagnesian minerals as well as the oxide minerals.

Oxides

Oxides of iron and titanium comprise between one and two percent of the andesitic volcanic rocks of Mt. Rainier. They occur as medium grained phenocrysts and as microlites in the glassy matrix. S.E.M. backscattered microanalysis show that the most common compounds are titaniferous iron oxide (titanomagnetite) and iron-titanium oxides (illmenite). Pure iron oxide (magnetite), ferrian rutile, and rutile occur, but are rare. All of the oxides usually contain trace amounts of manganese, chromium, vanadium, aluminum, magnesium, and silicon. The titaniferous magnetite and illmenite occur as discrete grains or as intermixtures of the two compounds. The mixed grains may be composite, layered (sandwich), or trellis. Occasionally the titaniferous magnetite forms symplectites, that always form within silicate (pyroxene) crystals. The separate grains seem to dominate the oxide inventory in most of the rocks examined with an average of one third being illmenite and two thirds titaniferous magnetite. Mixed grains were also present in all of the samples studied. The borders of most of the grains are sharp, but in about ten percent of the grains the edges are ragged with narrow reaction zones, which contain an enrichment of magnesium. Because the inventory of oxide types varies from sample to sample, counts of the grain "species" should provide a method for characterizing the rock, and possible correlation of flows.

Conclusions

The chemical data, plots, and graphs show chemical variations within each sample which very weakly differentiates into different flows. Based on chemical data alone there is insufficient evidence to group flows into characteristic events on Mt. Rainier. The andesites of Mt. Rainier can be correlated to different flows and somewhat to different eruptive events on the basis of petrography and physical attributes, as was the case with several studies before this one. There was little or no evidence using the S.E.M. that would suggest two different compositional magmas. Visual differences between groundmass using the petrographic microscope showed no difference in composition using backscattered detection and analysis on the S.E.M. Variations within individual crystals were evenly distributed throughout all of the samples. The ratio of "species" of oxides was not thoroughly studied but no samples were void of at least one of all the "species." Grain counts could be used to bolster this line of reasoning, and perhaps that would supply a means of better differentiating flows based on oxide intermixtures. Small variations in the chemical composition of the phenocrysts, especially the pyroxenes and plagioclase, and the variation in the microlite/glass ratio provide a way to characterize the individual rock flows in the stratigraphic sequence. This could be seen from the triangle plots.

Further Study

Grain counts should provide a better way to differentiate samples based upon oxide intermixtures, ferromagnesian variations, and plagioclase zonation. Chemical compositions from other areas of Mt. Rainier should also help correlate the flows and provide better evidence of a possible magma mixing event.

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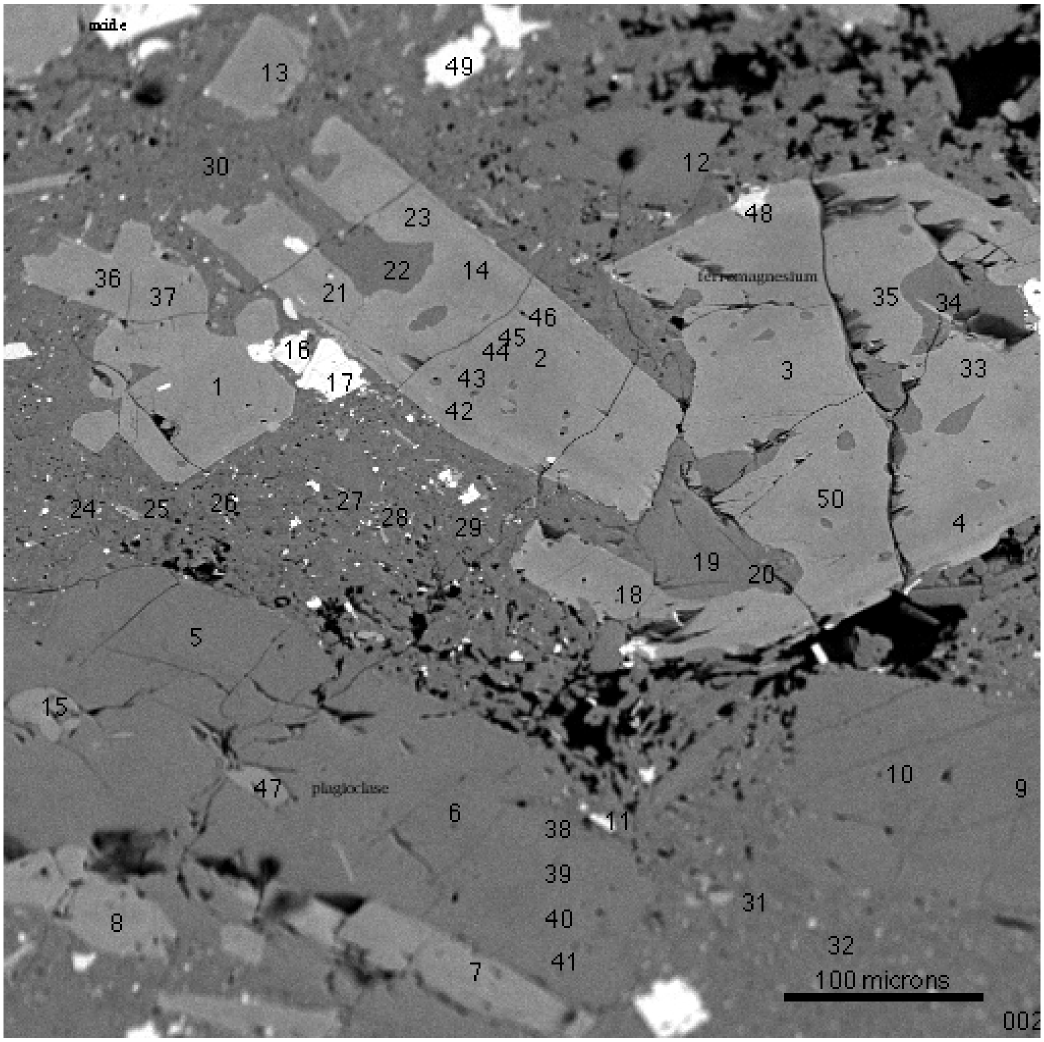
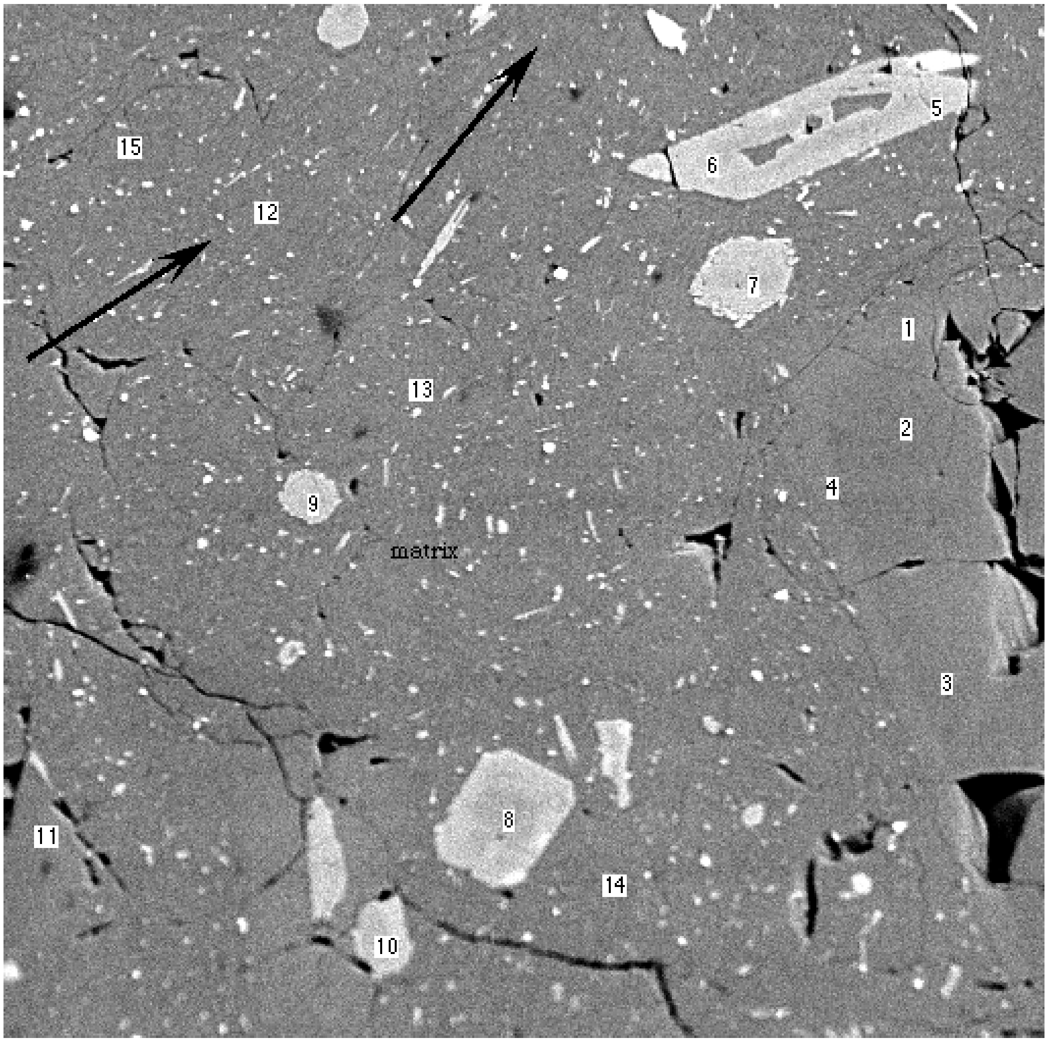


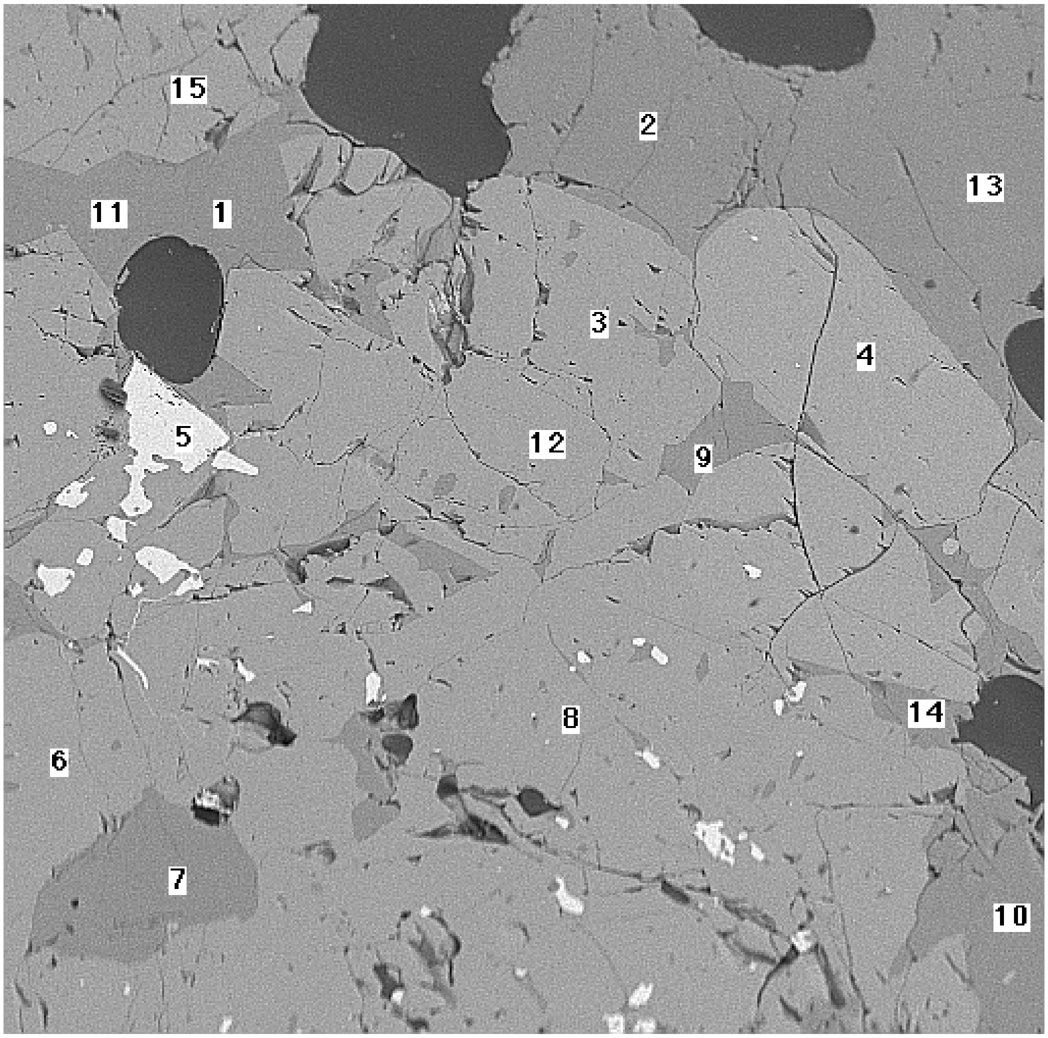
map 1

Scanning electron micrograph showing points used in data collection. The difference in grayscale values represents differences in atomic number.



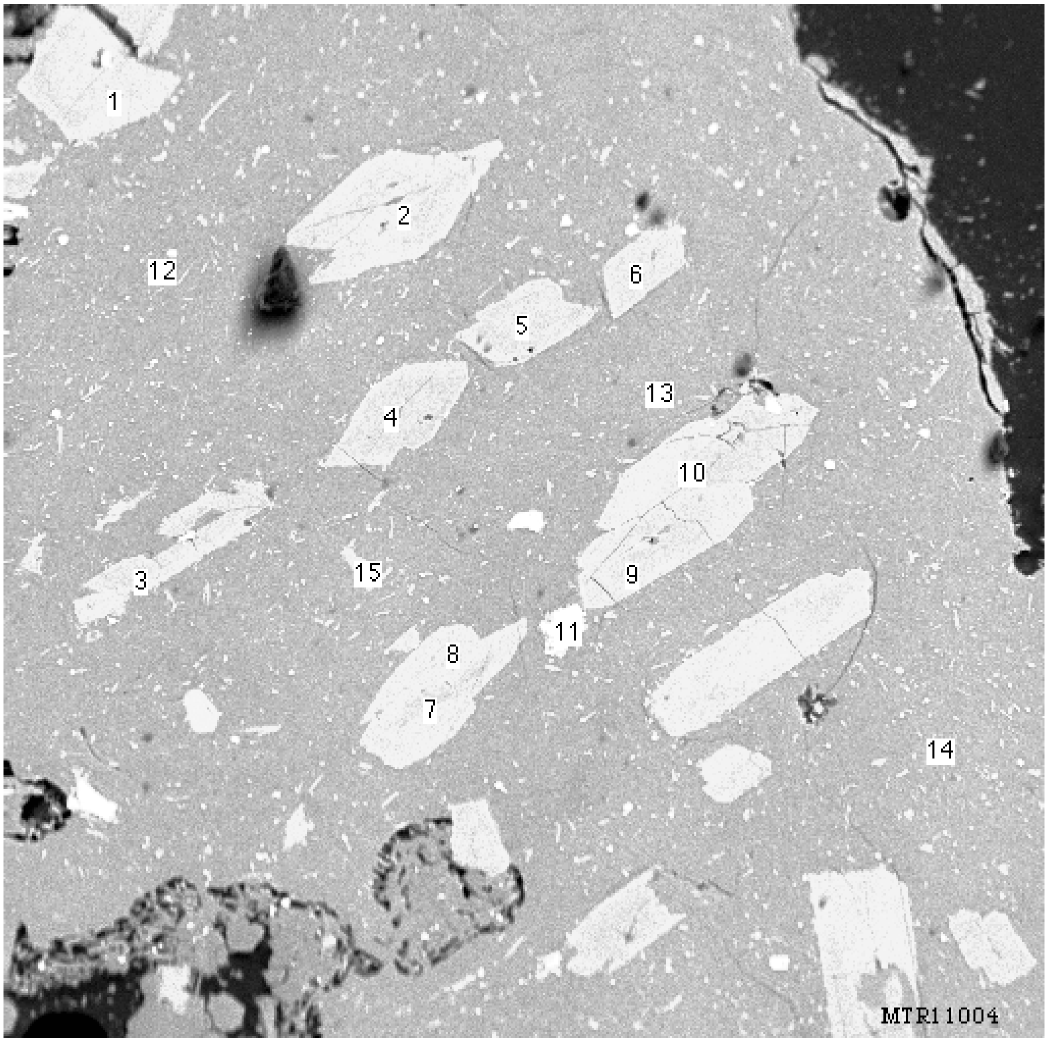
map 2

Scanning electron micrograph showing a general view in MTR11003. Notice desrect patterns within the matrix as well as microcrystalline laths. See arrows. This image is magnified 30 times.



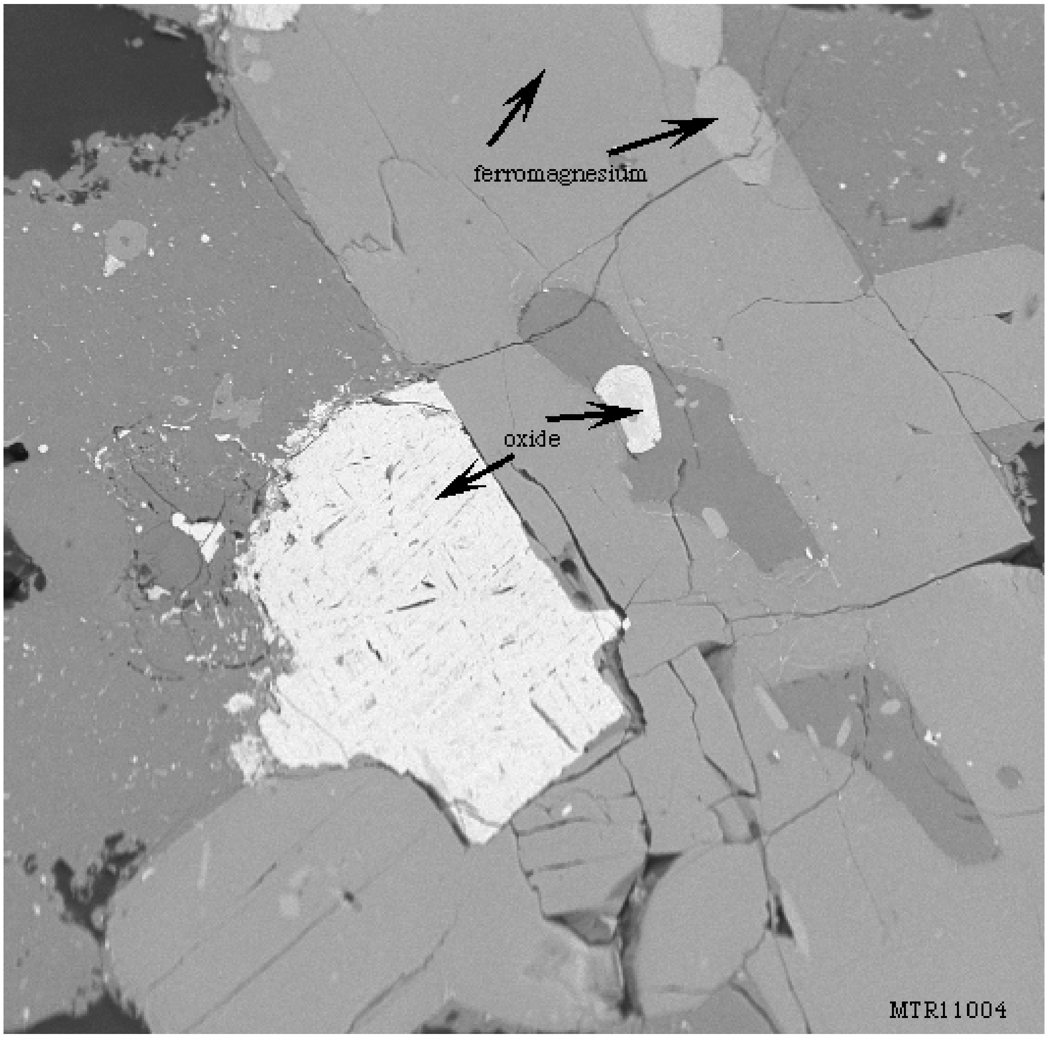
map3

Scanning electron micrograph showing a general view in MTR11003.
Notice the absence of matrix in this sample. The points are areas where data was taken.



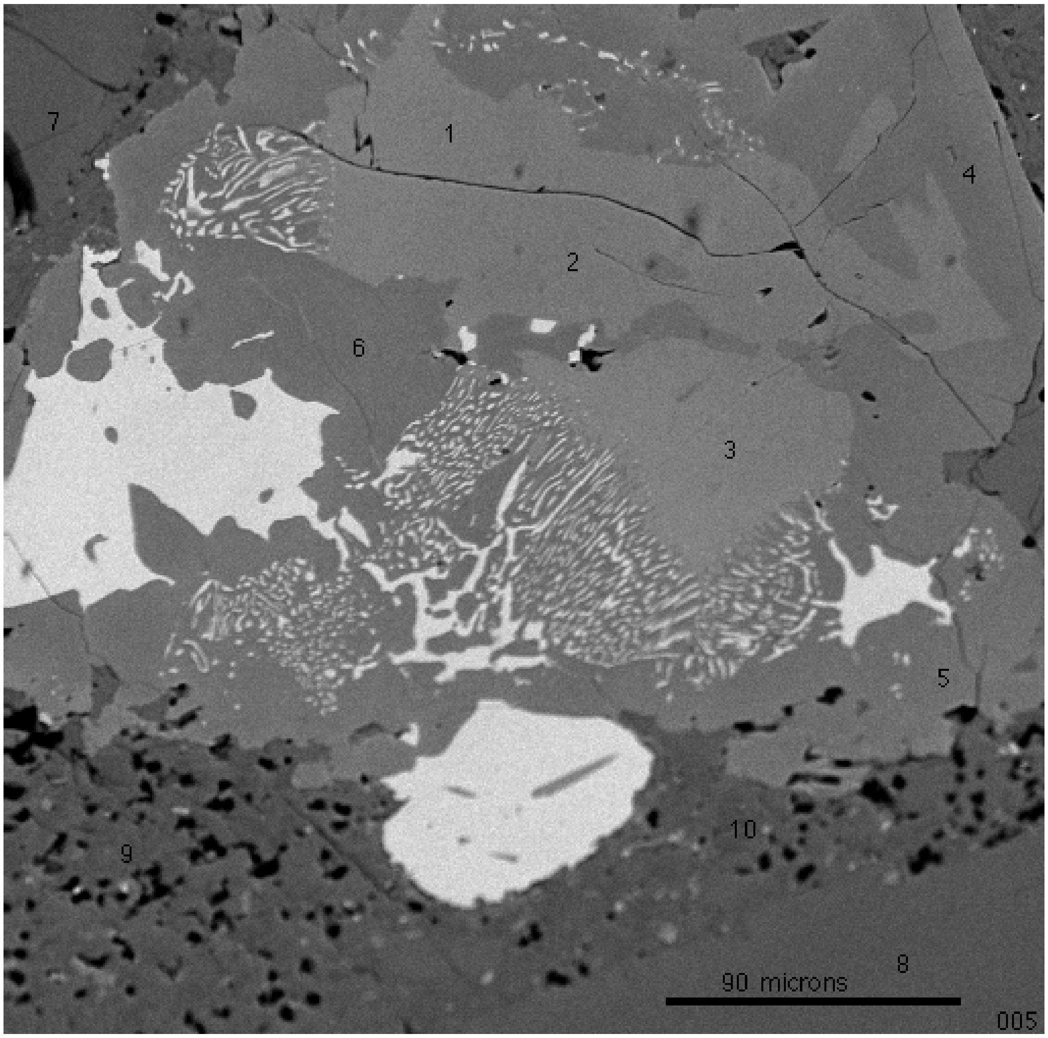
map4

Ferromagnesium crystals aligned in a matrix of finer grained material.



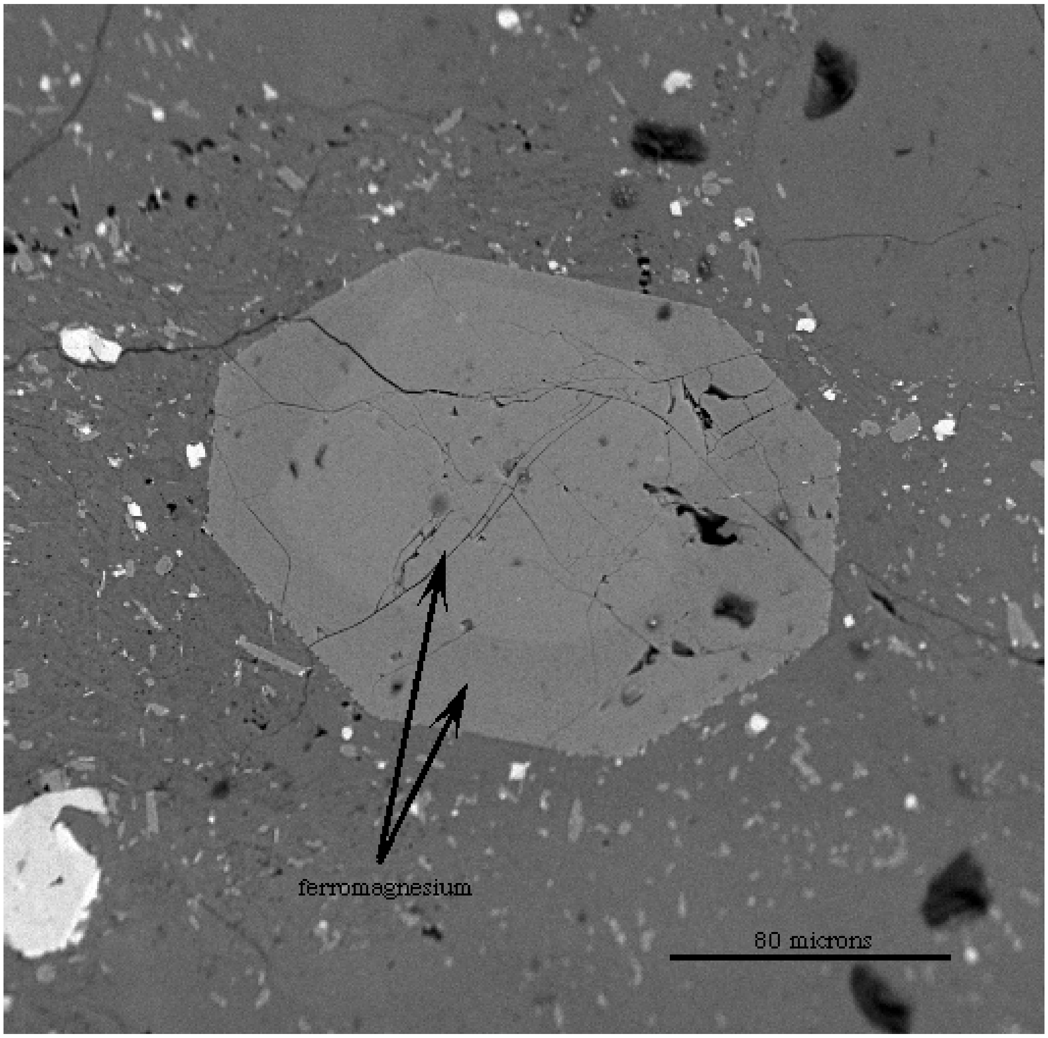
map 5

Micrograph showing a comples intermixture in the oxide. This form is classified as a trellis pattern. Notice also the chemical variations in the ferromagnesium crystals.



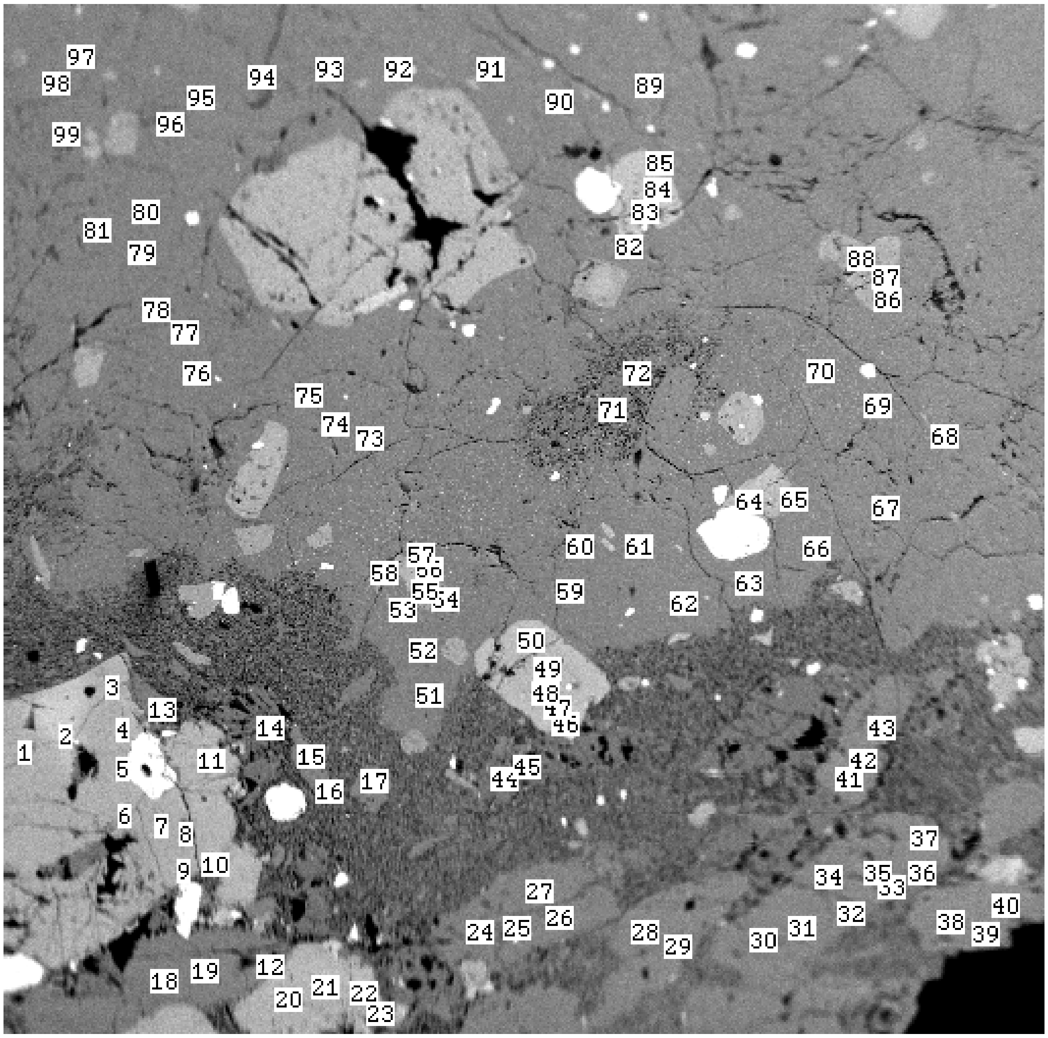
map 6

Micrograph showing a complex intermixture in the oxide. This form is classified as a symplectite.



map 7

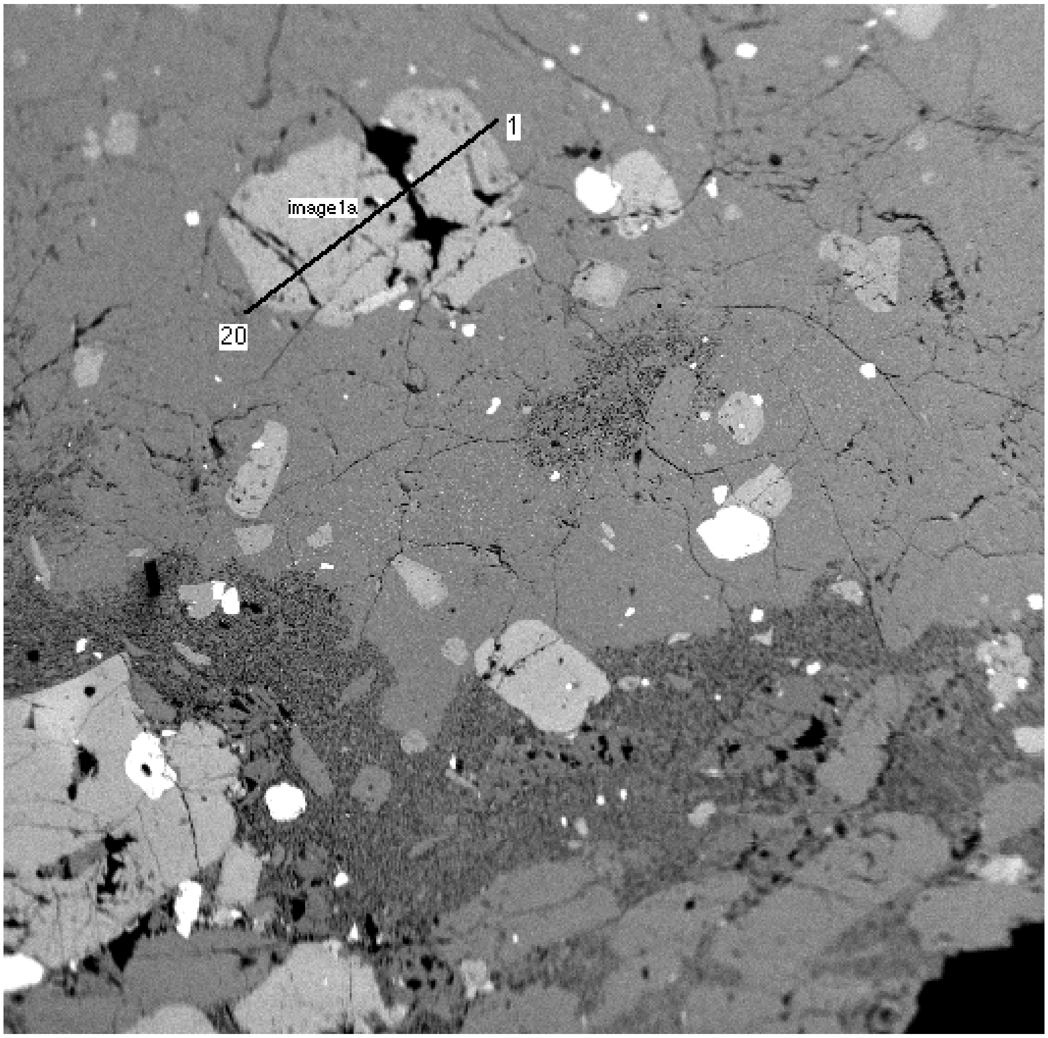
A euhedral ferromagnesium crystal showing variable composition between the edges and the middle.



MTR11008

map 8

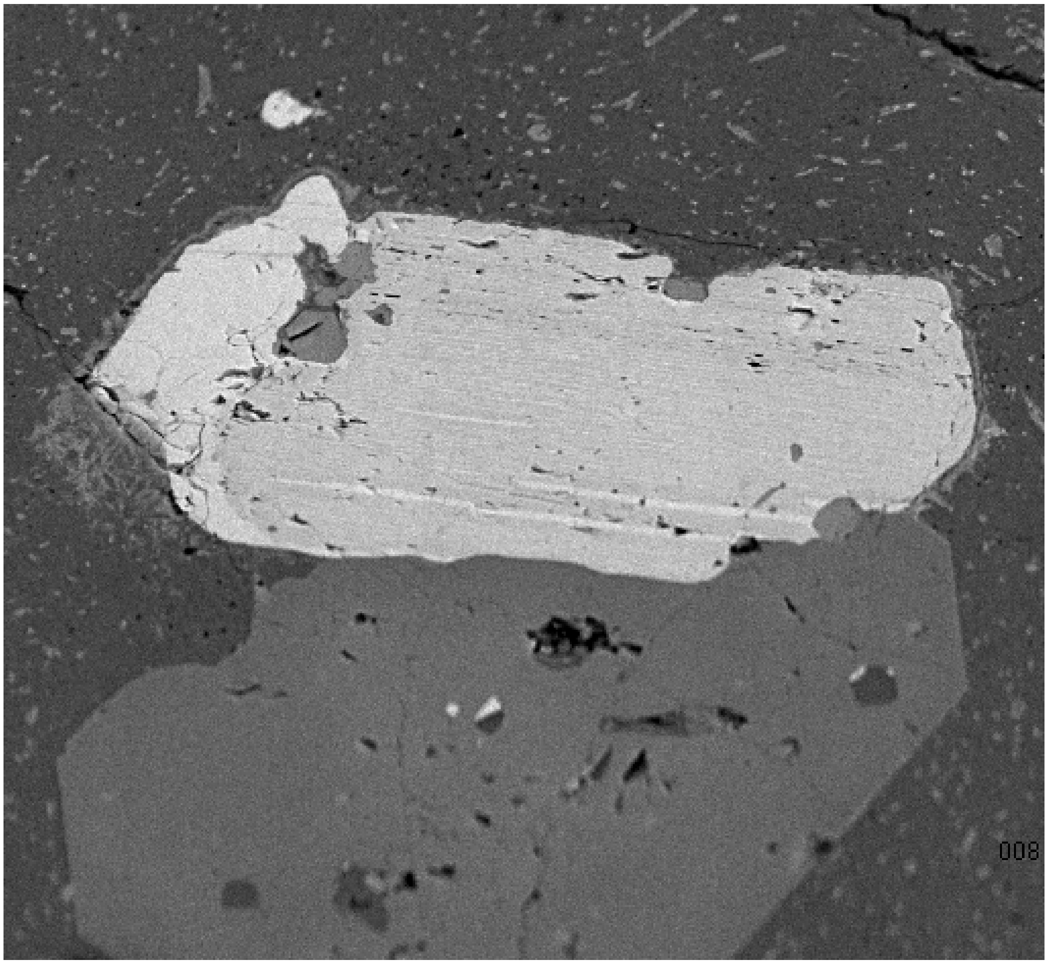
Sample showing the technique of aquiring 99 data points in one run. The higher the gray-scale, the higher the atomic number. Acquisition time was approx. 7 hours.



MTR11008 map 9

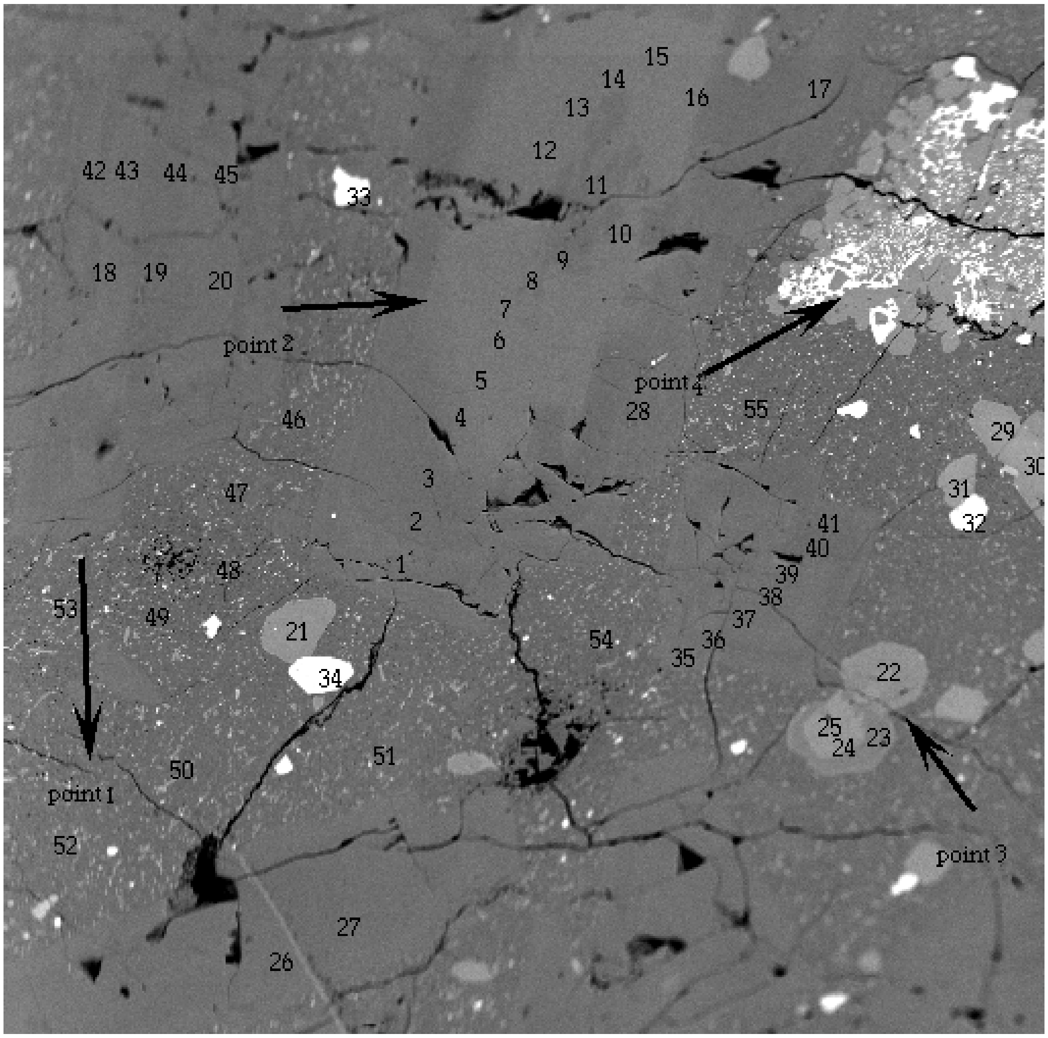
Sample showing the technique of a line-scan.

Points are speread evenly over a line of given length.



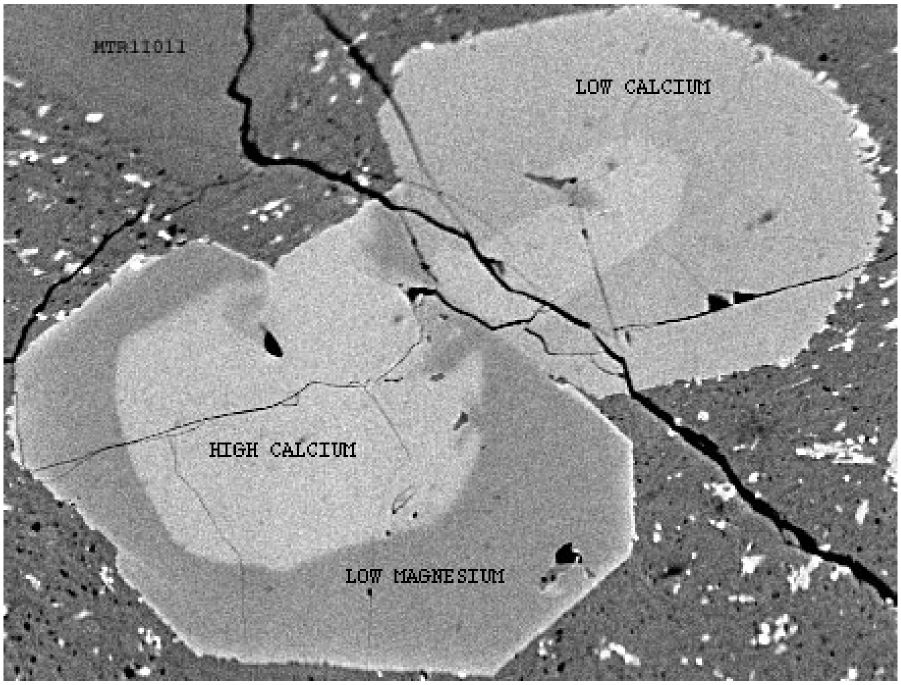
MTR11008 map 10

micrograph of a sandwiched oxide grain next to a ferromagnesium grain. approx. 80 times magnification.



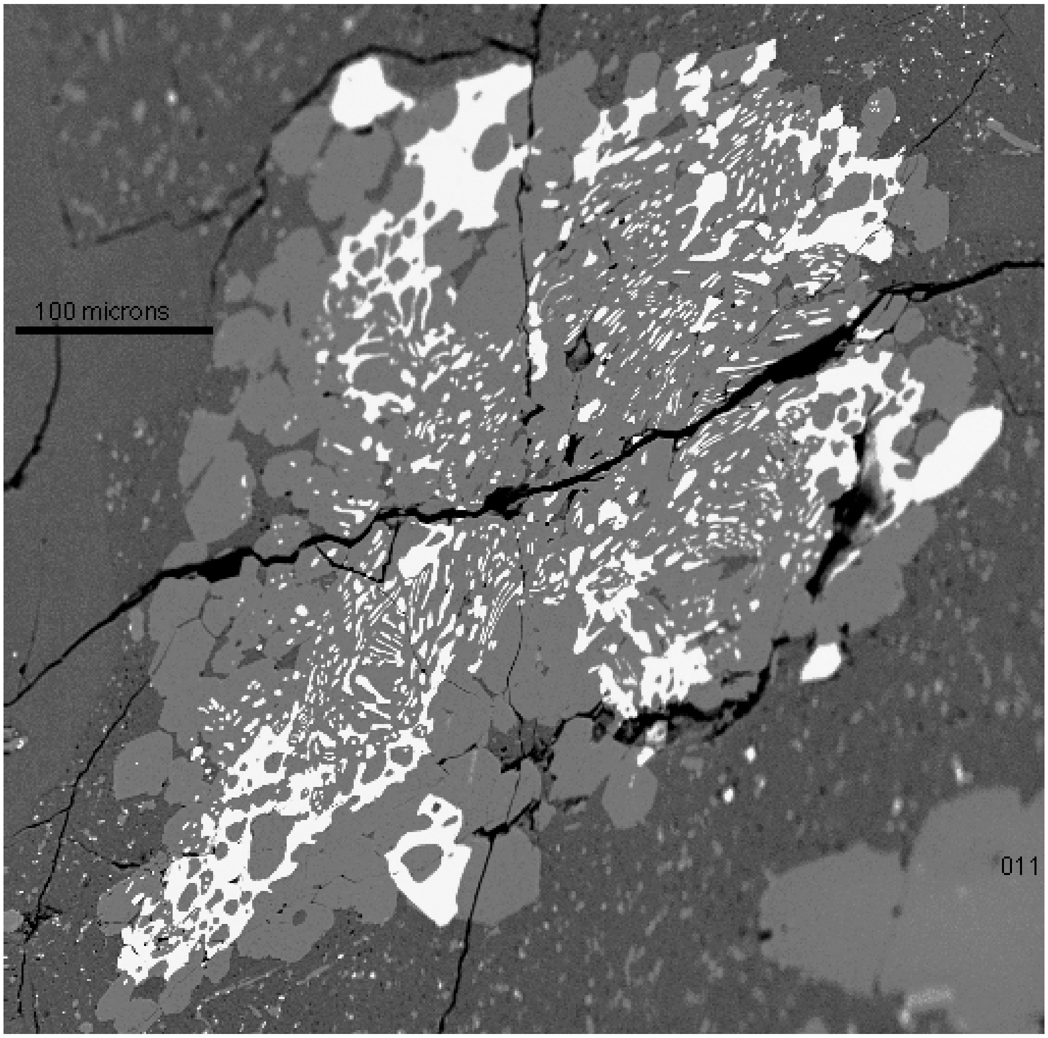
MTR11011 map 11

Point 1 is a typical area of matrix. Point 2 is a zoned plagioclase which is also typical. Point 3 is inset on map 12 . Point 4 is a symplectite seen in map 13 .



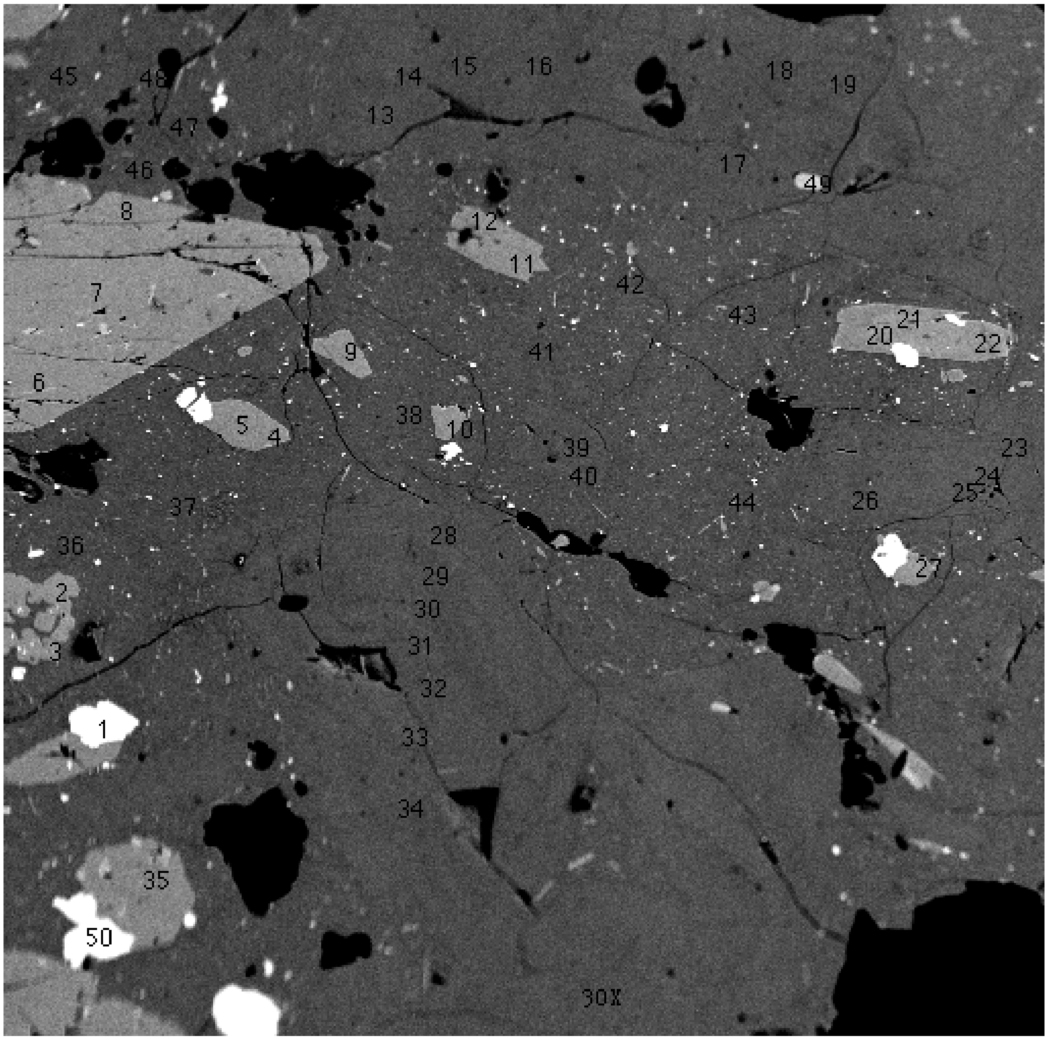
MTR11011 map 12

A complex ferromagnesium crystal showing multiple chemical variations.



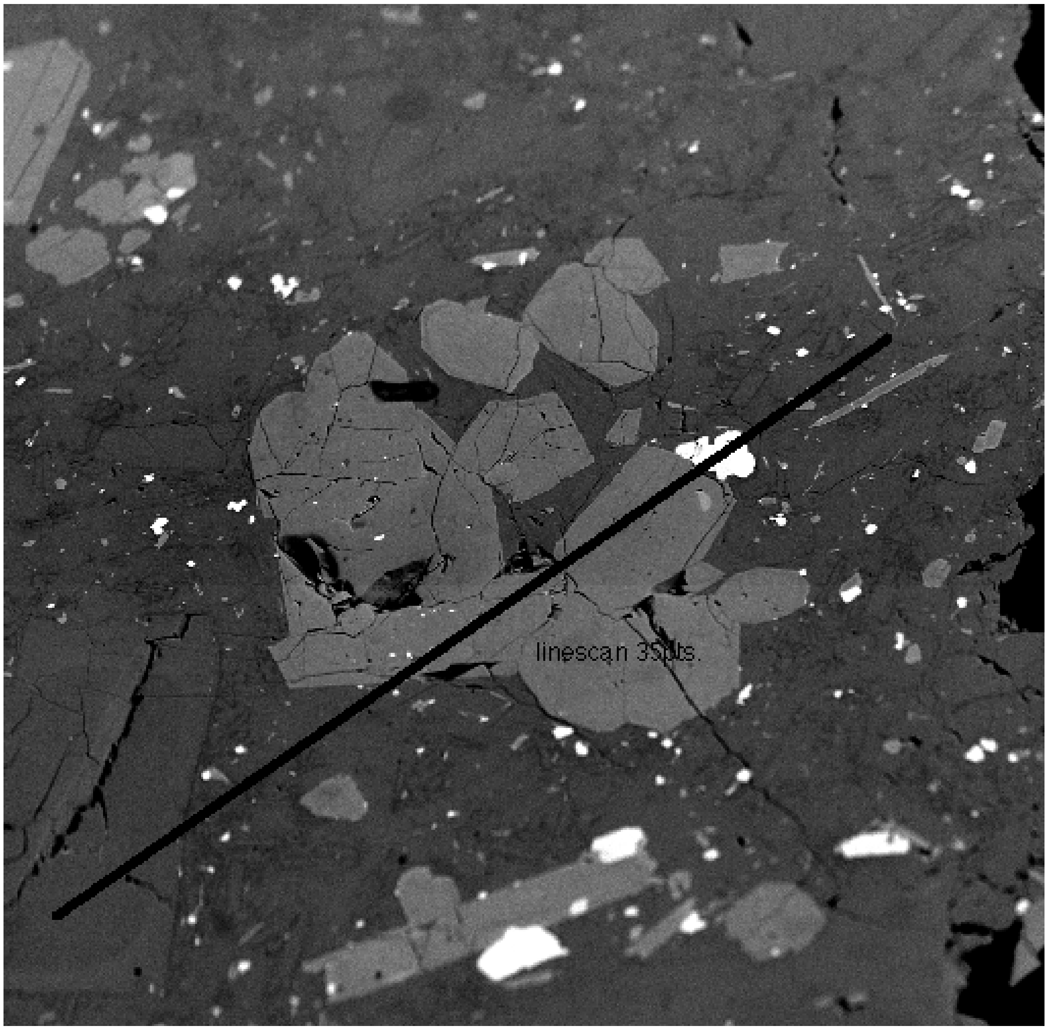
MTR11011 map 13

A rather unusual symplectite.



MTR11019 map 14

General view of MTR11019



MTR11020

map 15

Some good crystals of ferromagnium minerals as well as a zoned plagioclase at the bottom left. Another example of a line-scan, this one had 35 points.