APPENDIX 4

MINERALOGY REPORT

RAW MATERIALS TECHNOLOGY

Mineralogical Investigation into the Micro-fracturing of Iron Ore
at High Temperature

Prepared for

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By

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WINNING THROUGH INNOVATION

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Executive Summary

Seventeen different iron ore samples that had been heated to high temperatures, under varying atmospheric conditions, were observed under the Scanning Electron Microscope (SEM). The samples were studied in order to determine the degree of fracturing within the samples and the influence of mineralogy on the propagation, distribution and intensity of micro-fractures. Fracture formation and propagations depends on a variety of inter-related factors including:

1) The presence or absence of gangue phases

The presence of gangue phases appears to enhance fracture formation. Fractures that formed in samples that contain little or no gangue had an evenly spaced regular framework of fractures. Gangue minerals appear to influence the distribution of fractures. Fractures appear to form more prolifically in gangue minerals such as muscovite, the fractures often do not penetrate the surrounding hematite and are terminated at the grain boundary between the hematite and gangue minerals.

Therefore, although gangue minerals may not cause fractures to form, they do allow for fractures to mature more quickly. Furthermore, where gangue minerals occur, fractures deviate towards the gangue. In places where fractures occur and no gangue minerals are present, the fractures tend to form a regular framework.

2) Type of Gangue Mineral

The type of gangue mineral does not appear to be an important factor in the formation or propagation of fractures. Most of the gangue mineral observed in this study have similar densities and all the gangue minerals are significantly less competent than hematite. Quartz appears to fracture slightly more than P bearing minerals as there does not appear to be a network of secondary fractures developed in apatite when it is intersected by a fracture, as is the case when a fracture intersects quartz. The secondary fracture network does not extend into the surrounding hematite and therefore does not play a significant role in the overall fracture development within the sample.

3) Degree of Reduction

The degree of reduction appears to be the primary influence on fracture formation in all the samples observed. The more reduced a sample is, the more fractures there are. In most samples, fracture networks have developed only in areas where the hematite has been reduced and usually do not extend into areas where the ore has not been reduced.

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4) Sample Porosity
Extensive sample porosity can reduce the amount of fractures caused by reduction within a sample. The open pores allow for the volume increase without fracturing. Where fracturing does occur it usually originates and terminates at open pores. In samples that have extremely low porosity fractures are also rare as the sample can only be reduced around the edges.

For the maximum amount of fracturing to occur within a sample, the sample must be porous enough to allow for reduction of the sample, whilst not having enough open pores to allow for the volume increase to be accommodated by the pores.

5) Internal structure
Where a preferred orientation or foliation fabric occurs the internal structure of the samples has an influence on fracture propagation as fractures tend to exploit the planes of weakness within the sample.

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1. INTRODUCTION

1.1 AIM

The aim of the investigation is to describe the influence of mineralogy on the micro-structural behavior of iron ore samples heated under various atmospheric conditions with the aim of determining the effects, if any, of mineralogy on the propagation, distribution and intensity of micro-fractures in iron ore samples undergoing reduction at high temperatures (500 ⁰C - 700 ⁰C).

1.2 ORIGIN OF SAMPLES

The samples were received as small discs 8mm in diameter and 2m thick. The discs had been heated under reducing conditions in a high temperature microscope.

Table 1 lists the original sample labels as well as the environmental conditions under which the samples were heated.

Table 1: Sample List

	Sample	Temp (⁰C)	Time (min)	Atmosphere
1	Ore Type 5 B	500	60	CO/CO_2
2	Ore Type 3 B	500	60	CO/CO_2
3	Ore Type 4 A	500	60	CO/CO_2
4	Northern Cape Std	500	60	CO/CO_2
5	Northern Cape Std B	700	30	CO/CO_2
6	Northern Cape Ore Type 2 C	500	60	CO/CO_2
7	Northern Cape Ore Type 5	500	30	

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8	Northern Cape Std C	500	60	CO/CO_2
9	Northern Cape Std Test1	700	30	
10	Ore Type 4 D2	500	60	CO/CO_2
11	Ore Type 4 B	700	30	CO/CO_2
12	Ore Type 3 D	500	60	CO/CO_2
13	Northern Cape Std Test	500	60	CO/CO_2
14	Ore Type 5	500	60	CO/CO_2
15	Ore Type 5 C	500	60	CO/CO_2
16	Northern Cape Std A	500	60	CO/CO_2
17	Ore Type 4 C	500	60	CO/CO_2

METHODOLOGY

Samples were mounted in epoxy resin, polished and coated with gold in a sputter coater. They were observed in a JOEL 5800 scanning electron microscope at the Department of Microscopy and Micro-Analysis at the University of Pretoria,

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2. DISCUSSION: MICRO-TECTONICS

Rheology is the study of the quantitative response of rocks to stress. Rocks under stress can deform either by brittle or ductile mechanisms. Brittle behavior takes place at lower temperatures and shallower depths in the Earth's crust than ductile behavior. The deformation of rocks is achieved by a large number of processes on the scale of individual grains.

Mineralogy has been recognized as an influencing factor on the deformation mechanisms of rocks under stress. *Passchier, C.W. and Trouw, R.A.J.* ascribe the deformation mechanisms in rocks to be dependant on their, "mineralogy, composition of inter-granular fluid, grain size, porosity and permeability, temperature, pressure, differential stress and externally imposed strain rate."

In this study we only observe brittle deformation mechanisms in mono-mineralic, bi-mineralic and poly-mineralic samples comprising predominantly of hematite with minor amounts of gangue minerals. **Table 2** lists the minerals identified in this study. The behavior of poly-mineralic samples under stress is complex and one has to take into consideration the concept of a, "stress-supporting network." If "hard" (e.g. hematite) and "soft" (e.g. muscovite) minerals occur together in the same sample the strength of the sample does not increase linearly in relation to the amount of "hard" mineral present. In this study, most samples comprise predominantly of hematite and the small amount of gangue minerals present is unlikely to have an influence on the overall stress supporting network.

When observing samples under the SEM that have undergone deformation, with the aim of understanding the mechanisms of deformation and metamorphism, one must be mindful of the fact that the sample is only being observed in 2 dimensions whilst deformation has taken place in 3 dimensions.

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In iron ore samples, the primary mechanism for the formation of fractures under reducing conditions in hematite samples is due to the volume increase as hematite is reduced to a porous form of magnetite.

Table 2: List of Minerals

MINERAL	IDEAL FORMULA
Apatite	$Ca_5(PO_4)_3(OH,F,Cl)$
Hematite	Fe_2O_3
Magnetite	Fe_3O_4
Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$
Quartz	SiO_2

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3. RESULTS

Each sample is discussed and described individually, however the samples are also grouped according to the predominant feature observed in the sample. Samples were allocated into the following groups:

1. Mono-mineralic hematite samples   (Samples 3, 4, 8, 11, 12, 13 and 17)
2. Poly-mineralic samples   (Samples 1, 5, 7, 10, 14 and 15)
3. Porous samples   (Samples 2, 9 and 16)
4. Other   (Sample 6)

Table 4. Summary of results

	SAMPLE	HEMATITE	GANGUE	GROUP	POROSITY	FRACTURE TYPE
1	Ore Type 5 B	Granular/ Specularite	Apatite/ Quartz	2	Low	Extensive, throughout the sample
2	Ore Type 3 B	Granular/ Specularite	None	3	Variable	Regular network
3	Ore Type 4 A	Granular	None	1	Low	Perpendicular to edge
4	Northern Cape Std	Granular	None	1	Medium	Parallel to edge
5	Northern Cape Std B	Granular	Quartz	2	Low	Extensive, throughout the sample
6	Northern Cape Ore type 2 C	Granular	Quartz	4	Low	Parallel to foliation
7	Northern Cape Ore Type 5	Specularite	Apatite/ Quartz	2	Medium	Parallel to edge Regular network
8	Northern Cape Std C	Granular	None	1	Low	Perpendicular to edge
9	Northern Cape Std Test1	Granular	None	3	High	Perpendicular to edge
10	Ore Type 4 D2	Granular	Quartz/ Muscovite	2	Low	Parallel to edge
11	Ore Type 4 B	Granular	None	1	Low	Parallel/ Perpendicular to edge
12	Ore Type 3 D	Granular	None	1	Low	Parallel/ Perpendicular to edge
13	Northern Cape Std Test	Granular	None	1	Low	Parallel/ Perpendicular to edge
14	Ore Type 5	Granular	Apatite/ Quartz	2	Low	Parallel Regular network to edge
15	Ore Type 5 C	Granular	Al-silicates/ Apatite	2	Low	None
16	Northern Cape Std A	Granular/ Specularite	None	3	Low	Associated with Specularite
17	Ore Type 4 C	Granular	None	1	Low	Parallel to edge

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Group 1: Mono-mineralic hematite samples

These samples can be considered to be mono-mineralic and comprise essentially exclusively of hematite. The samples all show very similar physical characteristics in that they have low porosity, essentially no gangue minerals and they also have similar micro-fracture characteristics.

The samples all exhibit fracturing on the samples edges, the first place in which reduction occurs. The fractures are usually oriented perpendicular to the sample edge ad radiate inwards. The fractures only penetrate as far as the sample has been reduced. Internal fractures occur in a regularly spaced framework.

3.1.1 Sample 3: Ore Type 4 A

This sample is homogeneous and does not have any primary gangue minerals or porosity. Fracturing is generally rare and fractures are predominantly observed at the edge of the sample, where the sample has been reduced. These fractures are radial and only occur perpendicular to the edge of the sample.

A few fractures are observed filled with muscovite indicating that these are pre-existing fractures. A few randomly distributed fractures occur internally within the sample however these fractures are not associated with any gangue minerals

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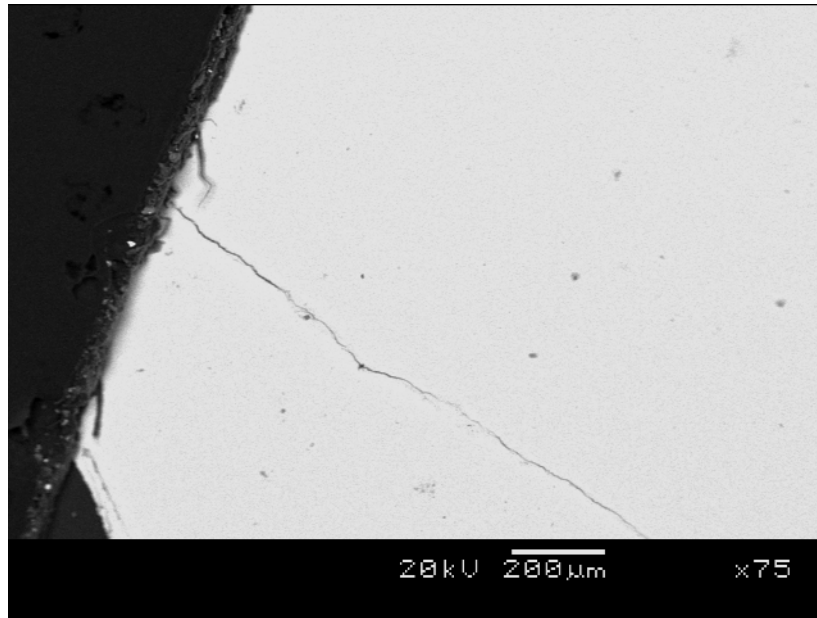
Figure 1. Electron backscatter image of sample 3 showing the homogeneity of the sample. The sample is essentially mono-mineralic and comprises almost exclusively of hematite. Small radial fractures occur at the edge of the sample, where it has been reduced.
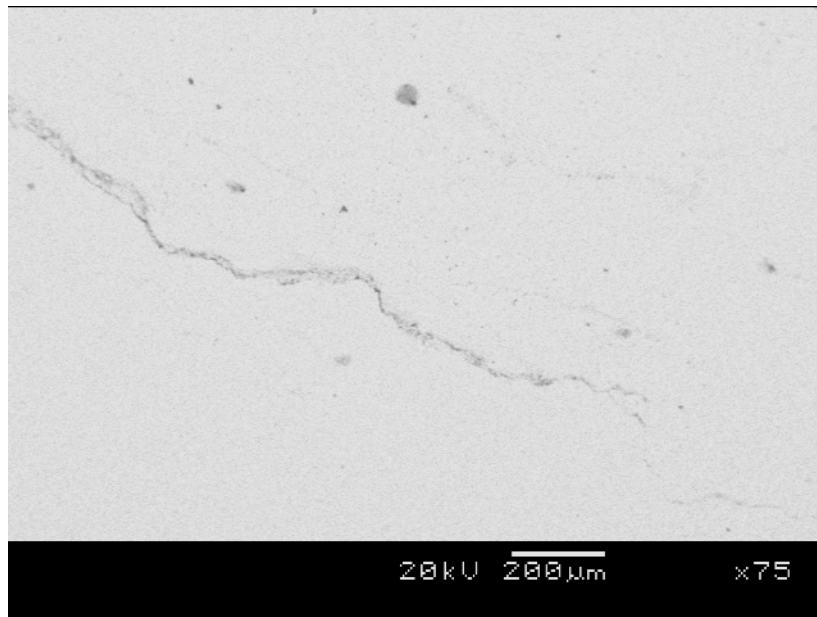
Figure 2. Electron backscatter image of sample 3 showing a rare internal fracture. This fracture is not associated with gangue minerals, porosity or reduction.
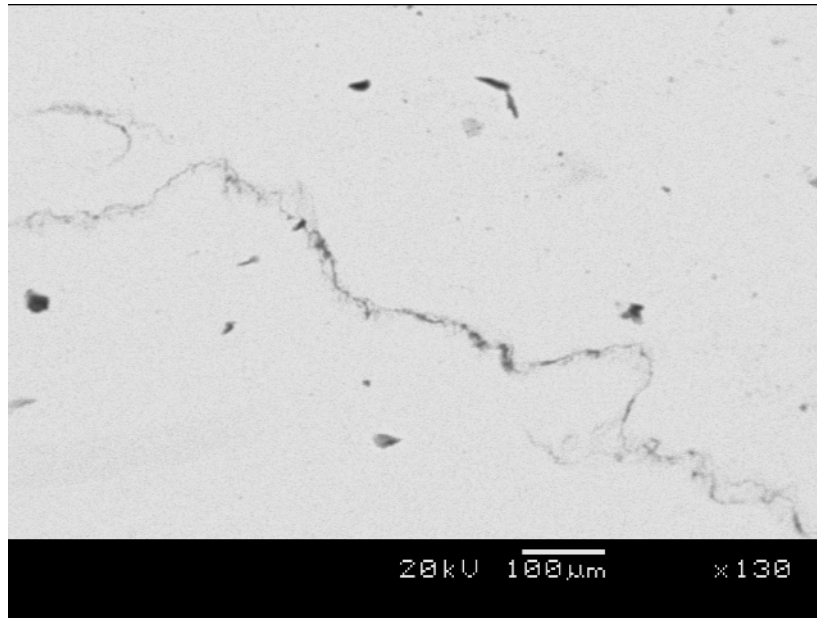
Figure 3. Electron backscatter image of sample 3 showing a pre-existing fracture filled with muscovite.
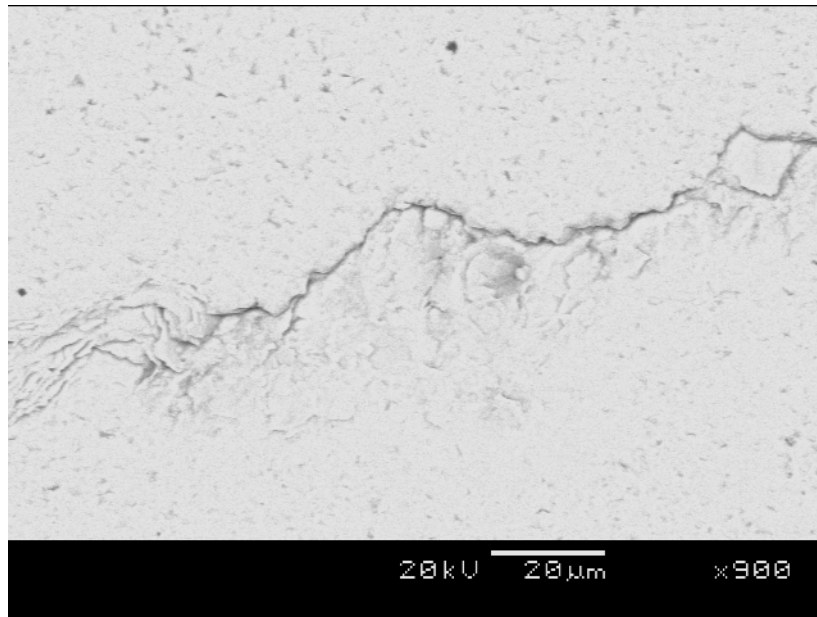
Figure 4. Electron backscatter image of sample 3 showing a rare internal fracture. This fracture is not associated with gangue minerals, porosity or reduction.

3.1.2 Sample 8: Northern Cape Std (C)

This sample is almost completely homogeneous with very little gangue and low porosity. It comprises almost exclusively of granular hematite. The only fracturing observed in the sample occurs at the edge of the sample where it has been

reduced. The fractures are perpendicular to the edge of the sample and only penetrate the sample as afar as it has been reduced.
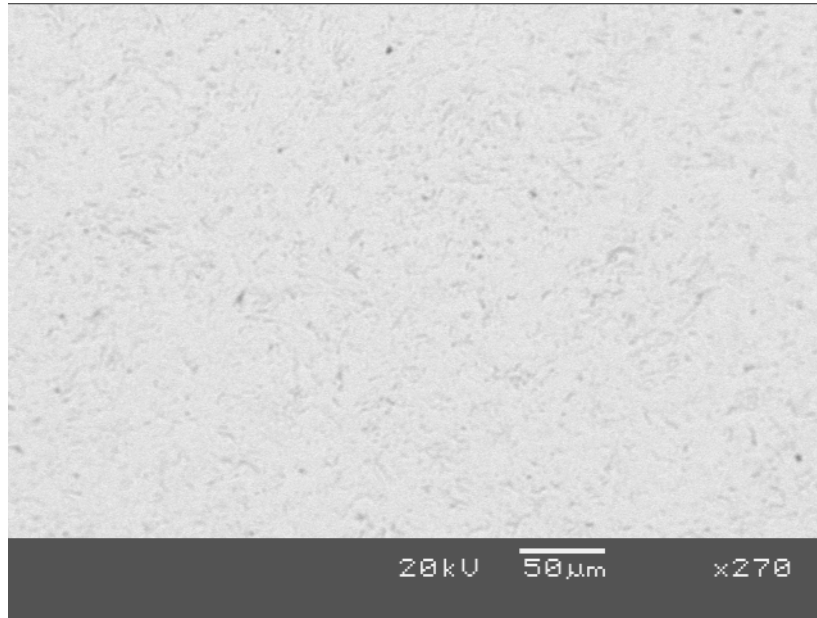
Figure 5. Electron backscatter image of sample 8 showing the homogeneity of the sample. The sample is essentially mono-mineralic and comprises almost exclusively of hematite.
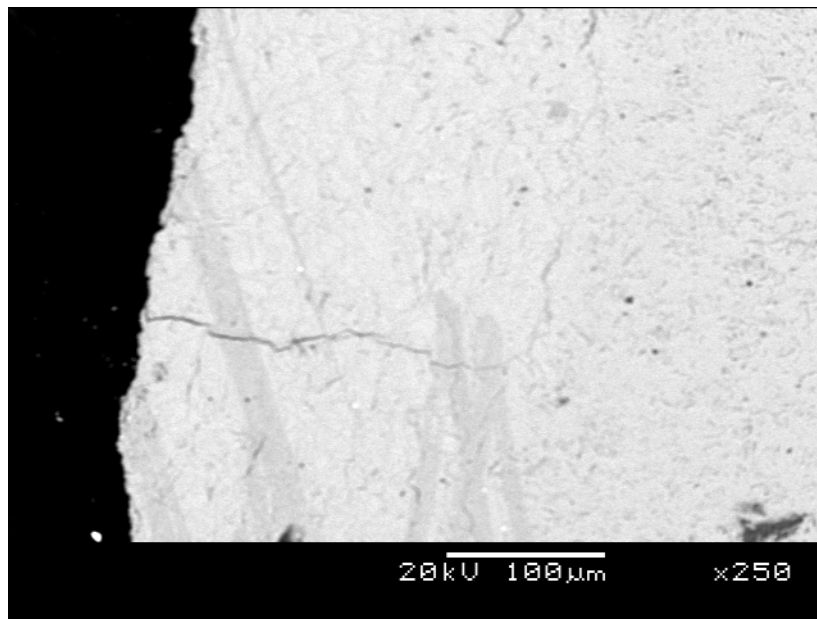
Figure 6. Electron backscatter image of sample 8 showing a fracture perpendicular to the sample edge. The fracture only penetrates as far as the sample has been reduced.
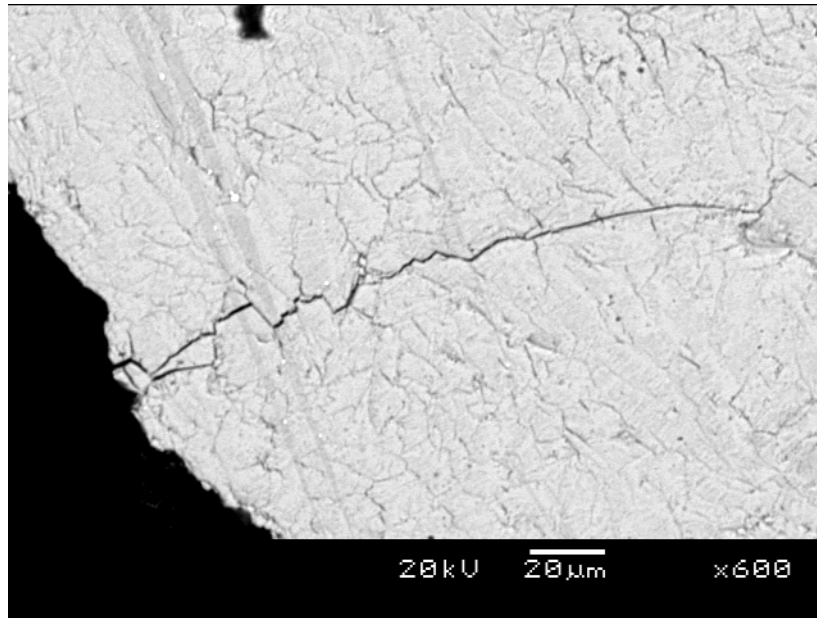
Figure 7. Electron backscatter image of sample 8 showing another radial fracture perpendicular to the edge of the sample.

3.1.3 Sample 4: Northern Cape Std

This sample, as with the other samples observed in this group is a mono-mineralic sample comprised almost exclusively of hematite. Unlike the other samples in this group, this sample has slightly higher porosity. The sample is reduced around the edges and has associated fractures. The interior of the sample, where no reduction has taken place, is homogenous and even small fractures are absent. This may be due to the increased porosity of the sample.

Unlike the other mono-mineralic samples, the fractures formed during reduction occur parallel to the sample edge and not perpendicularly as is more commonly observed.
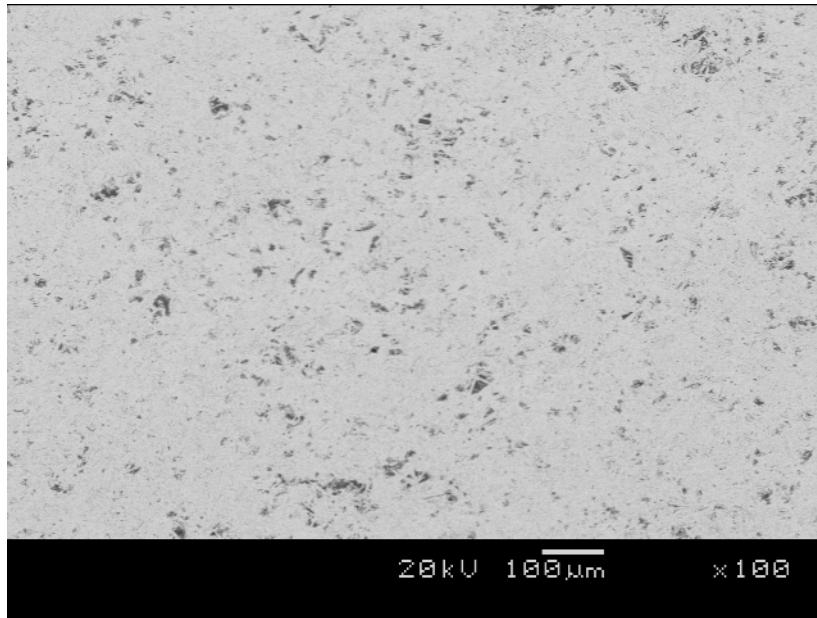
Figure 8. Electron backscatter image of sample 4 showing a homogenous mono-mineralic sample, with slight higher porosity than the other samples in this group.
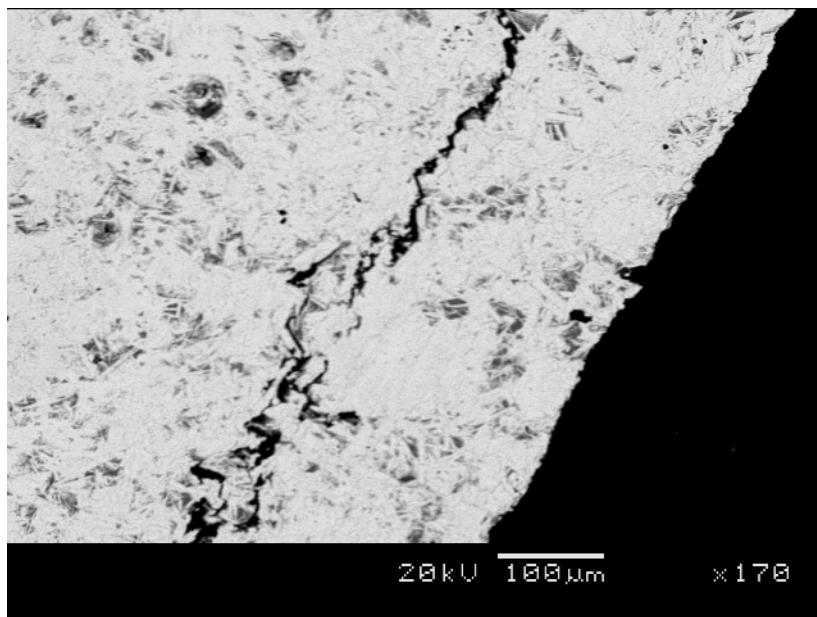
Figure 9. Electron backscatter image of sample 4 showing fractures parallel to the sample edge caused by the volume increase when hematite is reduced to magnetite.
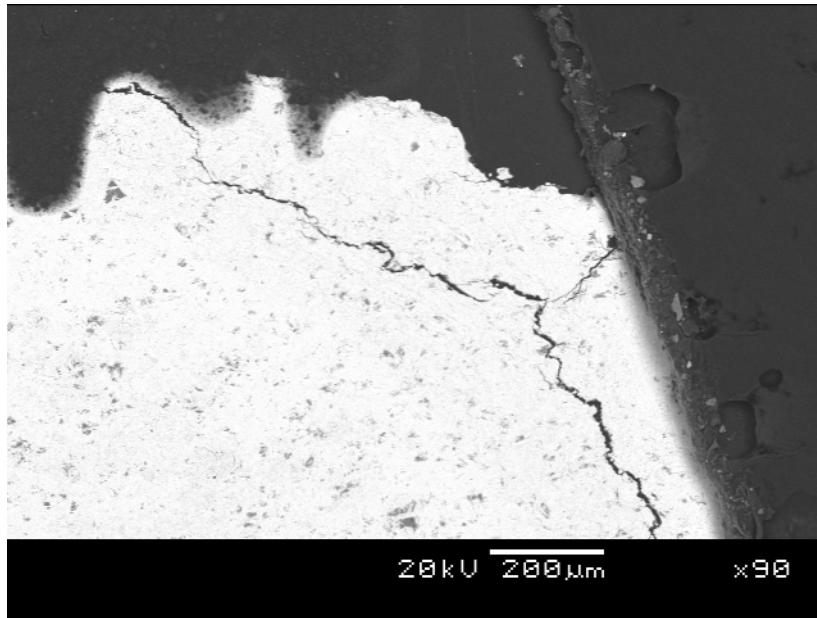
Figure 10. Electron backscatter image of sample 4 showing fractures parallel to the sample edge caused by the volume increase when hematite is reduced to magnetite.
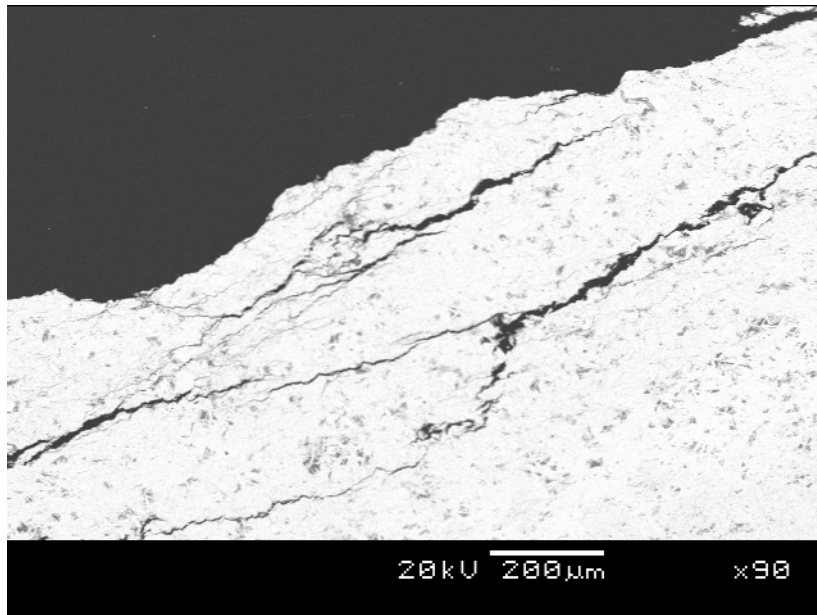
Figure 11. Electron backscatter image of sample 4 showing multiple fractures parallel to the sample edge caused by the volume increase when hematite is reduced to magnetite.

3.1.4 Sample 11: Ore Type 4B

This sample is a mono-mineralic sample comprised almost exclusively of hematite. The sample has very low porosity. Fractures occur throughout the

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sample wherever the hematite has been reduced. Fractures occur primarily at the edge of the sample both parallel and perpendicular to the sample edge. Where the sample has not been reduced there are no clearly defined fractures.
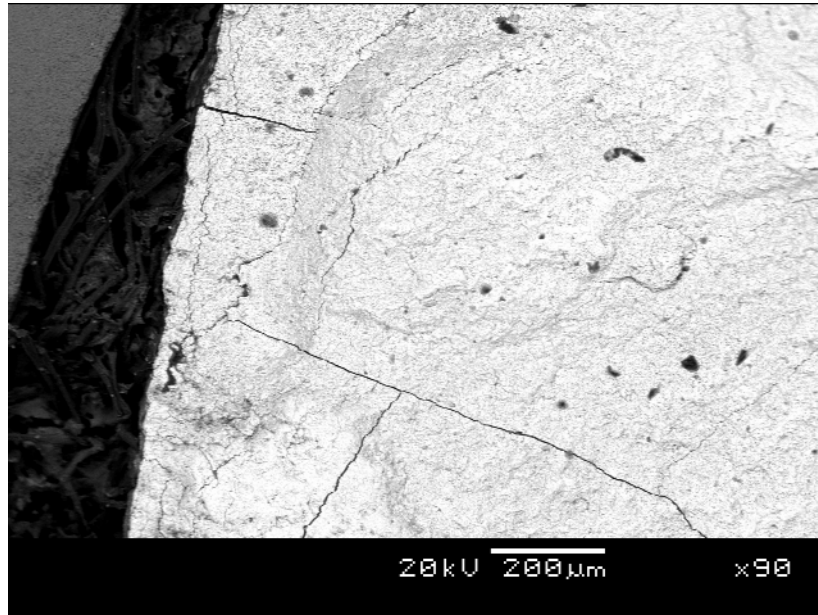
Figure 12. Electron backscatter image of sample 11 showing fractures both perpendicular and parallel to the sample edge where the ore has been reduced.
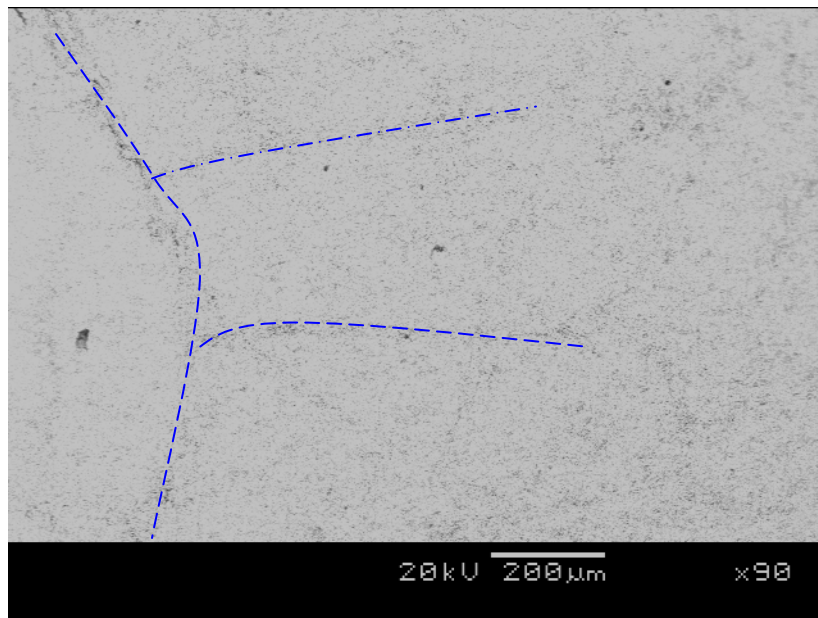
Figure 13. Electron backscatter image of sample showing the homogenous, mono-mineralic interior of the sample. A few proto-fractures appear to have formed (stippled line) however no actual fracturing has taken place.
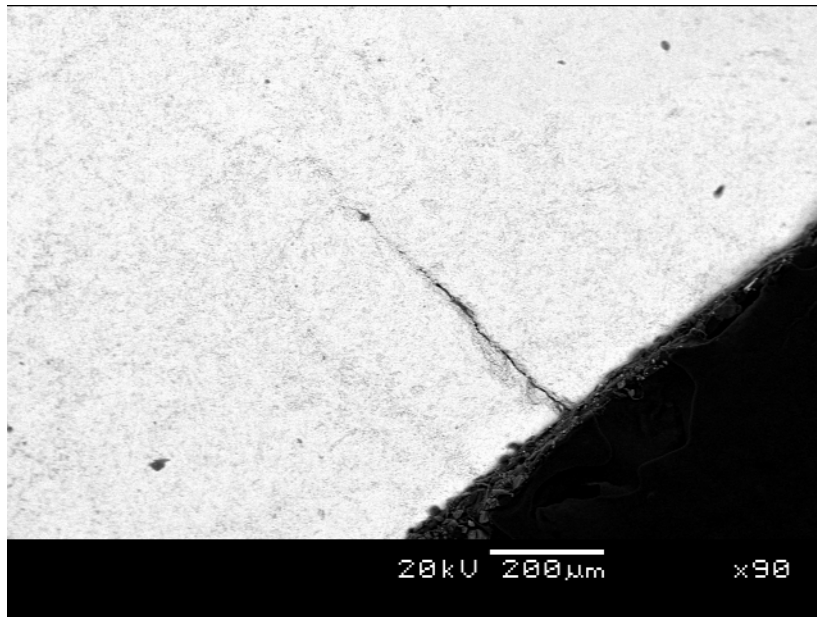
Figure 14. Electron backscatter image of sample 12 showing a small fracture that has developed perpendicular to the sample edge, where the ore has been reduced.
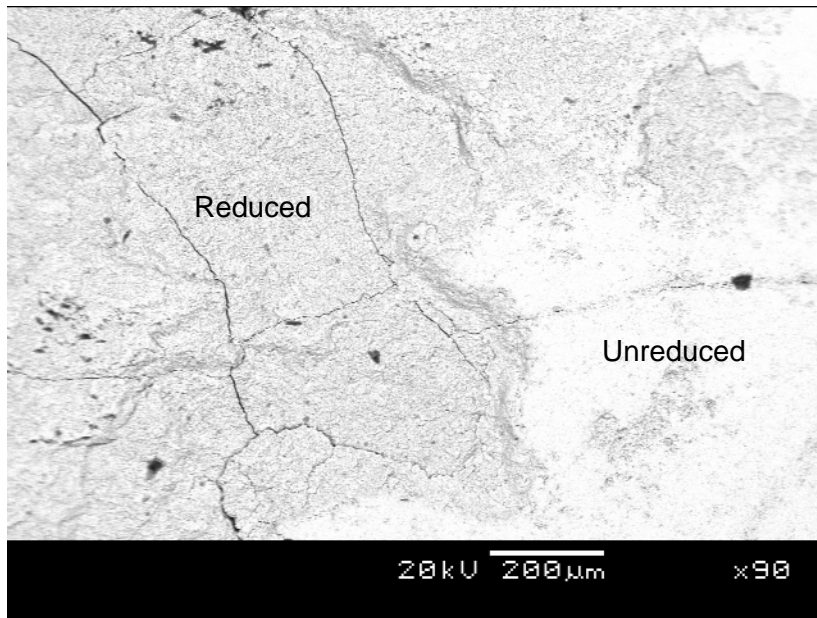
Figure 15. Electron backscatter image of sample 11 showing an area of reduced ore (left) and an area of unreduced ore (right) . Notice the network of fractures that has developed where reduction has taken place.

3.1.5 Sample 12: Ore Type 3 D

This sample is a very low porosity, mono-mineralic hematite sample. There are very few open pores and almost no gangue phases observed. Fracturing occurs primarily at the edge of the sample where it has been reduced. The fractures only penetrate the sample as far as it has been reduced. The interior of the sample is homogenous with no fractures, no gangue, no open pores and no reduction.
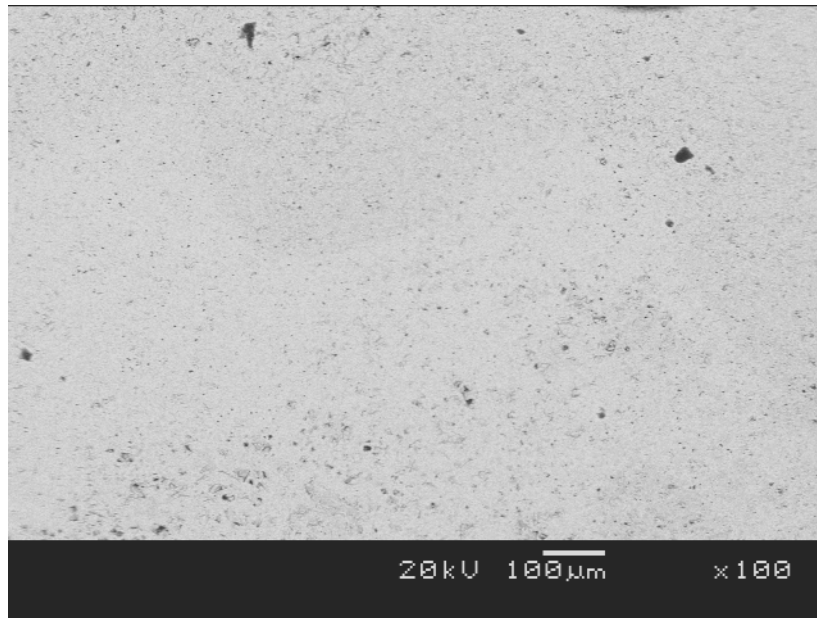
Figure 16. Electron backscatter image of sample 12 showing the homogeneity of the sample. No gangue minerals are observed and the sample has very low porosity.
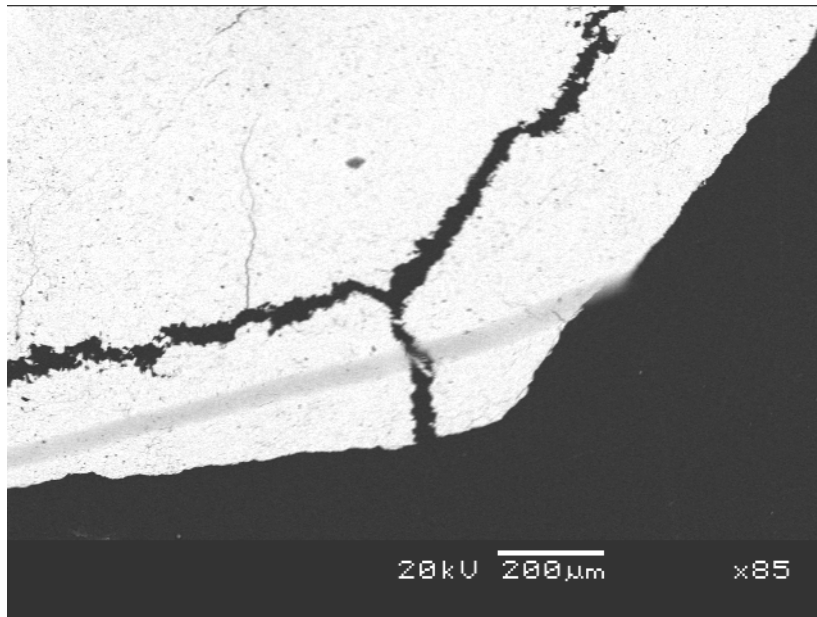
Figure 17. Electron backscatter image of sample 12 showing large fractures perpendicular and parallel to the edge of the sample.
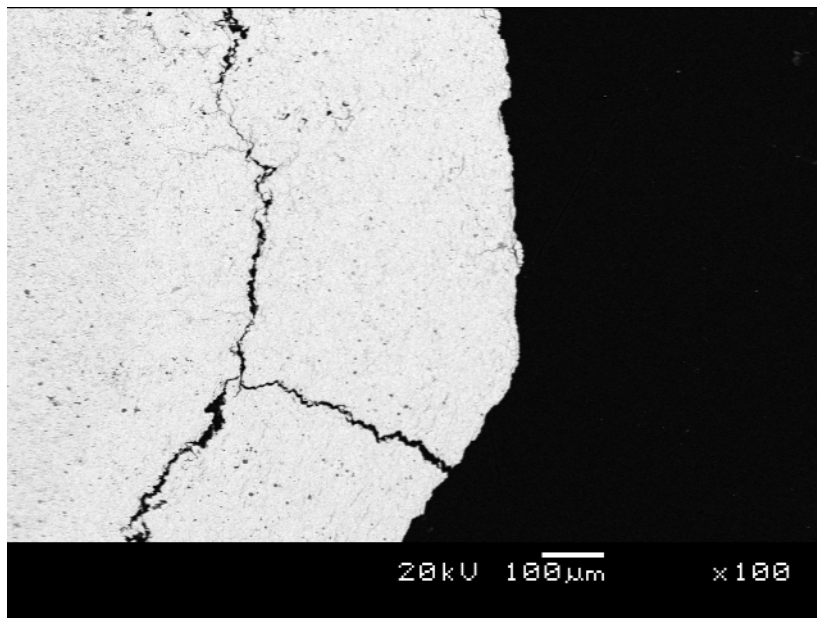
Figure 18. Electron backscatter image of sample 12 large fractures perpendicular and parallel to the edge of the sample.

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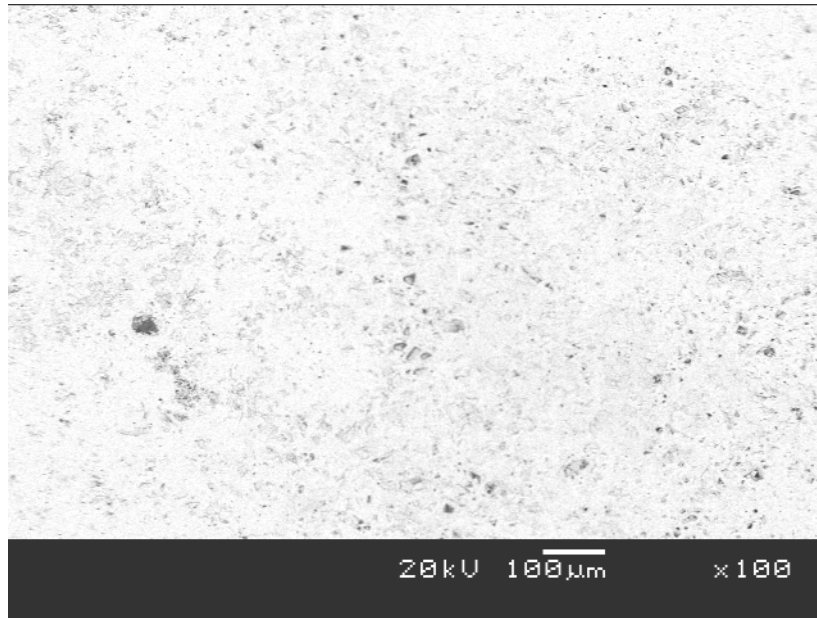
Figure 19. Electron backscatter image of sample 12 showing the homogeneity of the sample.
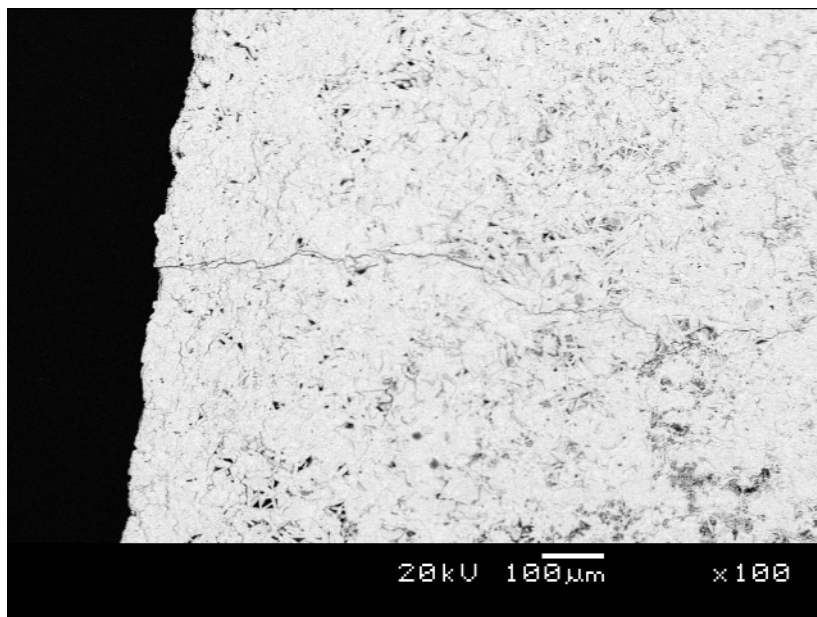
Figure 20. Electron backscatter image of sample 12 large fractures perpendicular and parallel to the edge of the sample.
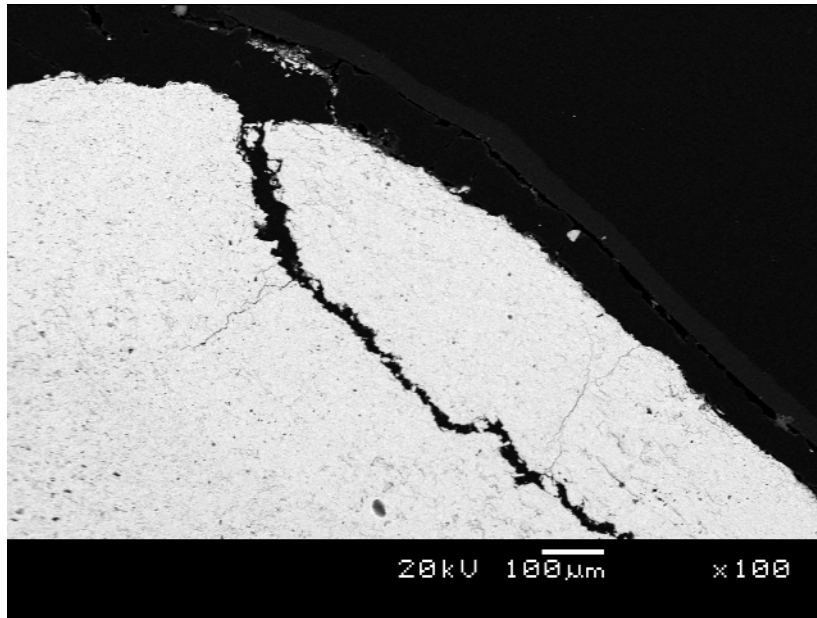
Figure 21. Electron backscatter image of sample 12 large fracture parallel to the edge of the sample. Smaller fractures occur perpendicular to the edge of the sample.

3.1.6 Sample 13: Northern Cape Std Test 7/06/06

This sample is similar to sample 12 in that it comprises predominantly of hematite. The sample has very few open pores and very few gangue minerals. Most fractures that occur within the sample occur at the sample edge where reduction has occurred. The fractures occur both parallel and perpendicular to the sample edge however the fractures that occur parallel to the sample edge are more pervasive.
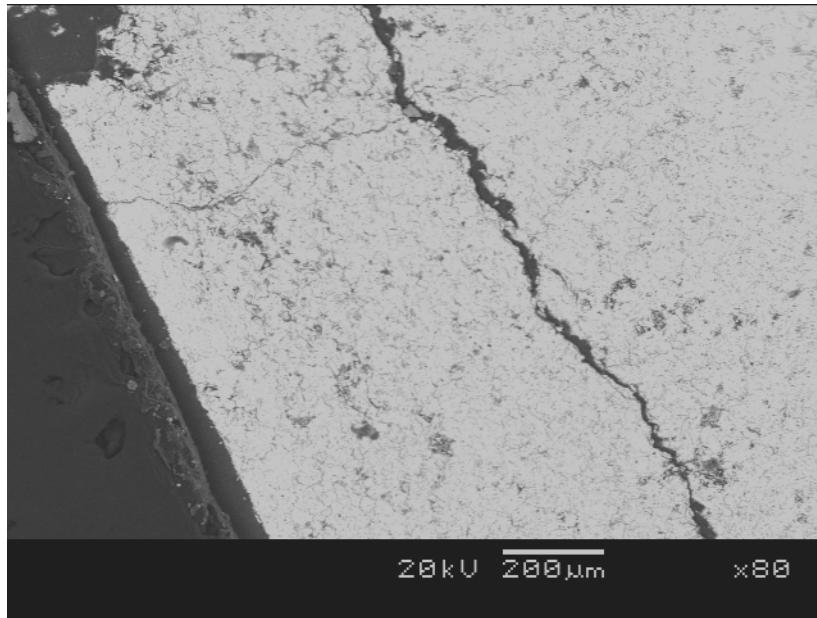
Figure 22. Electron backscatter image of sample 13 showing fractures parallel and perpendicular to the edge of the sample, where the sample has been reduced.
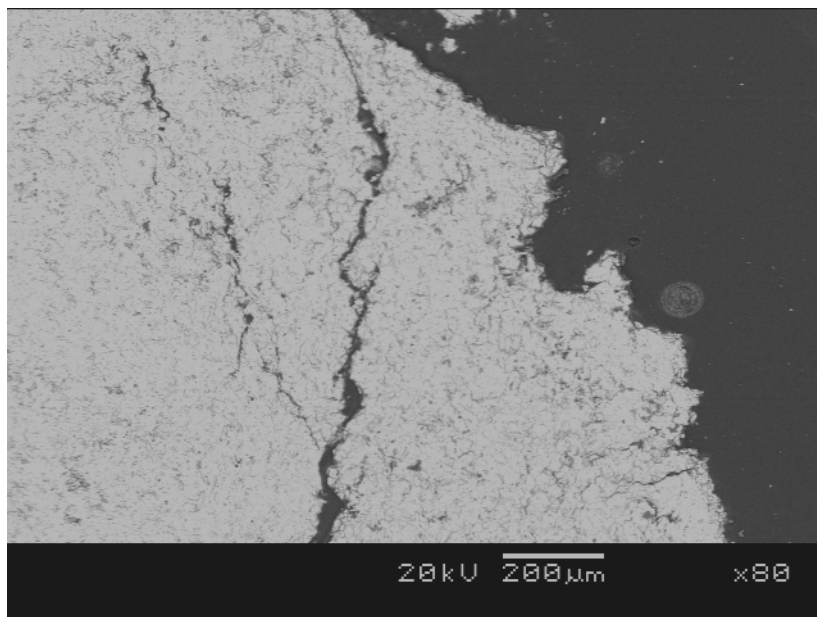
Figure 23. Electron backscatter image of sample 13 showing fractures parallel to the edge of the sample, where the sample has been reduced.
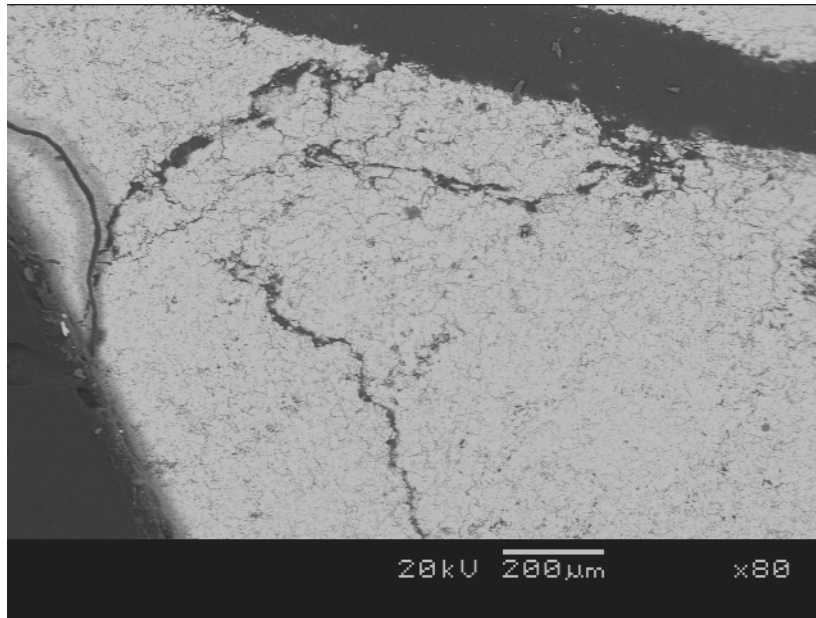
Figure 24. Electron backscatter image of sample 13 showing fractures parallel and perpendicular to the edge of the sample, where the sample has been reduced.
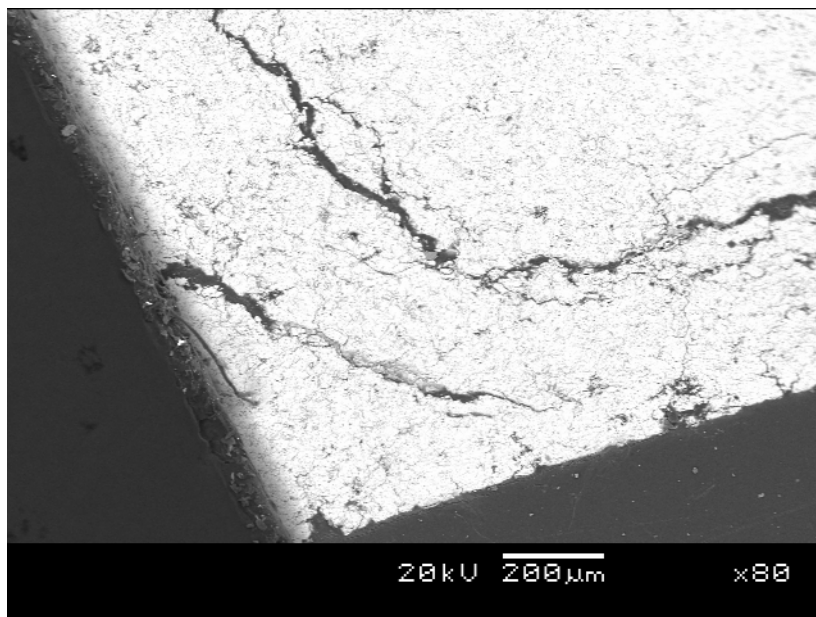
Figure 25. Electron backscatter image of sample 13 showing fractures parallel to the edge of the sample, where the sample has been reduced.

3.1.7 Sample 17: Ore Type 4 C

This sample is a homogeneous mono-mineralic sample comprising almost exclusively of hematite. Most fractures observed in this sample occur at the edge of the sample. The fractures are radial, and occur perpendicular to the edge of

the sample. The only other fractures observed in this sample are a regularly spaced set of fractures. The fractures intersect at right angles within the sample.
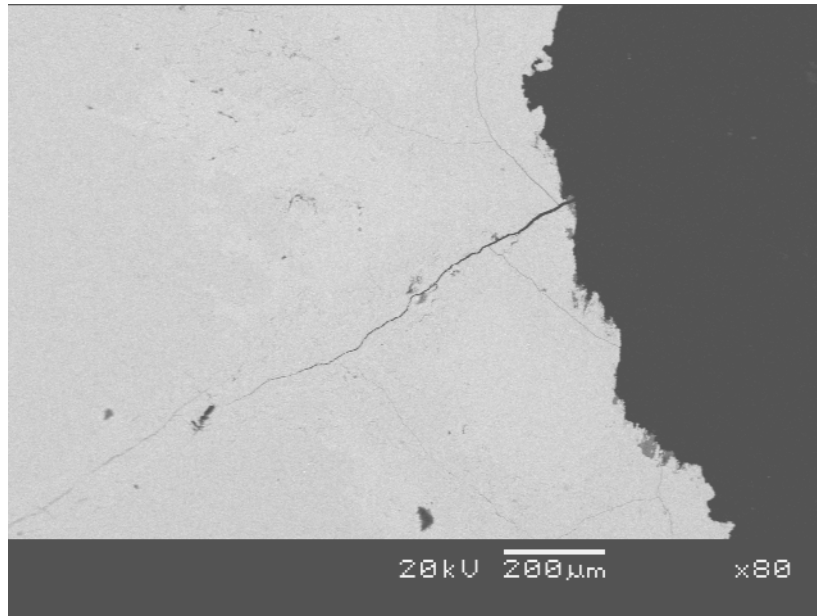
Figure 26. Electron backscatter image of sample 17 showing a fracture perpendicular to the sample edge. The fracture only penetrates as far as the sample has been reduced.
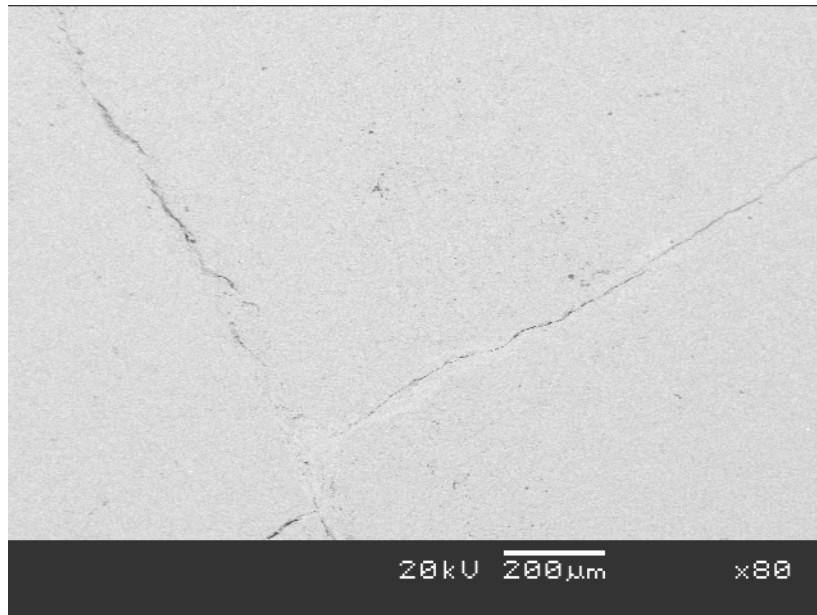
Figure 27. Electron backscatter image of sample 17 showing regularly spaced fracture/joint set in the sample.
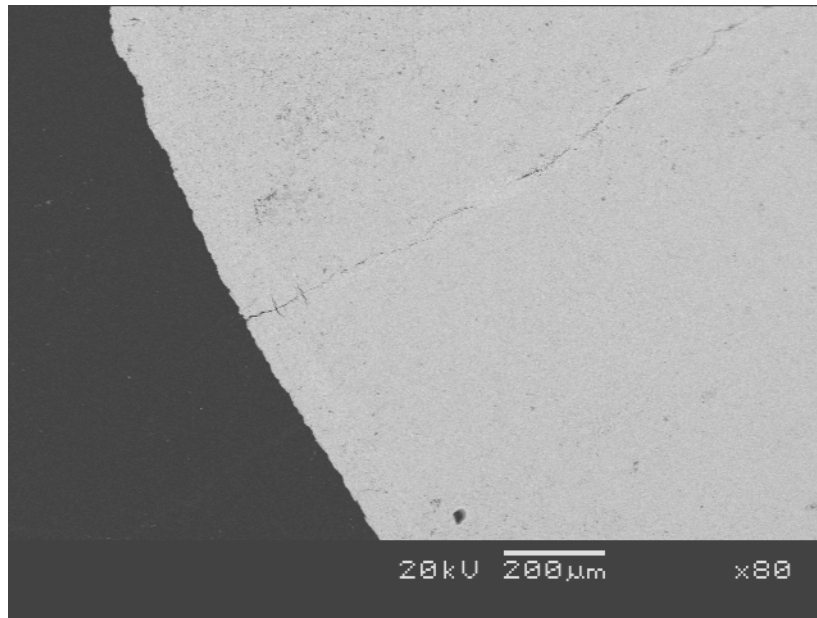
Figure 28. Electron backscatter image of sample 17 showing a fracture perpendicular to the sample edge. The fracture only penetrates as far as the sample has been reduced.
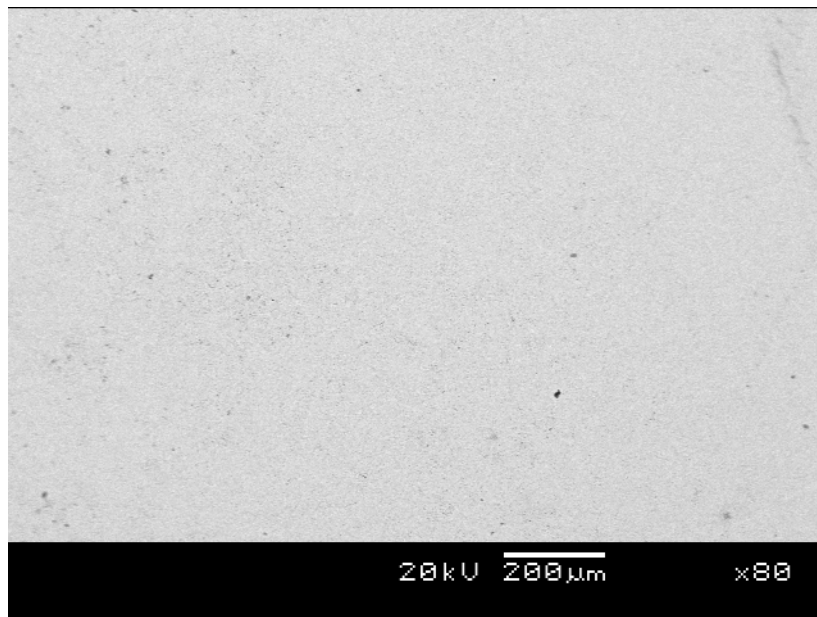
Figure 29. Electron backscatter image of sample 17 showing the homogeneity of the sample. The sample is essentially mono-mineralic and comprises almost exclusively of hematite.

Group 2: Poly-mineralic Samples

This group comprises of samples that have a significant proportion of gangue minerals. The results from the various samples in this group indicates that the presence of gangue minerals alone do not cause fractures to form. However, gangue minerals do influence the direction and intensity of fractures and gangue minerals, especially quartz, tend to fracture more easily than hematite due to their lower competency.

3.2.1 Sample 1: Ore Type 5 (B)

This sample appears to comprise of intergrown hematite and quartz. The sample is extensively fractured with both small and large fractures observed throughout the sample. The presence of gangue minerals appears to facilitate fracturing. Many fractures originate and terminate within gangue minerals without extending into the surrounding hematite.

In this sample it appears as though the presence of gangue minerals only appears to have an impact on the fracture frequency and fracture path up until a certain size of fracture is reached. Thereafter with large fractures, the fracture propagates irrespective of the presence or absence of gangue minerals.

Fractures on the edge of the sample that are directly related to reduction are also observed.

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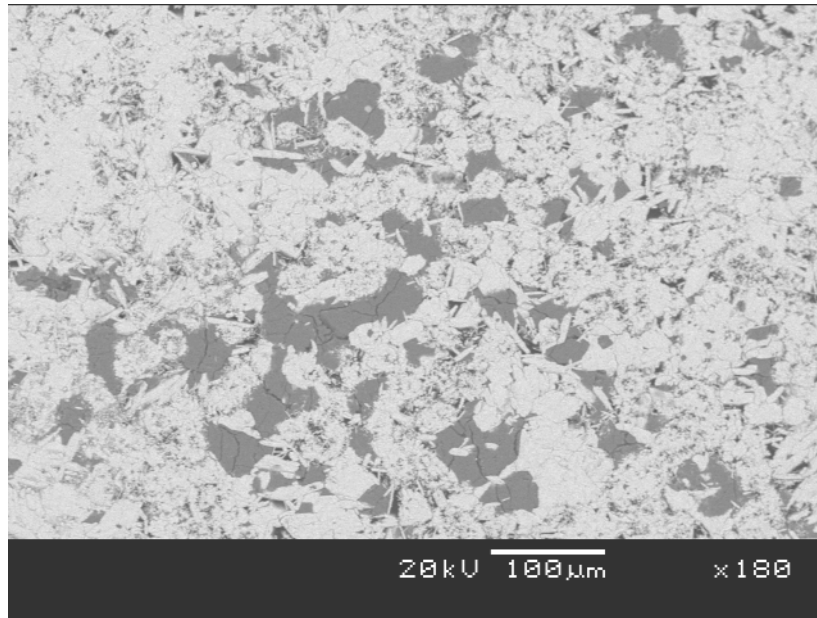
Figure 30. Electron backscatter image of sample 1 showing intergrown hematite (white) and quartz (light grey).
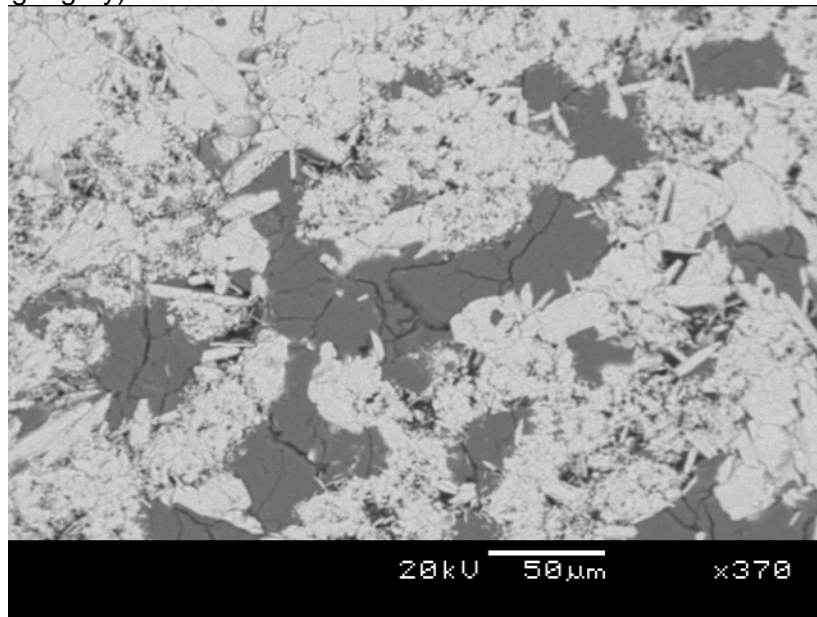
Figure 31. Electron backscatter image of sample 1 showing fractures originating and terminating within quartz (grey) without extending into the surrounding hematite.
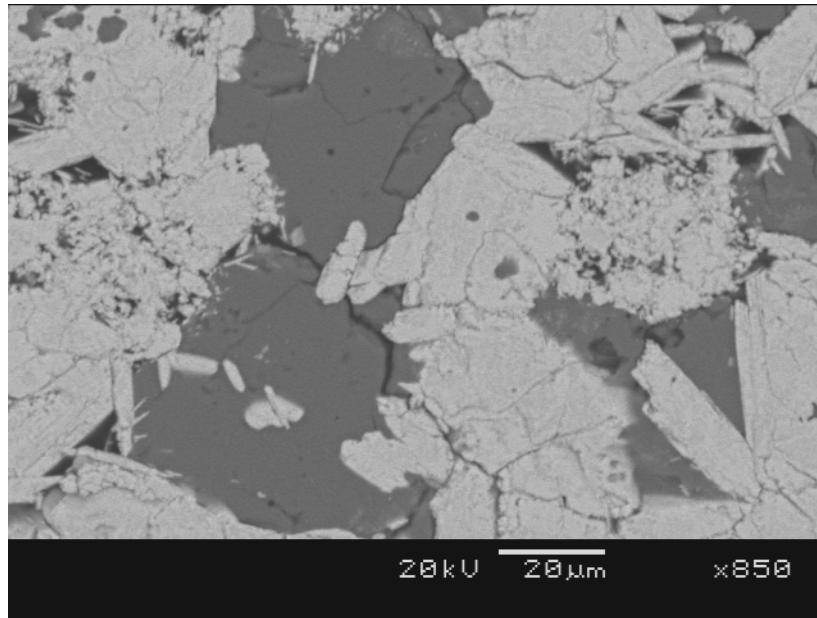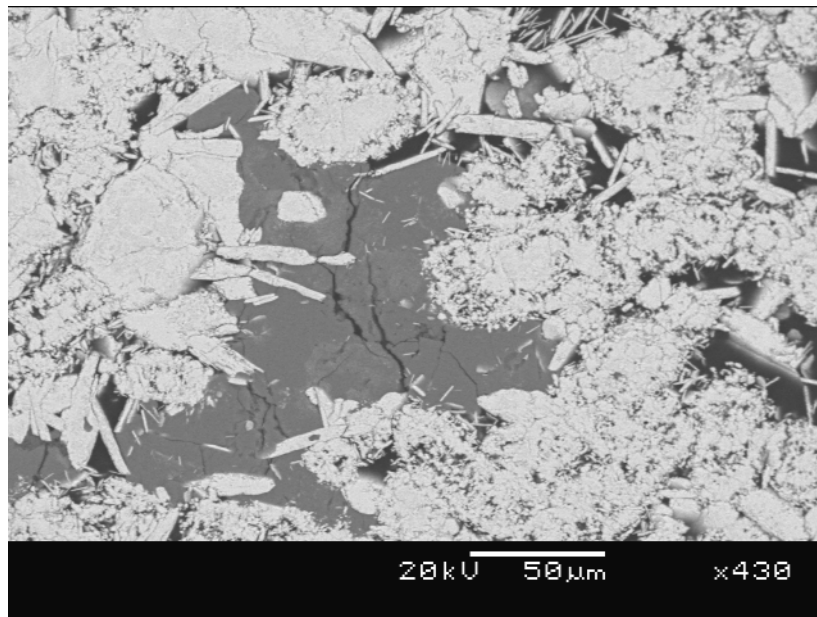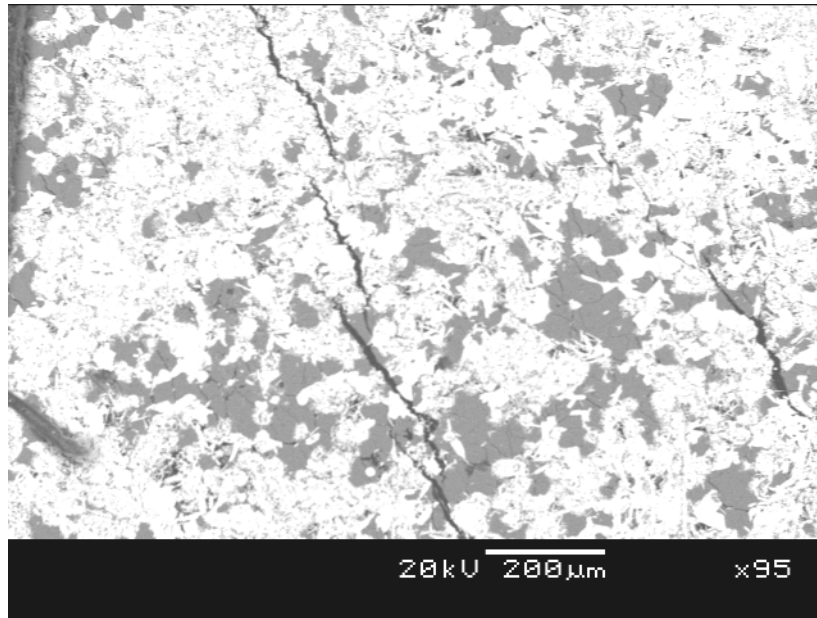
Figure 32. Electron backscatter image of sample 1 showing fractures originating and terminating within quartz (grey) without extending into the surrounding hematite.

Figure 33 Electron backscatter image of sample 1 showing fractures originating and terminating within quartz without extending into the surrounding hematite.

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Figure 34. Electron backscatter image of sample 1 showing large fractures that do not appear to be influenced by the sample mineralogy. The fractures propagate through both gangue and ore minerals.
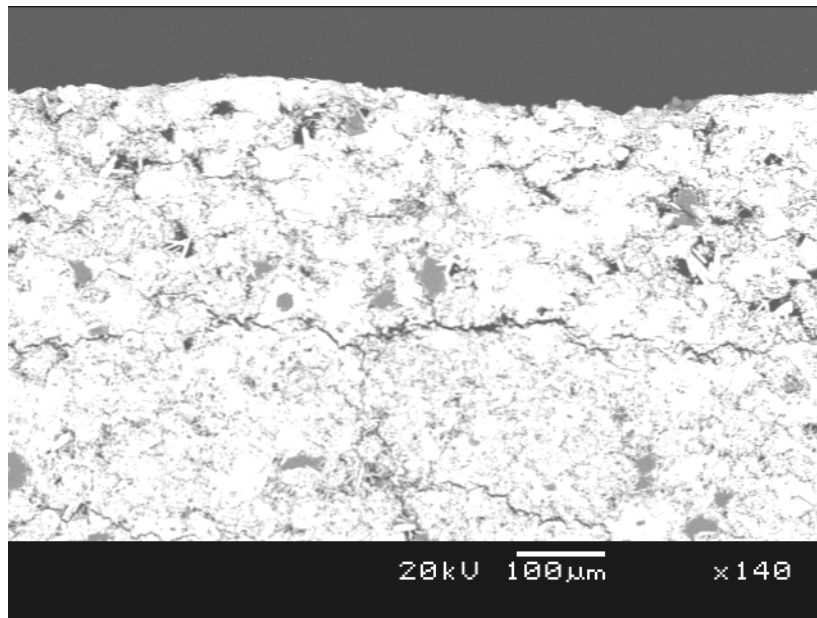
Figure 35. Electron backscatter image of sample 1 showing regularly spaced fractures at the edge of the sample, related to the volume change during the reduction of hematite to magnetite.

3.2.2 Sample 5: Northern Cape Std (B)

This sample contains large amounts of quartz intergrown with hematite throughout the sample. In places the quartz defines very weak banding in the sample as it occurs in a preferred orientation. Fractures are widely developed in the quartz, due to its lower competency, and these fractures do not always extend into the surrounding hematite.

Some fractures propagate parallel to the preferred orientation usually exploiting the less competent quartz phase. Not all the fractures observed exploit the gangue minerals
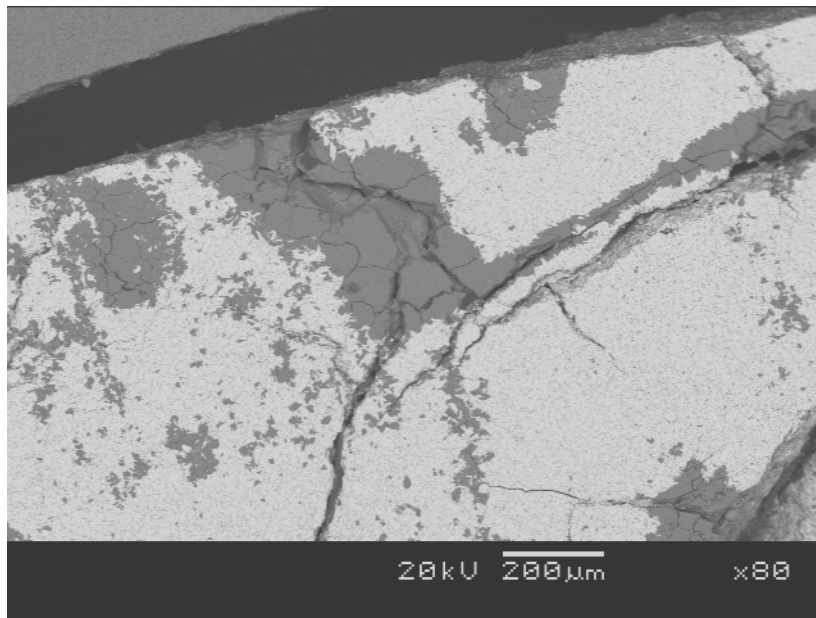
Figure 36. Backscatter electron image of sample 5 showing fractures at the edge of the sample. Notice how the fracture network is better developed when they occur in the gangue phase.

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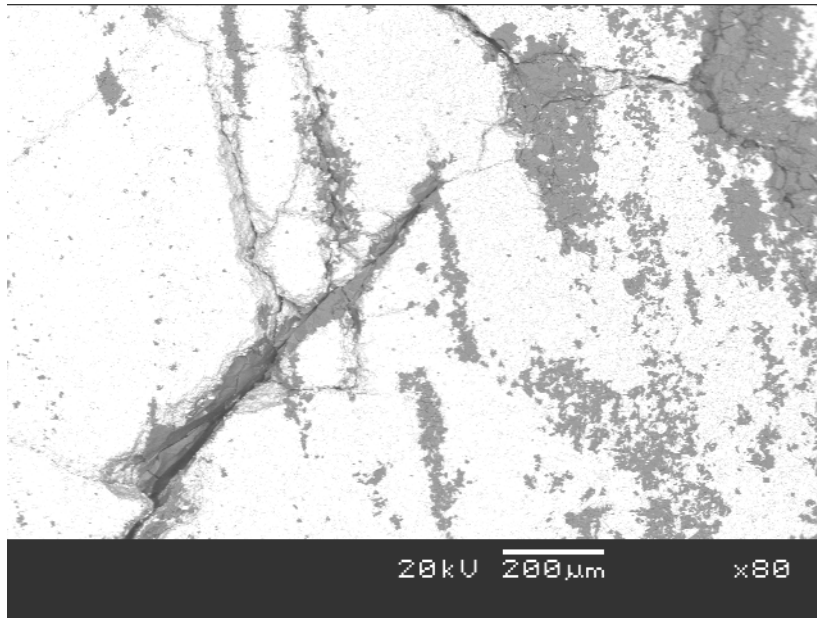
Figure 37. Backscatter electron image of sample 5 showing the quartz defined banding. Some fractures appear to occur parallel to the banding, exploiting the less competent quartz.
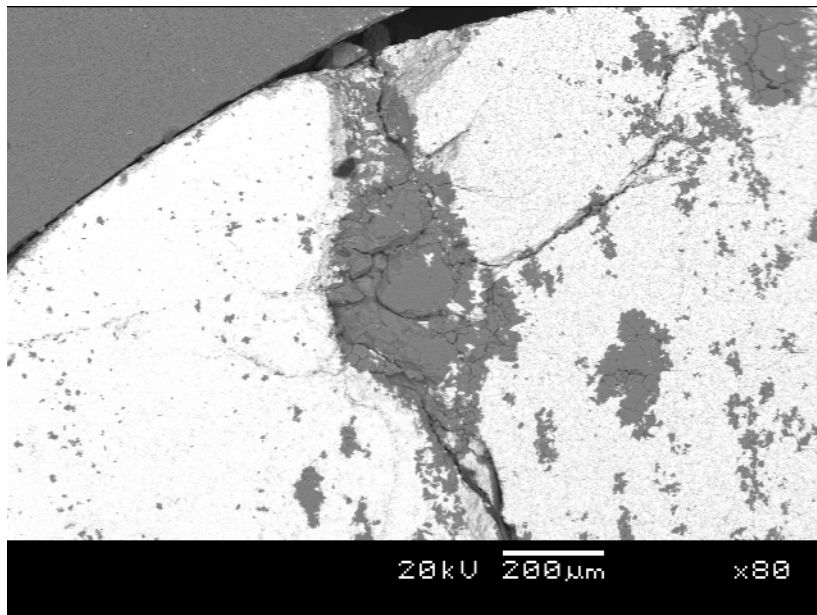
Figure 38. Electron backscatter image of sample 5 showing the development of secondary fractures in quartz.
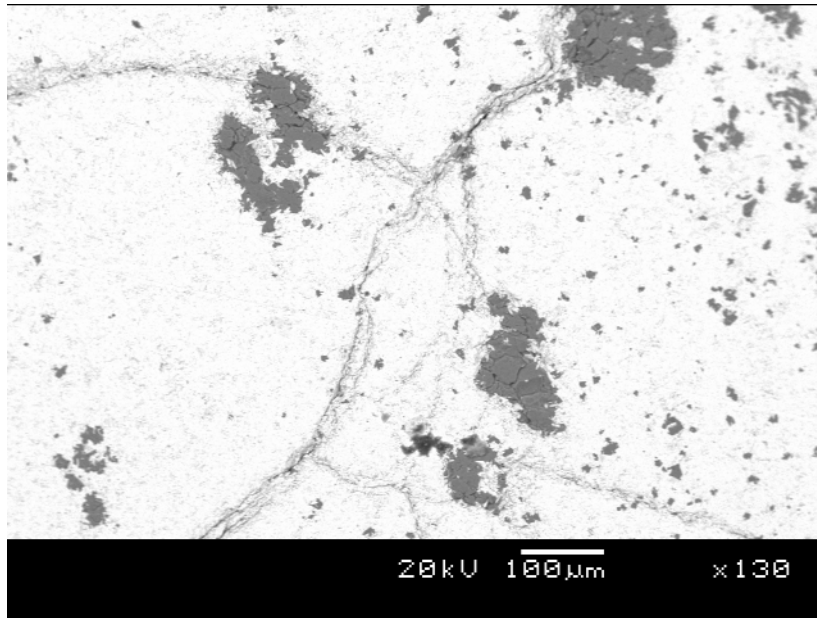
Figure 39. Electron backscatter image of sample 5 showing the relation between fractures and gangue minerals. Although the fractures are not caused by gangue, the distribution of the fractures is influenced. Notice how the fractures always appear to intersect gangue minerals.
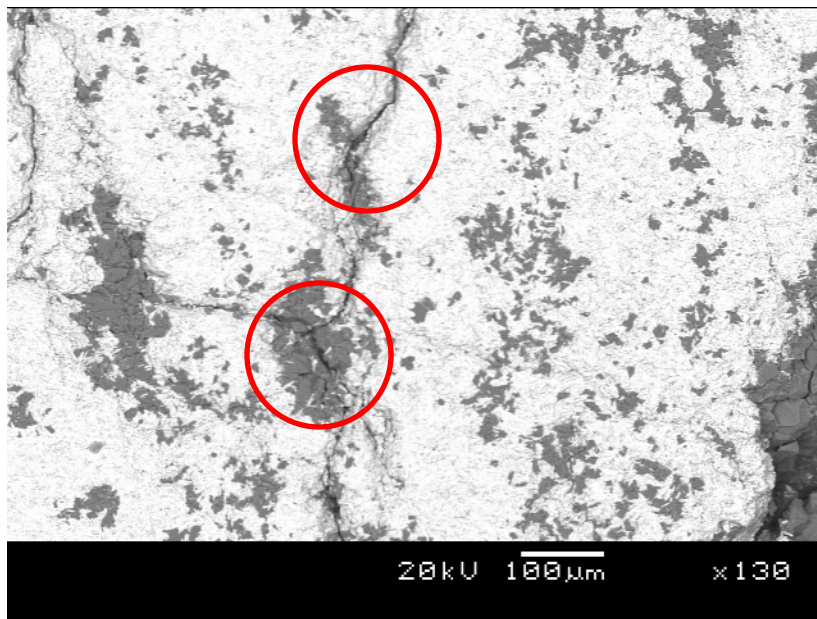
Figure 40. Electron backscatter image of sample 5 showing the dilation of fractures where they occur in gangue.

3.2.3 Sample 7: Ore Type 5 18/06/06

This sample comprises predominantly of specularitic hematite and is relatively porous. Gangue minerals such as apatite occur throughout the sample and appear to have some influence on fracture propagation. In areas where gangue minerals are not present, fractures appear to occur regularly spaced and at regular angles. Fractures are also observed on the edge of samples, these fractures occur parallel to the edge of the sample and are a direct result of sample reduction.
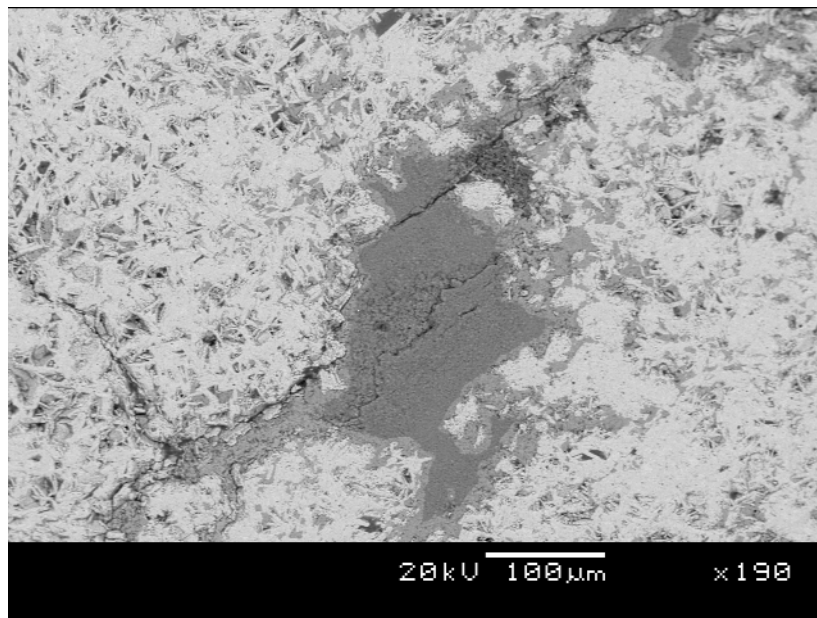
Figure 41. Electron backscatter image of sample 7 showing some secondary fracture development in apatite. The apatite appears to be slightly more competent than quartz.
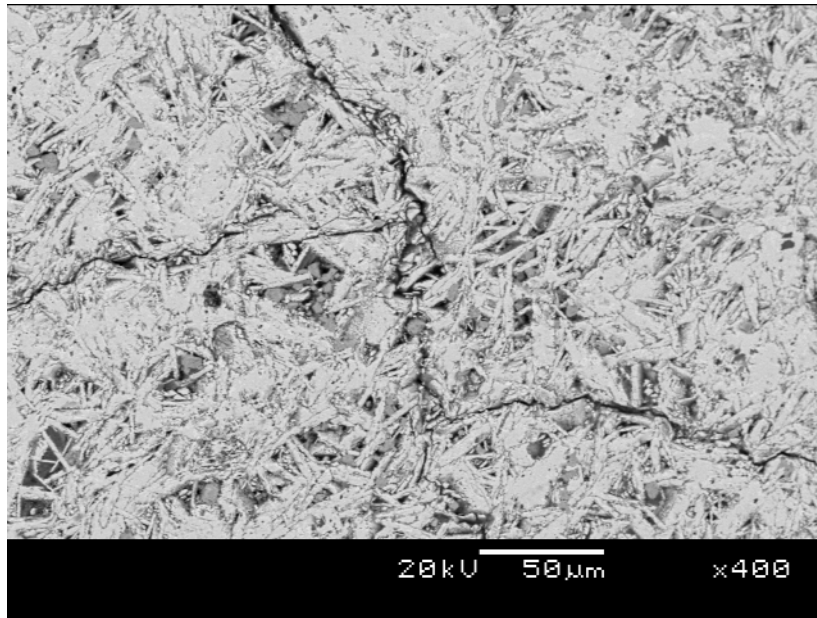
Figure 42. Electron backscatter image of sample 7 showing regularly spaced fractures at the interior of the sample.
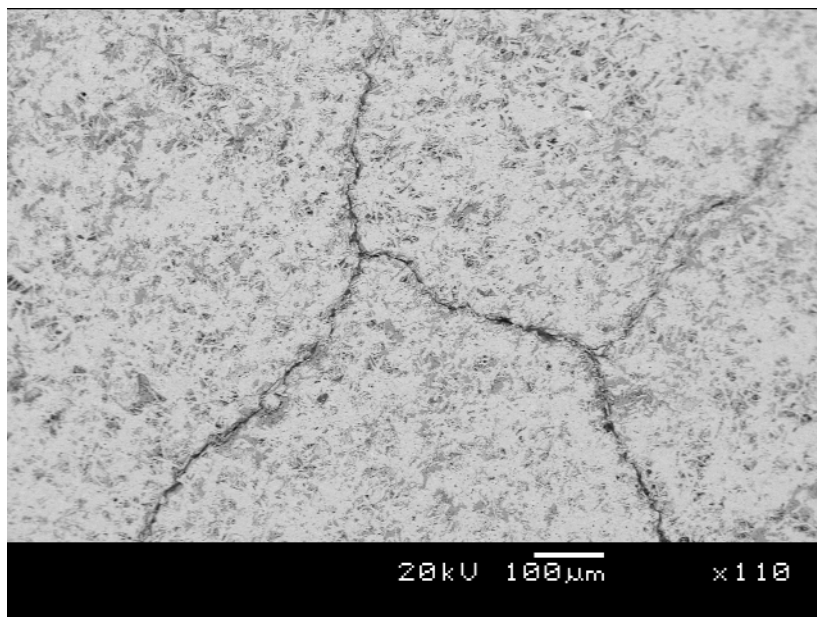
Figure 43. Electron backscatter image of sample 7 showing regularly spaced fractures at the interior of the sample.

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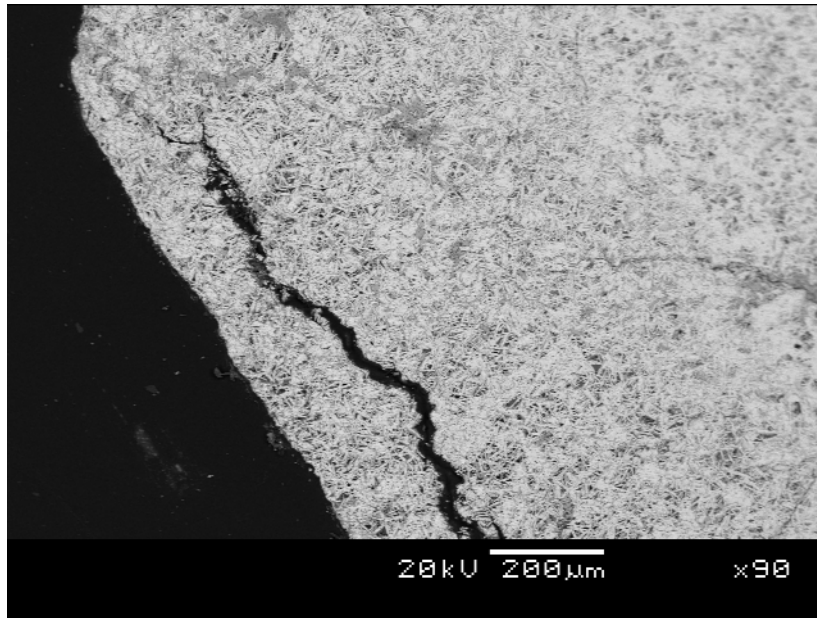
Figure 44. Electron backscatter image of sample 7showing a fracture at the edge of the sample, caused by the volume change during the reduction of hematite to magnetite.
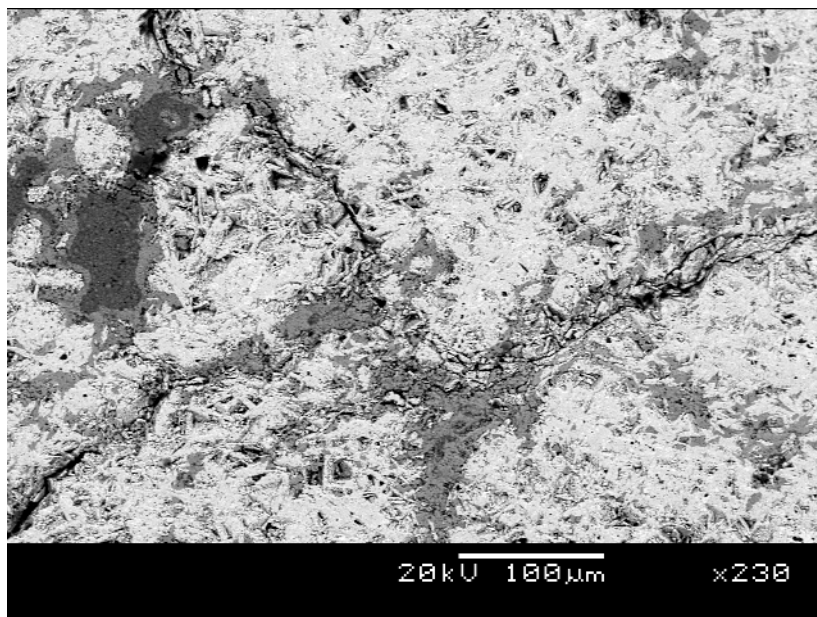

Figure 45. Electron backscatter image of sample 7 showing fractures that appear to occur in association with apatite. Unlike with quartz, there does not appear to be secondary fractures developed within the apatite.

3.2.4 Sample 10: Ore Type 4 D2

The sample is a dense sample with very low porosity. Despite the dense nature of the sample and the abundance of gangue minerals, fracturing is rare and most fractures occur on the edge of the sample, where the sample has been reduced.

Where gangue minerals are present the gangue appears to be fractured more extensively than the surrounding, more competent, hematite. The dearth of fractures may be directly related to the low-porosity of the sample. The sample has only been able to reduce along the edges and therefore there have been no volume changes, and no resultant fracturing internally within the sample.
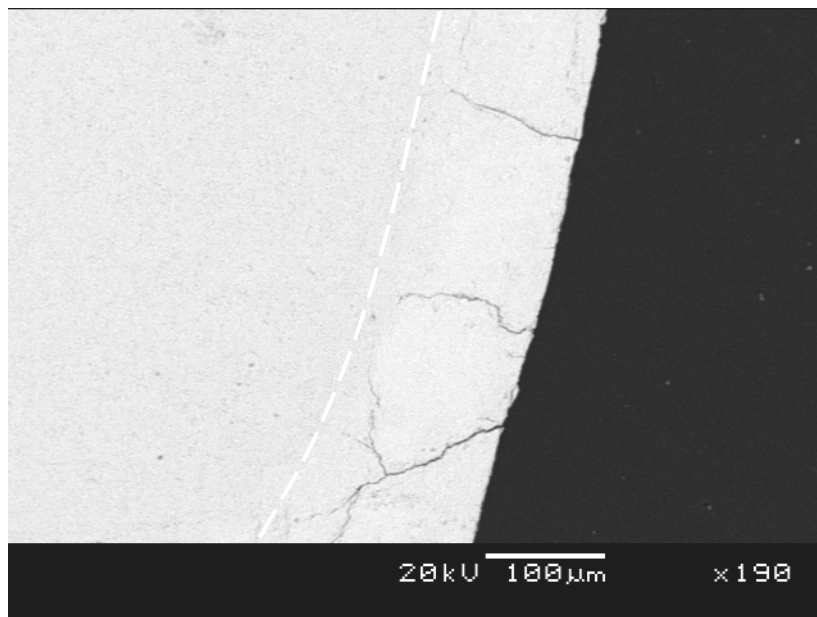
Figure 46. Electron backscatter image of sample 10 showing the development of fractures along the edge of the samples, where it has been reduced. The stippled line indicates where the sample has been reduced.
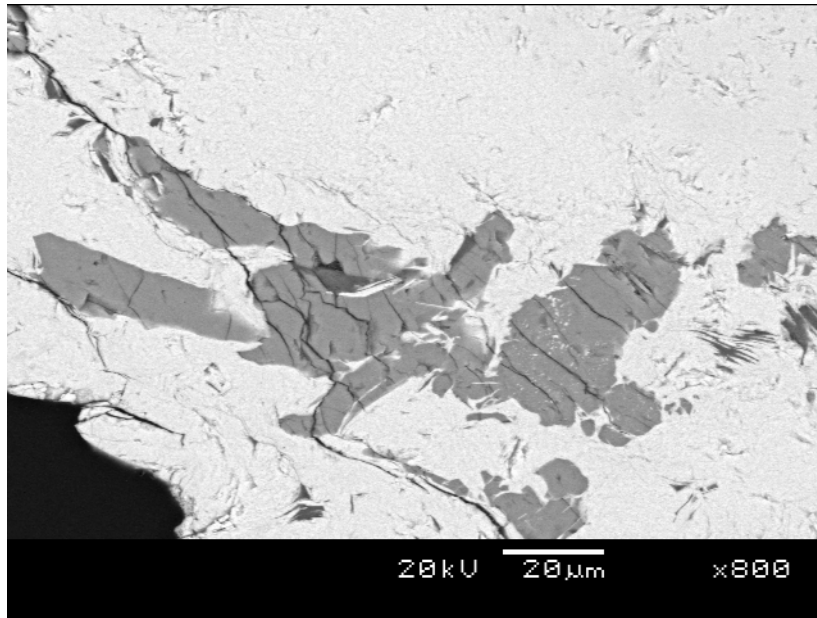
Figure 47. Electron backscatter image of sample 10 showing the development of fractures in quartz. The secondary fractures do not extend into the surrounding hematite.
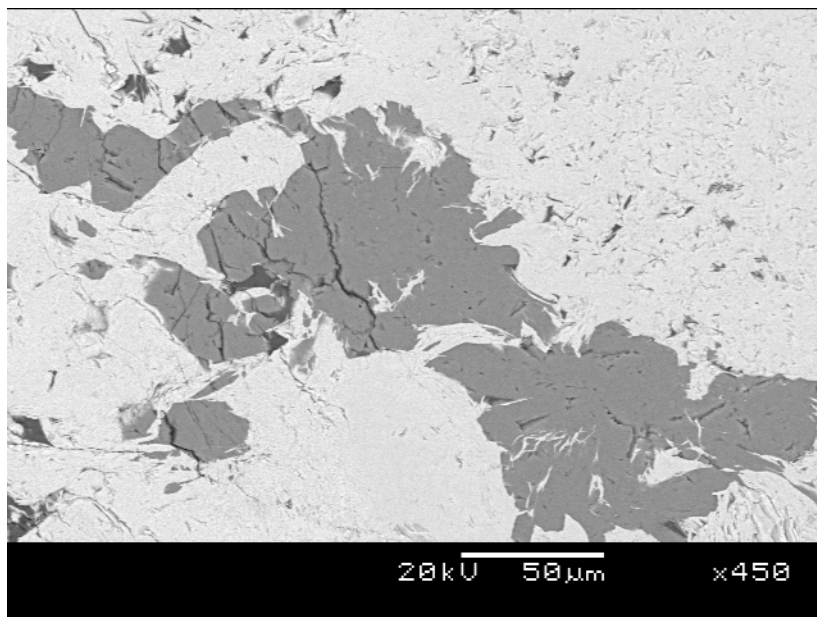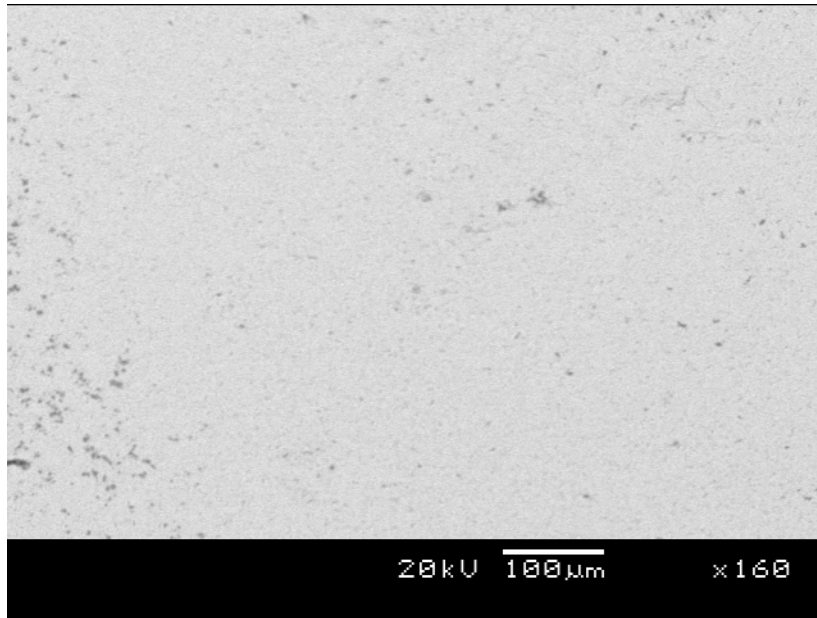

Figure 48. Electron backscatter image of sample 10 showing the development of fractures in quartz. The secondary fractures do not extend into the surrounding hematite.

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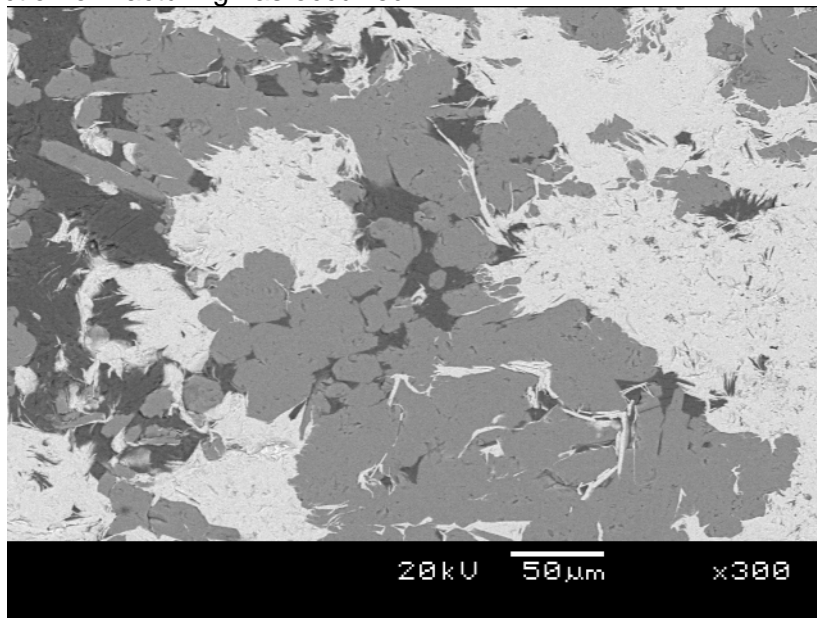Figure 49. Electron backscatter image of sample 10 showing an area within the sample where no reduction or fracturing has occurred.

Figure 50. Electron backscatter image of sample 10 showing intergrown hematite and gangue. The presence of gangue phases does not necessarily lead to fracture formation.

3.2.5 Sample 14: Ore Type 5

This sample has relatively large amount of gangue, found intergrown with hematite throughout the sample. Quartz and apatite appear to be the most abundant gangue minerals. The sample has very low porosity and very few fractures. The fractures are usually observed at the edge of the sample, where the sample has been reduced.

Although the presence of gangue may not result in fractures forming, where a fracture intersects gangue minerals the gangue appear to facilitate the development of fractures that do not extend into the surrounding hematite.

In the center of the sample very few fractures are observed. The fractures that do occur are associated with open pores and reduction and are not related to the presence or absence of gangue minerals. The fractures appear to link a series of open pores where reduction has occurred.
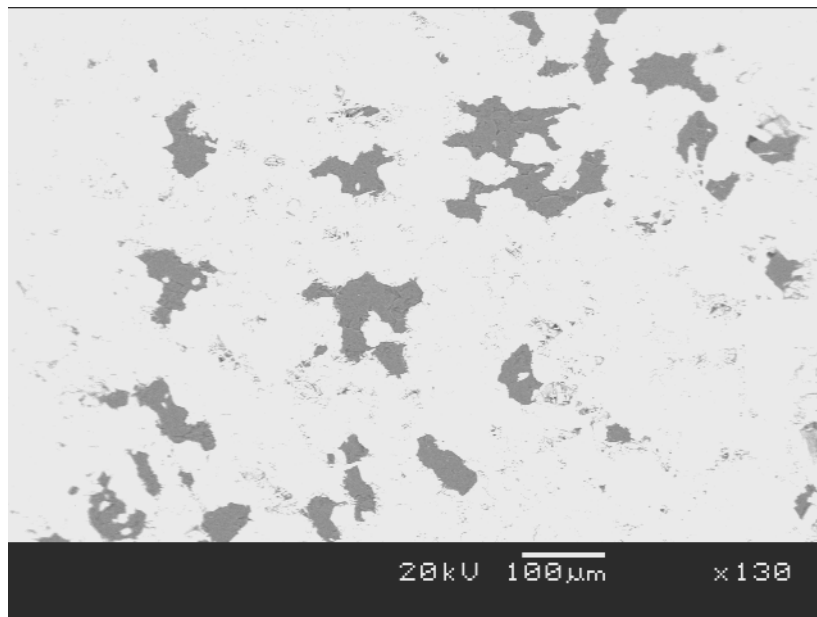
Figure 51. Electron backscatter image of sample 14 showing intergrown hematite and quartz in the center of the sample. There are o fractures observed here as no reduction has been able to occur with the low sample porosity.

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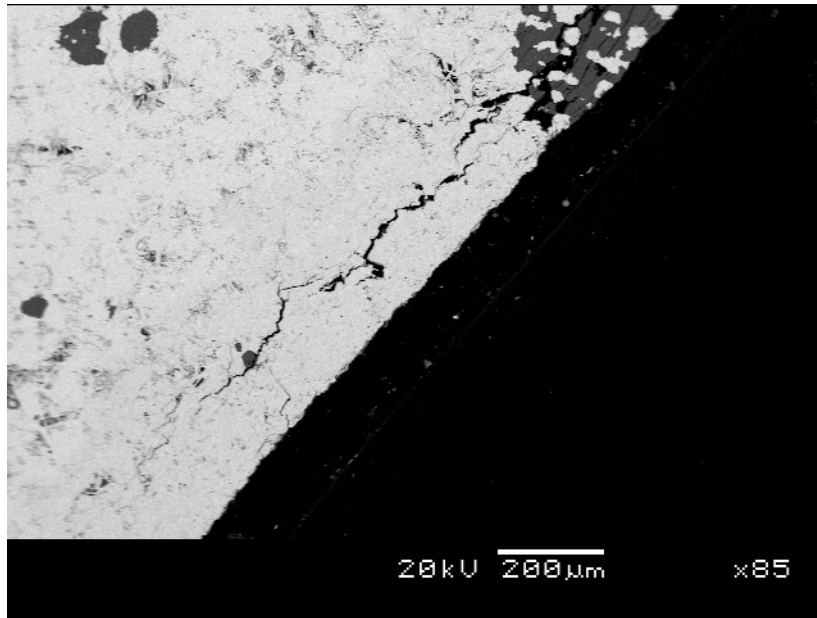UNIVERSITY OF PRETORIA
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Figure 52. Electron backscatter image of sample 14 showing fractures developed at the edge of the sample where reduction has occurred.
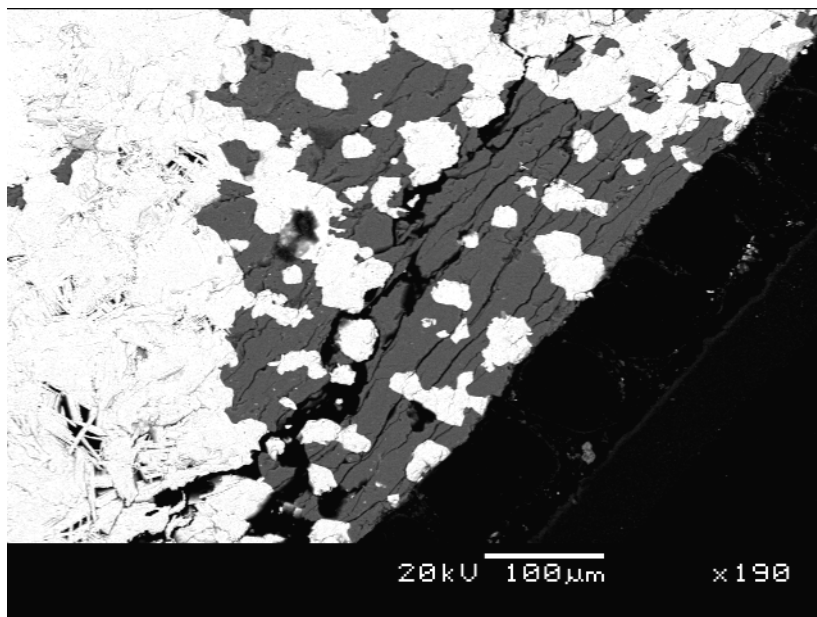

Figure 53. Electron backscatter image of sample 14 showing fractures developed at the edge of the sample where reduction has occurred. Notice how the gangue allows for more extensive development of the fracture network that does not extend into the surrounding hematite.
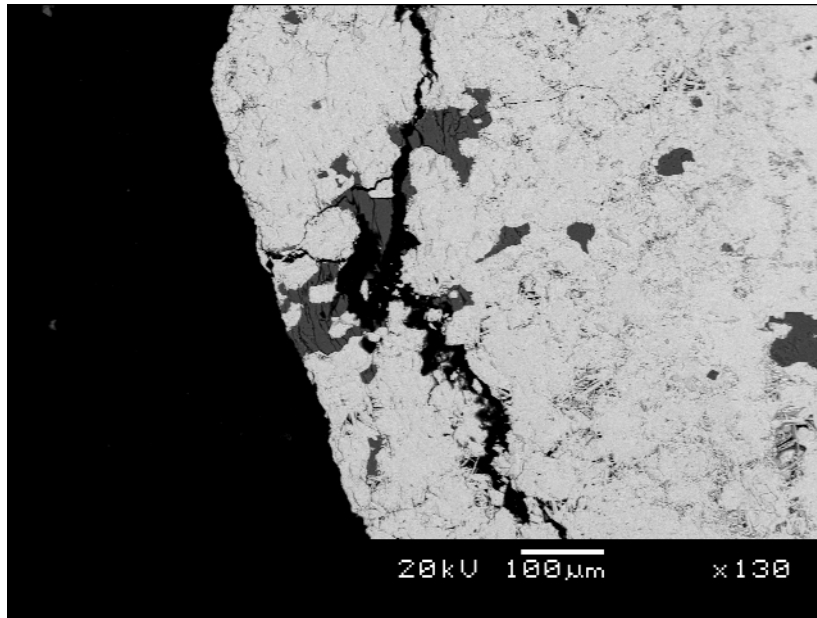
Figure 54. Electron backscatter image of sample 14 showing fractures developed along the edge of the sample where it has been reduced. Where a fracture intersects gangue minerals the gangue appears to facilitate the development of fractures.
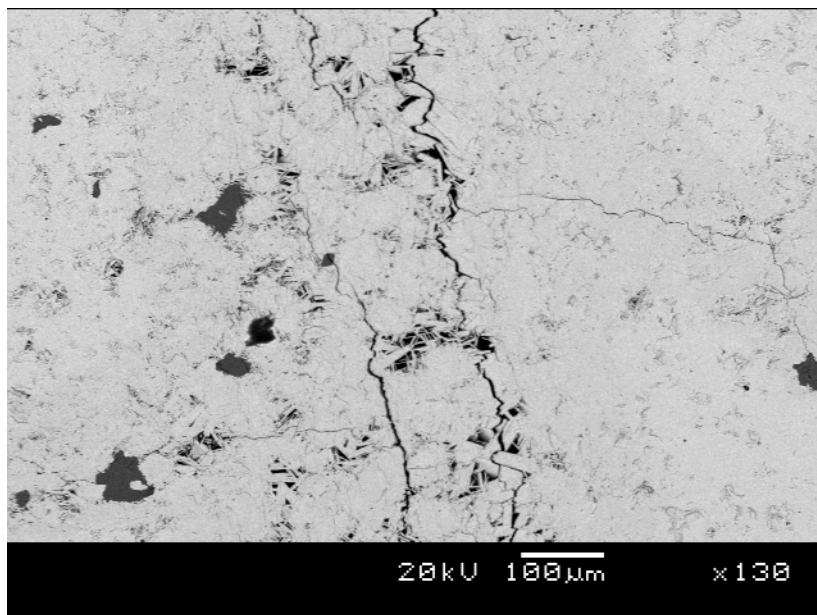

Figure 55. Electron backscatter image of sample 14 showing fractures developed within the sample. The fractures appear to join open pores where reduction has occurred.
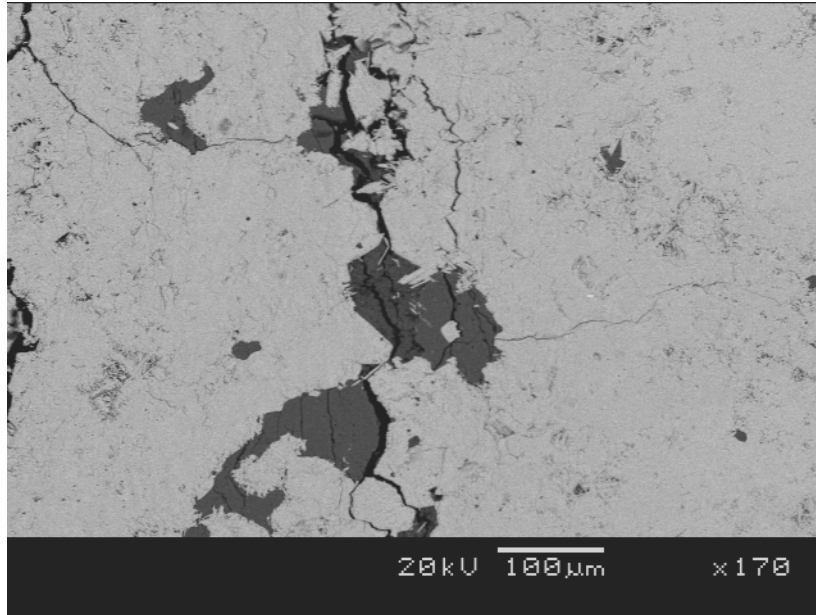
Figure 56. Electron backscatter image of sample 14 showing fractures developed within the sample. Where a fracture intersects gangue minerals the gangue appears to facilitate the development of fractures that do not extend into the surrounding hematite.

3.2.6 Sample 15: Ore Type 5 (C)

This sample comprises intergrown hematite and gangue. The gangue is abundant throughout the sample and comprises predominantly of alumino-silicates. The sample has very low porosity and also has very few fractures.
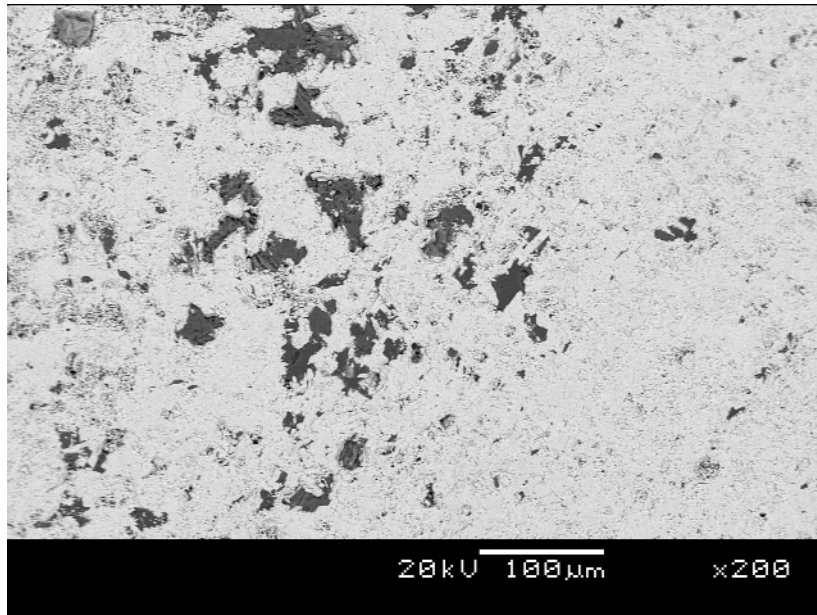
Figure 57. Electron backscatter image of sample 15 showing intergrown hematite and gangue with very low porosity and no visible fractures.
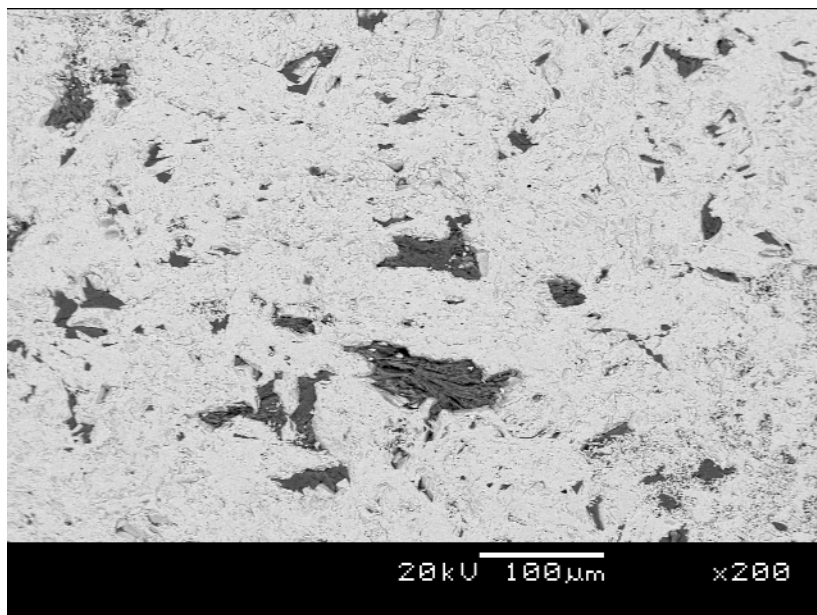

Figure 58. Electron backscatter image of sample 15 showing intergrown hematite and gangue with very low porosity and no visible fractures.
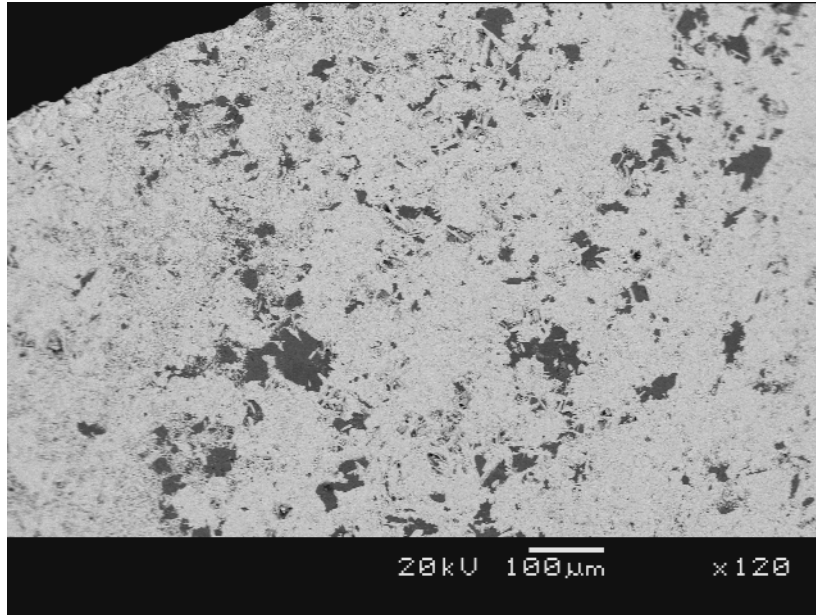
Figure 59. Electron backscatter image of sample 15 showing intergrown hematite and gangue with very low porosity and no visible fractures, even at the edge of the sample where fractures are unusually prolific.

Group 3: Porous Samples

Only two samples are found in this group. Sample 2 comprises of bands of acicular hematite with very high porosity whilst sample 9 has a homogenous high-porosity texture throughout the sample. Both samples do not exhibit extensive fracturing most probably due to the fact that the numerous open voids allow for the volume increase during reduction and therefore prevent extensive fracturing.

3.3.1 Sample 2: Ore Type 3 (B)

This sample comprises predominantly of hematite with very little gangue. The most interesting feature of this sample is the porosity defined banding that appears to have an impact on fracturing. Porous specularite (acicular hematite) would not be affected by the volume increase during reduction and would be more competent in accommodating strain. Therefore fractures would terminate in areas of high porosity.

Where gangue minerals are not present and there are no large changes in porosity, fractures appear to occur evenly spaced at regular intervals and at similar orientations.

The large fractures in this sample are interesting in that they do not occur with a large network of finer fractures or ancillary fractures, as observed in other samples.
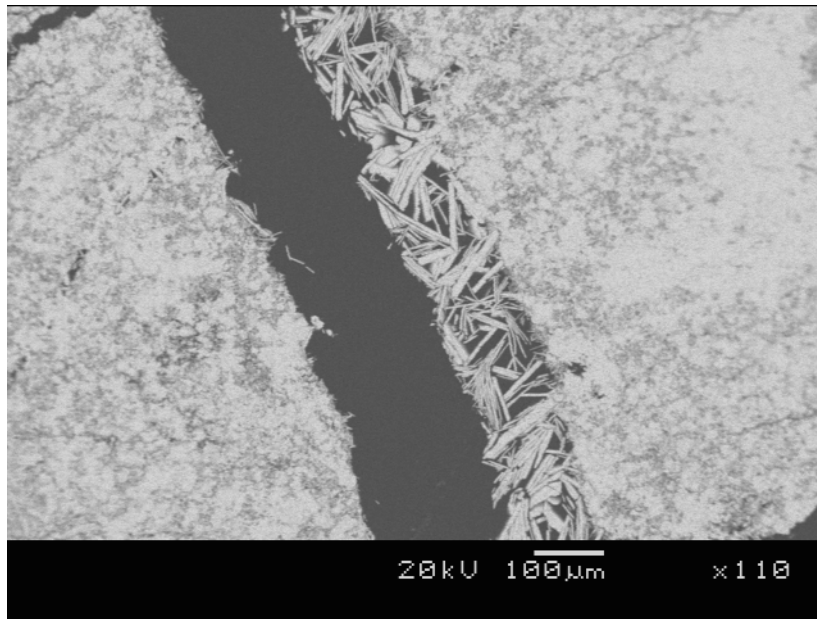

Figure 60. Electron backscatter image of sample 2 showing a very large fracture that has occurred at a boundary between granular hematite (left) and porous specularite (acicular hematite).
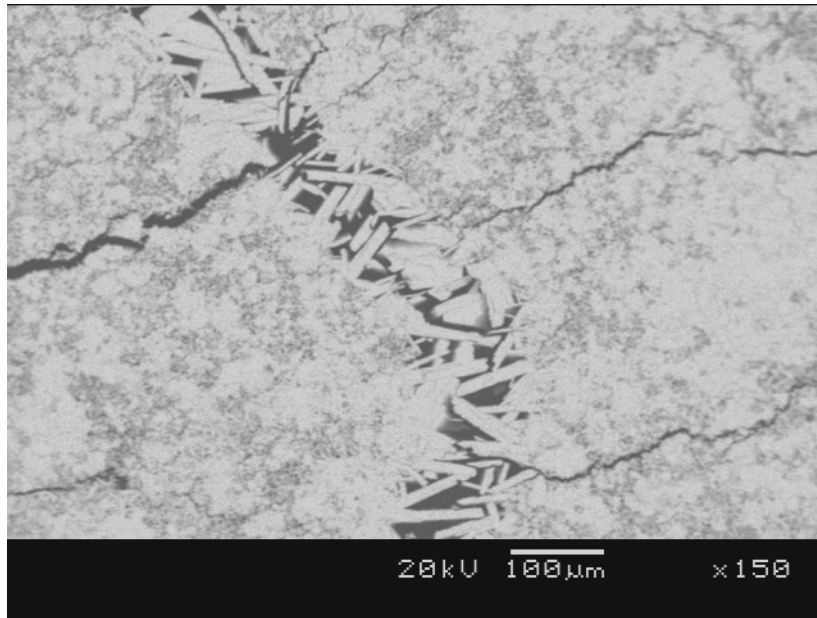
Figure 61. Electron backscatter image of sample 2 showing large fractures originating/terminating in areas of low porosity.
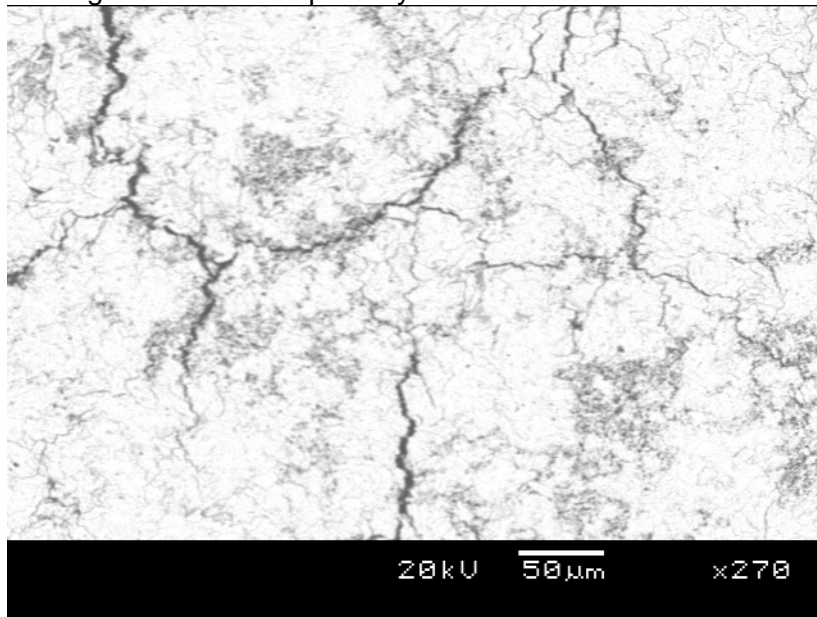

Figure 62. Electron backscatter image of sample 2 showing a network or regularly spaced and oriented fractures formed in an area of dense homogenous ore.
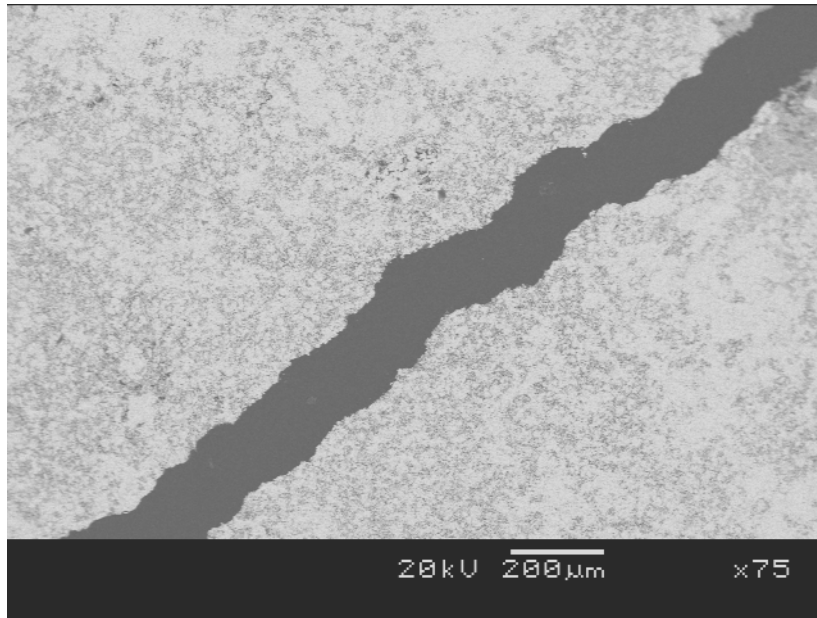
Figure 63. Electron backscatter image of sample 2 showing a large fracture through low porosity granular hematite. The fracture occurs without a large network of feeder fractures or ancillary fractures.

3.3.2 Sample 9: Northern Cape Std Test 1

This sample is a homogenous sample compressing predominantly of granular hematite. The sample is very porous. Most fractures occur at the edge of the sample and are related to the hematite reduction.

Internally within the sample there are not many fractures that have formed. This may be due to the high porosity that allows for the increased in volume during reduction. Where fractures do occur they typically originate and terminate at open pores.
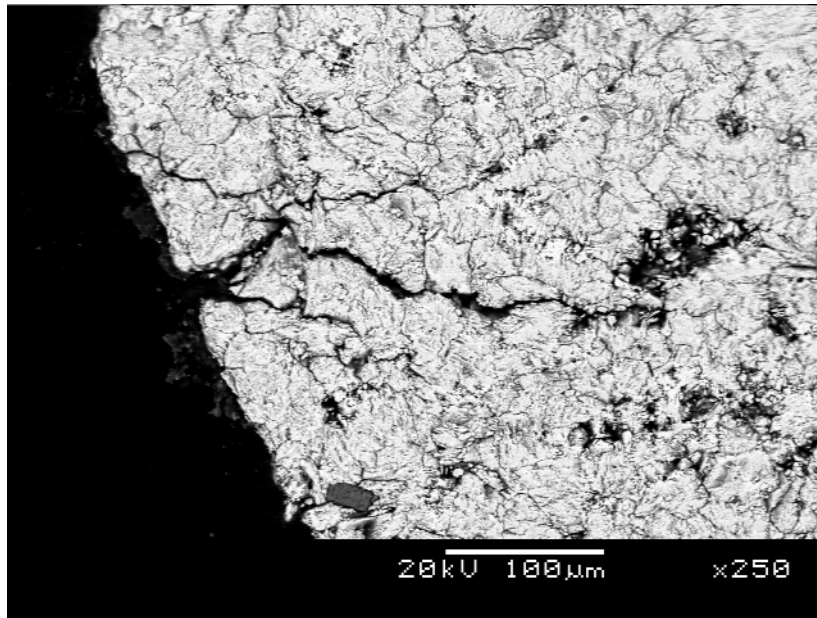
Figure 64. Electron backscatter image of sample 9 showing fractures perpendicular to the sample edge
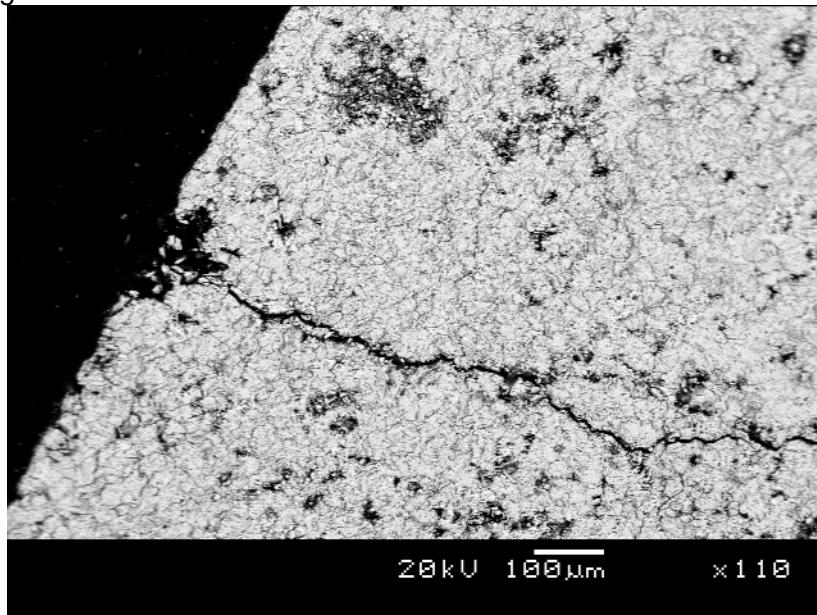

Figure 65. Electron backscatter image of sample 9 showing a fracture perpendicular to the sample edge.
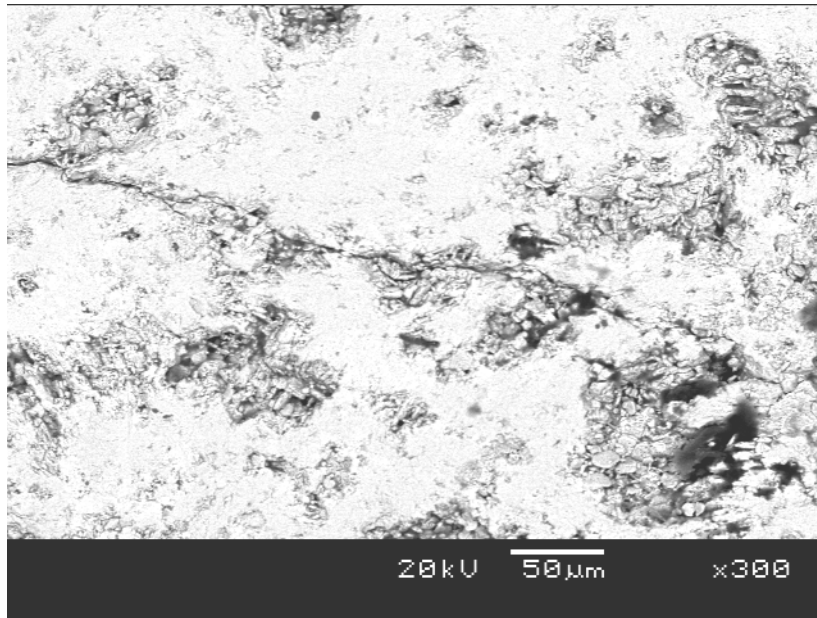
Figure 66. Electron backscatter image of sample 9 showing a fracture within the sample that terminates at an open pore.
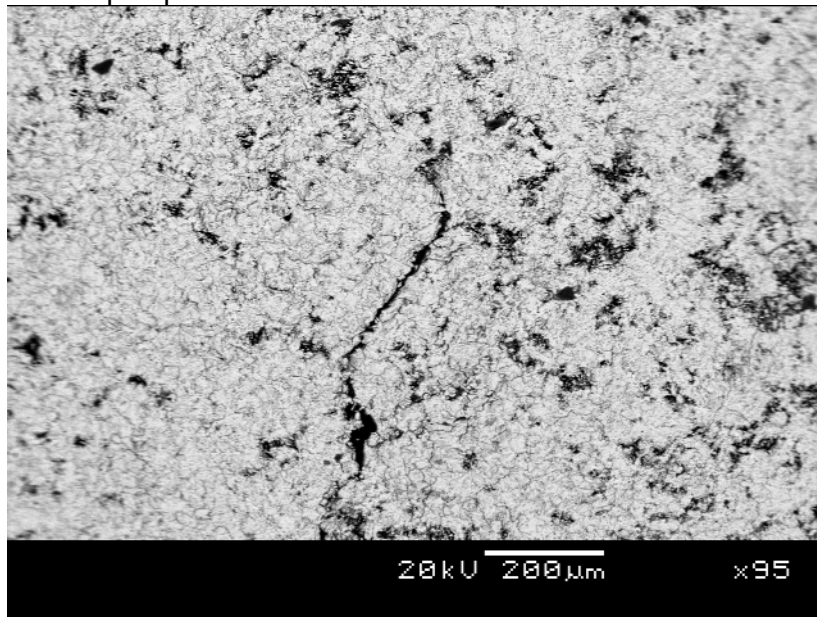

Figure 67. Electron backscatter image of sample 9 showing a fracture that has developed within the sample. Notice the overall sample porosity.
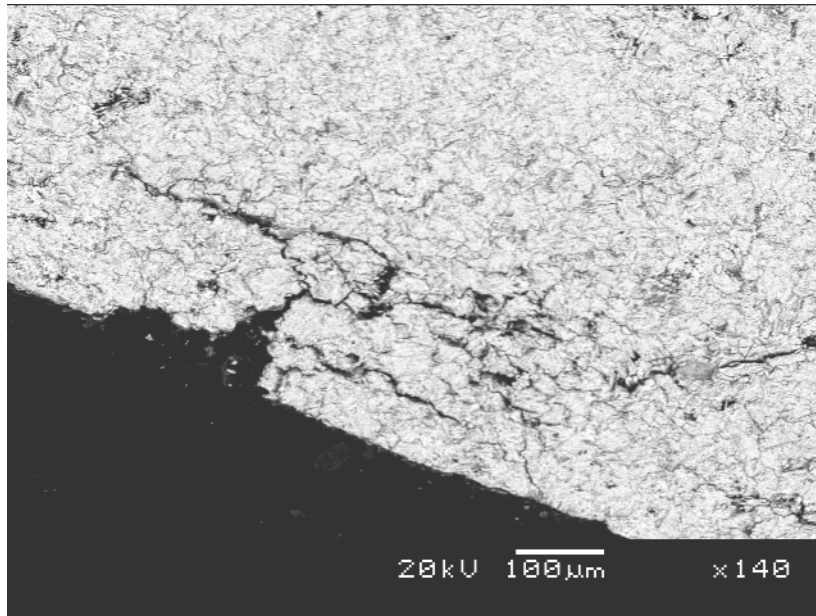
Figure 68. Electron backscatter image of sample 9 showing a fracture network developed parallel and perpendicular to the sample edge.

3.3.3 Sample 16: Northern Cape Std "A"

This sample comprises predominantly of low porosity hematite with very little gangue. Many large and extensive fractures are observed throughout the sample. Fractures are observed in two distinct areas:

1) At or near the sample edge where reduction has occurred.
2) Associated with porous acicular hematite.

The fractures associated with the acicular hematite may be related to the increased porosity in-between the acicular hematite that results in increased reduction, or it may be associated with the brittle nature of the acicular hematite or the increased amount of gangue intergrown with the hematite.
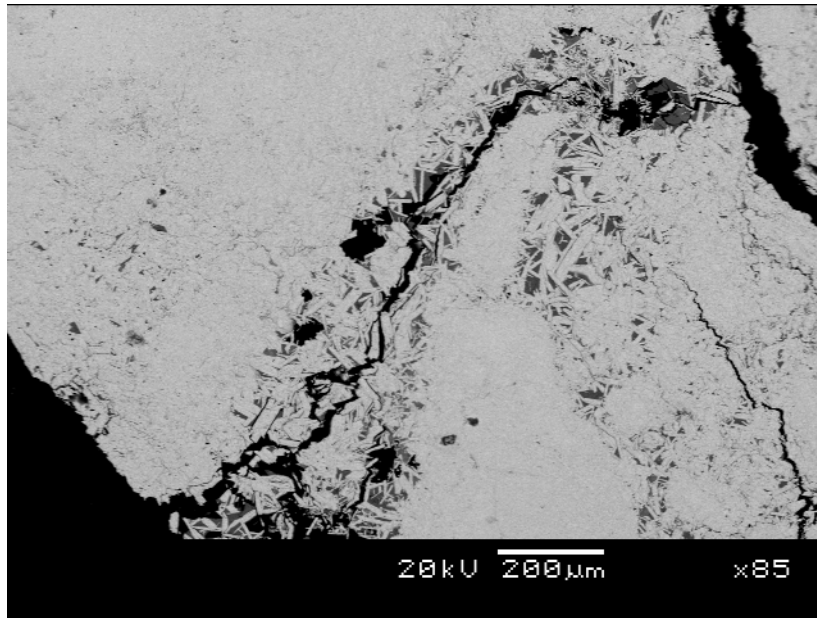
Figure 69. Electron backscatter image of sample 16 showing a large fracture associated with acicular hematite
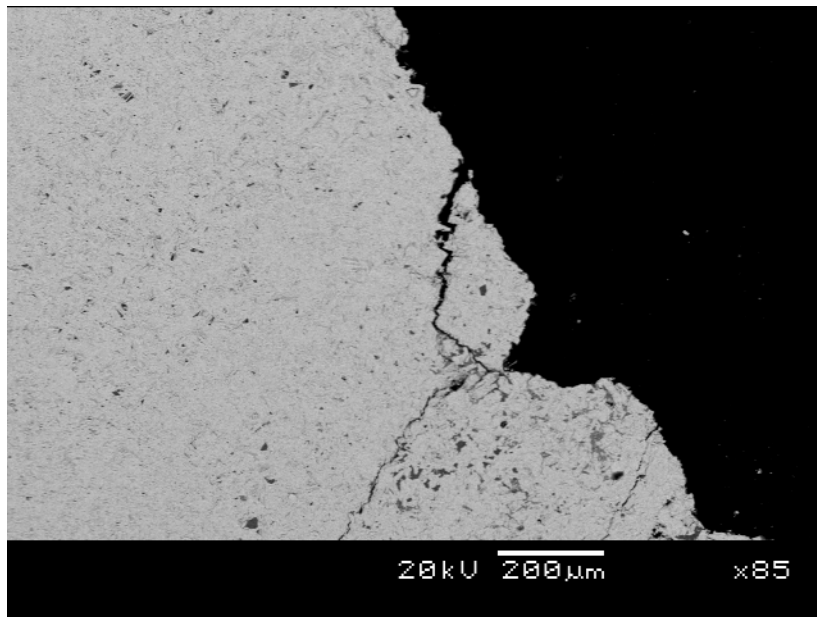

Figure 70. Electron backscatter image of sample 16 showing a small fracture at the edge of the sample associated with reduction of hematite.
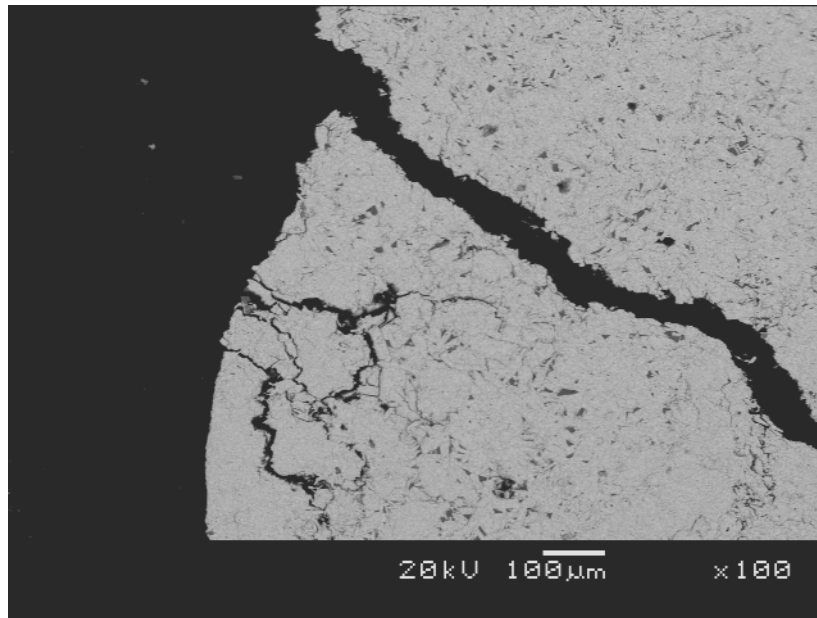
Figure 71. Electron backscatter image of sample 16 showing fractures at the edge of the sample were reduction has taken place.
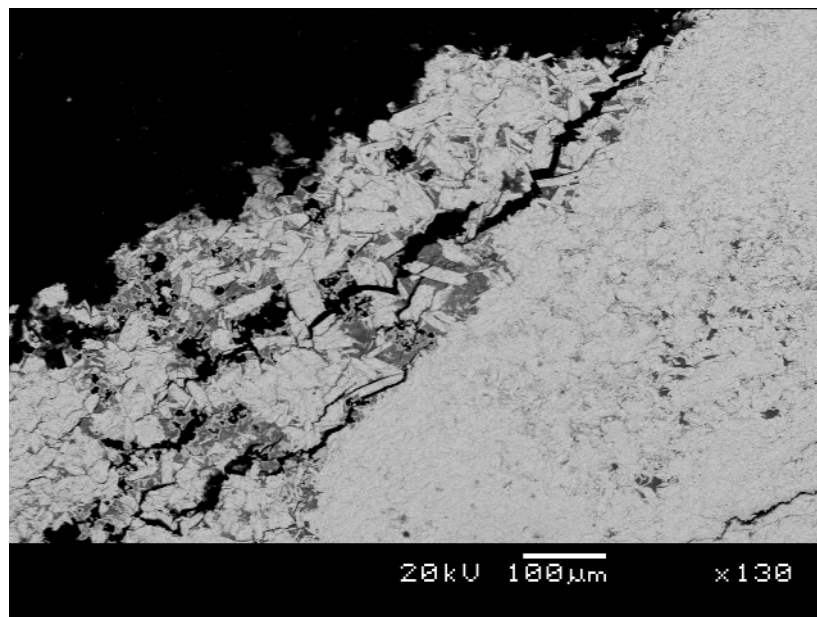

Figure 72. Electron backscatter image of sample 16 showing fractures at the edge of the sample where reduction has taken place. The influence of acicular hematite and gangue minerals is uncertain.

3.4 Group 4: Other

3.4.1 Sample 6: Northern Cape Ore Type 2 C

This sample contains very little gangue and comprise predominantly of hematite. The sample is unique in this study as it is the only sample observed with a clearly observed foliation fabric. The foliation fabric defines the primary plane of weakness in the sample and is an important influence on the fracture that form in the sample. Most fractures occur parallel to the foliation fabric.

Where the foliation fabric is less pronounced or is absent then the fractures appear to occur at regular intervals with similar orientations to form a fracture framework.
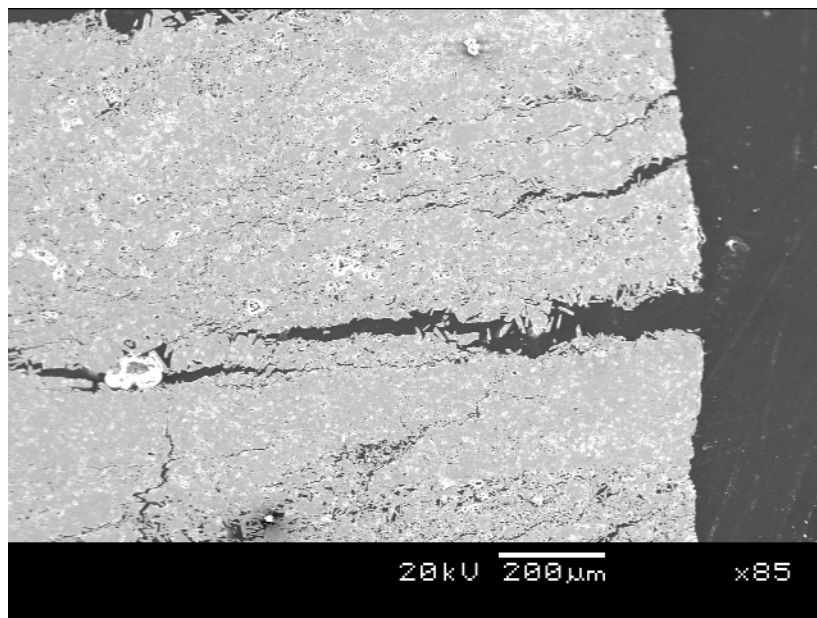

Figure 73. Electron backscatter image of sample 2 showing fractures oriented parallel to the foliation fabric.
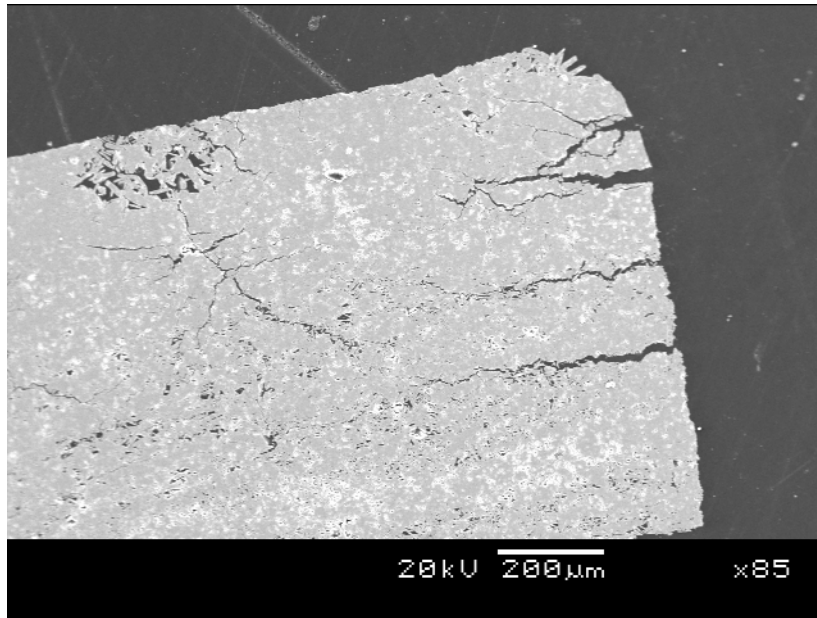
Figure 74. Electron backscatter image of sample 2 showing fractures oriented parallel to the foliation fabric.
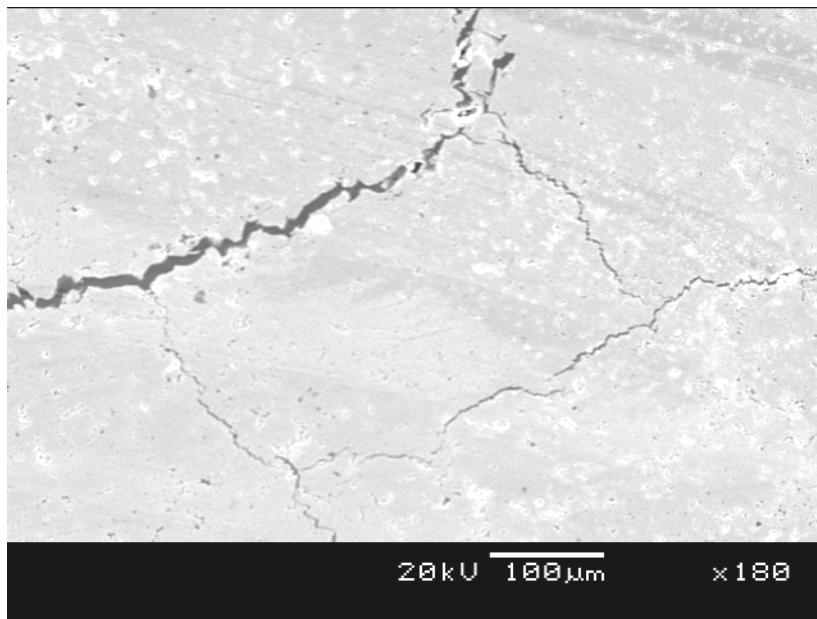

Figure 75. Electron backscatter image of sample 2 showing a regularly spaced network of fractures that occur at right angles to each other. There are no compositional or textural features to influence the fracture orientation.

4.0 CONCLUSION

1. Mono-mineralic particles fracture with radial fractures occurring on the edges of particles penetrating the sample only as far as it has been reduced. These fractures appear to be directly related to the volume change during reduction. Internal fractures do occur in mono-mineralic particles where fractures occur regularly spaced at right angles to one another.

2. It appears as though the presence of gangue minerals only appears to have an impact on the fracture path up until a certain size of fracture is reached. Thereafter with large fractures, the fracture propagates irrespective of the presence or absence of gangue minerals. Fractures often dilate as they pass through gangue minerals and a secondary network of smaller fractures is often developed, especially in quartz. The secondary fractures do not extend into the surrounding hematite.

3. Porous samples appears to be less fractured as the open pores impede fracture formation as the pores is able to accommodate the strain during volume increase during reduction.

4. Features such as internal foliation fabric and/or bedding planes have a significant influence on the orientation of fractures as the foliation/bedding plane is the primary plane of weakness in the sample.

5. Where there are no compositional or textural features in a sample that can have an influence on fracture propagation then fractures will form at regular intervals with similar orientations, often at right angles to one another.

5.0   References

Passchier, C.W. and Trouw, R.A.J. Microtectonics….

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