



Characterization of clay mineral fractions in tuffisitic kimberlite breccias by X-ray diffraction

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Synopsis

During research on mainly the weathering of kimberlite, it became evident that its mineralogical composition is an important factor in the complex process of physical and chemical disintegration. The mineralogy of tuffisitic kimberlite breccias from two localities, the Cullinan and Venetia mines, is compared with special reference to the occurrence of associated clay minerals. The clay mineral composition influences the engineering properties of these rock types. It is illustrated how the presence of swelling clay components can be confirmed by ethylene glycol treatment and chlorite minerals by heat treatment using X-ray diffraction. Smectites are present in both tuffisitic kimberlites, dominant at Venetia while chlorite is more frequent at Cullinan. More tuffisitic kimberlite breccias samples from Venetia were also characterized. It was found that kimberlite disintegration is correlated with the presence and abundance of smectite.

Introduction

Kimberlite is described as a diverse and complex hybrid rock in the literature. It is also described as volatile rich, potassic, ultrabasic, igneous rocks that occur as volcanic pipes, dykes and sills¹. The minerals present in kimberlites vary widely and can include from trace to predominance any of the following minerals: apatite, calcite, chlorite, diopside (pyroxene), magnetite, monticellite, olivine, phlogopite (mica), quartz, serpentine, smectite, talc and vermiculite.

Tuffisitic kimberlite breccia (TKB) is one of several types of kimberlite that occur in both Cullinan (previously Premier) and Venetia mines. The formation of tuffisitic kimberlite breccia is discussed by Clement². Bartlett⁸ gives an account of the kimberlite geology and related aspects of the Cullinan diamond pipe. The volcanological and structural aspects of the Venetia tuffisitic kimberlite breccia are described by Kurszlaukis and Barnett³. These two types of kimberlite contain different clay minerals in various quantities, apart from their specific assemblage of other kimberlitic minerals.

The presence of more than one type of clay mineral in a kimberlite (or members from different clay mineral groups) can cause

overlapping of peaks on X-ray diffractograms and results in complications when characterizing kimberlite mineralogy by X-ray diffraction (XRD). This problem can be resolved only by additional treatment of the sample to change the diffraction properties of the clays present.

Different treatments of clay-rich ores to enable accurate identification of the peaks have been discussed by a few authors⁴⁻⁷. The use of strongly orientated specimens is suggested by Böhmann⁴ and Moore and Reynolds⁷ as this enhances the basal (001) reflections which are the most diagnostic. The clay fraction of the ore can also be treated with ethylene glycol, glycerol and/or hydrazine before being heat-treated at 500°C. The XRD scans of these differently treated clay preparations are then compared to review the movement, collapsing or enhancement of peaks as discussed by Böhmann⁴. In this paper these sub treatments when utilizing XRD are applied to kimberlite material.

During an investigation of the engineering properties of a number of kimberlites it was realized that the type and quantity of clay minerals in kimberlites relate to certain of these properties, especially weathering characteristics. Tuffisitic kimberlite breccia can contain a significant clay component, which influences its physical properties. Samples from the Cullinan and Venetia TKBs were selected as both contain various clay minerals in different quantities. The purpose of this investigation is to establish the presence, identity, and relative abundance of clay minerals from both sample locations by XRD-techniques, especially after the above-mentioned preparation techniques were carried out to alter the diffraction properties.

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Experimental methods

The premilled samples as received were pulverized for ten minutes in a McCrone micronizing mill with the purpose to reduce all mineral particles to a relatively small size. Size differences may have an influence on the XRD peak intensities of the different mineral components of this rock type. The samples were side-mounted to minimize the effect of preferred orientation⁷. The reflection intensities of basal peaks are enhanced by preferred orientation while others become smaller or even disappear. Side mounting the sample obtains a more random orientation of the mineral particles and that insures that the incident X-rays have an equal chance of diffracting from any crystal lattice face of mineral present in the sample. This is especially important when attempting quantitative XRD work.

From the micronized material three representative sub-fractions were obtained for the following purposes:

- XRD on the first fraction was done on the material after micronizing and labelled 'untreated'.
- The second fraction was treated with ethylene glycol—this is used as an auxiliary treatment to expand swelling clays if present. Swelling clays include smectites (e.g. montmorillonite, nontronite), and some mixed-layer clays, and vermiculite. The sample was directly side loaded into the XRD sample holder and placed in a dessicator where it was exposed to ethylene glycol fumes for 12 hours at 60°C. Thereafter XRD was carried out on the sample.
- The third fraction was loaded into a porcelain crucible and heated for 2 hours in a muffle furnace in air at 550°C. XRD was carried out on the product. This was followed by a consecutive session of another two hours' heat treatment under the same conditions and XRD repeated.

The specifications of the XRD equipment and settings are shown in Table I.

Results and discussion

The results obtained for Cullinan and Venetia TKB

kimberlites are depicted as XRD scans in Figures 1 to 4, while other diffraction information is presented in Tables II to X.

Cullinan TKB

The XRD scans of the untreated and glycolated Cullinan TKB sample are compared in Figure 1.

In the untreated XRD scan the mineral groups/ minerals were identified for the untreated XRD scan. Certain minerals could be identified only with certainty as members of their mineral groups (e.g. smectite, mica, chlorite, amphibole, and pyroxene), while other minerals could be identified with certainty as species (e.g. talc and quartz). The minerals identified in the untreated sample and their measured 2θ and d-spacing are presented in Table II. The measured d-spacing corresponds with the literature 2θ and d-values of these minerals shown in Table III^{4,7}. The measured d-spacings of the minerals compare well with literature, although the smectite d-value falls within a range depending on the type of interlayer cation and the swelling condition. Glycol can enter the interlayer space and change the diffraction characteristics of smectite. Upon heat treatment the chlorite (001) peak is enhanced while the smectite structure collapses. The results are given in Table IV.

Table I
XRD equipment and specification

Instrument	Siemens D500
Radiation	Cu Kα
Temperature	25°C
Specimen	Flat-plate, rotating (30 rpm)
Power Setting	40 kV, 40 mA
Soller slit	2°
Divergence slits	0.3°
Receiving slits	0.15°
Monochromator	Secondary, graphite
Detector	Scintillation counter
Range of 2θ	3–30° 2θ
Step width	0.02° 2θ
Time per step	1 s

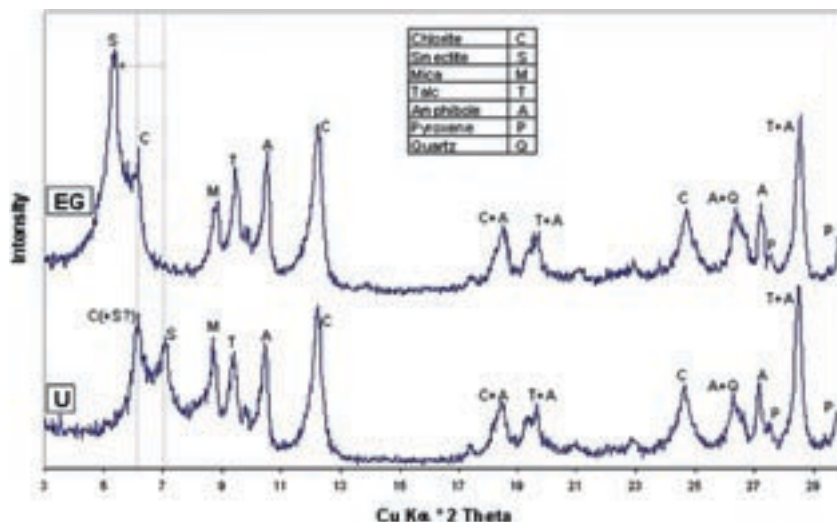


Figure 1—XRD scans of untreated (U) and treated Cullinan TKB (EG), displaying the peak shift that characterizes smectite (swelling clay)

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Figure 1 illustrates a peak shift after ethylene glycol treatment from 12.3 to 16.5 Å (with 2θ changing from 7.2 to 5.3°), indicating the presence of smectite (see Table IV). The peak at 12.3 Å (untreated sample) indicates that the smectite has one mono layer of H₂O. The XRD scans of orientated preparations up to 30° 2θ serve the purpose to show more detail of the X-ray reflections obtained on treated material at lower angles, especially displaying the 001 peaks. The untreated material was, however, scanned up to 80° 2θ . The position of the 060 reflection of smectite gives some information about whether dioctahedral or trioctahedral smectites are present. Dioctahedral smectites have reflections at 1.490–1.515 Å compared to trioctahedral smectites with reflections at 1.515–1.55 Å. In the case of Cullinan TKB the 060 smectite reflection is at 1.52 Å, indicating a trioctahedral smectite.

Chlorite was positively identified on the basis of the 14.1 Å ($2\theta=6.3^\circ$) and 7.2 Å ($2\theta=12.3^\circ$) peaks (Figure 2), but in order to establish the chlorite species chemical data are

required. The peak at 14.1 Å is positioned within the larger broad-based smectite peak. During the four-hour heat treatment, the 14.1 Å peak increased in size whereas the other peaks collapsed (shown in Figure 2). Table IV summarizes the observed changes in diffraction characteristics of clay minerals. Note that the smectite peak at 12.3 Å ($2\theta = 7.2^\circ$) collapsed after heat treatment.

During the experimental work it also became evident that the time allowed for the heat treatment is significant, as shown in Figure 2. With the two-hour heat treatment the chlorite peak at 14.1 Å increased in relative intensity while all the other chlorite peaks diminished to approximately half of their original size. With the four-hour heat treatment the 14.1 Å peak increased further in size while the other chlorite peaks disappeared, as expected. In addition to the peak changes of chlorite and smectite, the mica and talc peaks appeared to be also affected by the heat treatment. This can possibly be explained by an increase in crystallinity of these two mineral species after heating.

Table II

Minerals in the Cullinan TKB sample, identified by XRD in the 3–30° 2θ range

Mineral name (mineral group name and probable identity)	Formula	d-spacing values (Å) of most prominent peaks	2θ (°) values of most prominent peaks	Symbol used
Chlorite (clinochlore)	Mg ₅ Al(Si ₃ Al)O ₁₀ (OH) ₈	14.1, 7.2, 4.8, 3.6	6.3, 12.3, 18.5, 24.7	C
Smectite	(NaCaK)(MgAl ₂ Si ₄ O ₁₀)(OH) ₂ ·nH ₂ O	14.1, 12.3	6.3, 7.2	S
Mica (phlogopite ?)	KMg ₃ Al Si ₃ O ₁₀ (OH) ₂	10.1	8.8	M
Talc	Mg ₃ Si ₄ O ₁₀ (OH) ₂	9.3	9.5	T
Amphibole (tremolite)	Ca ₂ Mg ₅ Si ₈ O ₂₂ (OH) ₂	8.4, 3.2	10.5, 27.9	A
Pyroxene (diopside)	Ca(Mg,Al)(Si,Al) ₂ O ₆	3.0	29.8	P
Quartz	SiO ₂	3.3	27.0	Q

Table III

Information from literature for the Cullinan TKB sample in the 3–30° 2θ range

Mineral name (mineral group name and probable identity)	Formula	d-spacing values (Å) of most prominent peaks	2θ (°) values of most prominent peaks	Symbol used
Chlorite (clinochlore)	Mg ₅ Al(Si ₃ Al)O ₁₀ (OH) ₈	14.1, 7.1, 4.6, 3.6	6.3, 12.5, 19.3, 24.7	C
Smectite	(NaCaK)(MgAl ₂ Si ₄ O ₁₀)(OH) ₂ ·nH ₂ O	13–18	6.8–4.9	S
Mica (phlogopite ?)	KMg ₃ Al Si ₃ O ₁₀ (OH) ₂	10.1	8.8	M
Talc	Mg ₃ Si ₄ O ₁₀ (OH) ₂	9.3	9.5	T
Amphibole (tremolite)	Ca ₂ Mg ₅ Si ₈ O ₂₂ (OH) ₂	8.4, 3.2	10.5, 27.9	A
Pyroxene (diopside)	Ca(Mg,Al)(Si,Al) ₂ O ₆	3.0	29.8	P
Quartz	SiO ₂	3.3	27.0	Q

Table IV

Changes recorded in diffraction characteristics of untreated and treated clay minerals

Clay mineral	Peak position at specific d-value (Å) and effect of treatment			
	Untreated	Ethylene glycol	2h heat treatment	4h heat treatment
Chlorite (clinochlore)	14.1, 7.2, 4.86, 3.6	14.1, 7.2, 4.8, 3.6	14.1 increase in RPH* 7.2, 4.8 and 3.6 decrease in RPH*	14.1 increase further in RPH* 4.8 and 3.6 collapse
Smectite	14.1, 12.3	~16.5		~10 Å

*RPH–Relative peak height

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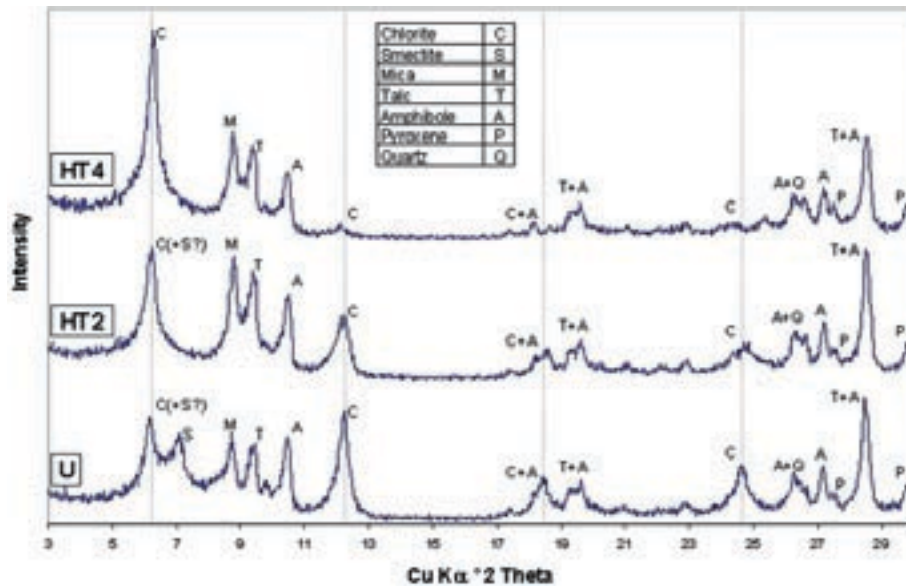


Figure 2—XRD scans of Cullinan TKB for untreated (U), two-hour (HT2), and four-hour heat-treated (HT4) conditions, displaying the effect on chlorite peaks

Table V
Basal spacings for smectite minerals

Condition/treatment	Individual d-spacing values measured experimentally or referred to in literature				
Air dried—experimental			14.2		12.3
Air dried—reference*					
Ethylene glycol treated—experimental	16.5				
Ethylene glycol treated—reference	17				
d-spacing scale	←17	←16	←15	←14	←13

* Depending on the type of smectite, the d-value can fall anywhere within this range

A summary of the experimental (measured at maximum peak height) as well as reference d-spacings obtained for smectite and chlorite with treatments are presented in Tables V and VI. The d-spacing scale is only schematic and not proportional to the true scale.

Clay minerals generally give intrinsically broad lines (peaks) because of small scattering domains, structural disorder, mixed layering, or some combination of these factors. Smectite minerals occur only in extremely small particles so that detailed diffraction data are difficult to

obtain. The d-values as presented in the Tables V and VI were given at maximum peak value to be compared with data from literature. A more definitive chemical composition of the minerals in the Cullinan TKB could be very informative to make a more precise mineral identification. Electron microprobe determinations on these clay minerals will be very useful but it could also be difficult to locate a suitable specimen for analysis due to the small size of clay minerals in general.

The estimated quantities of minerals in the Cullinan kimberlite are given in Table VII. All the minerals identified in the Cullinan kimberlite are presented, but not all of them appear on the XRD-scans presented in Figures 1 and 2, as these scans display only the 3–30° 2θ range.

To ensure control on the quality of the work, XRD analysis was repeated at three different institutions. Two of the three institutions compared well even in the estimation of abundance of minerals. Furthermore, the results of one institution reported around 50% quartz. The reader is cautioned against just accepting XRD results as correct without critically reviewing the validity. Critical evaluation by an experienced diffractionist can eliminate possible errors and prevent erroneous conclusions. Sampling is also critical as the sample of waste rock or large xenolith inclusions can result in an unrepresentative sample and incorrect mineralogical information.

Table VI
Basal spacings for chlorite minerals

Condition/treatment	Individual d-spacing values measured experimentally or referred to in literature											
Air dried—experimental	14.1							7.2			4.78	3.60
Air dried—reference	14.1							7.1			4.75	3.56
Ethylene Glycol treated—experimental	14.1							7.2			4.80	3.60
Heat-treated—reference	14.1							—			—	—
d-spacing scale	←15	←14	←13	←12	←11	←10	←9	←8	←7	←6	←5	←4

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Venetia red kimberlite

This kimberlite also contains a considerable clay mineral component, but on the other hand is a very different type of TKB when compared with Cullinan TKB. The same method of analysis was applied to this kimberlite for comparative purposes. The mineral species identified in this untreated red kimberlite sample and the associated d-spacings are presented in Table VIII. The ethylene glycol and temperature treated scans are compared with the untreated scan in Figures 3 and 4 respectively. A quantitative estimate of the mineral content of this kimberlite is given in Table IX.

With the Venetia red kimberlite a peak shift occurred from 14.1 Å ($2\theta=6.3^\circ$) to 17 Å ($2\theta=5.2^\circ$) after treatment with ethylene glycol (Figure 3) indicating the presence of a smectite (see Table IV). In contrast to the Cullinan TKB, this kimberlite contains smectite in predominant quantities. Noticeable for the Venetia TKB is the prevalence of a two water interlayer (14.3 Å) over a monolayer of water (12.3 Å) in the interlayer space of smectite. Very little chlorite is present, its peak at 14.1 Å ($2\theta=6.3^\circ$) after the ethylene glycol treatment appears to be covered by the large smectite first order basal peak. The 060 smectite reflection is at 1.49–1.50 indicating a dioctahedral smectite.

The small quantity of chlorite in this kimberlite reflects in the peak size at 14.1 Å. The collapsed peak at 12.3 Å ($2\theta=7.2^\circ$) after the two-hour heat treatment is shown in Figure 4. The four-hour heat treatment displayed a similar (001) reflection to the two-hour heat treatment.

Comparing the Venetia and Cullinan tuffisitic kimberlite breccias

When the two tuffisitic kimberlites are compared there are a few similarities but also major differences. In general the Cullinan TKB sample can be described as a far more complex kimberlite in terms of its mineral assemblage than the Venetia red TKB.

The major aim of the investigation was to identify the clay minerals that occur in the two kimberlites. Cullinan TKB contains a smectitic clay component as well as a significant chlorite component. Serpentine, mica and amphibole are some of the other mineral group components identified. On the other hand, the Venetia TKB contains mainly a smectitic clay with a small chloritic component, in combination with significant amounts of quartz and smaller quantities of calcite, feldspar and amphibole.

In a geological/mineralogical description of the Premier (Cullinan) kimberlites, Bartlett⁸ mentions that Cullinan grey TKB (Type I) groundmass (most of it presumably serpentine), has been considerably altered to clay. The brown kimberlite (Type 2) smectite was identified by Bartlett⁸ as predominantly saponite, the Mg-rich member of the smectite group. The technique used to classify the type of smectite is unknown. The kimberlite described in this work is part of the type I (grey) kimberlite as discussed by Bartlett. Bartlett describes this as a typical TKB containing abundant xenolithic inclusions of mostly country rock. The 060 reflections indicate trioctahedral smectite in the Cullinan kimberlite and dioctahedral smectite in the Venetia kimberlite. Saponite would give a 060 reflection of 1.537 and therefore the trioctahedral smectite in Cullinan is most likely not saponite. It is suggested that the Cullinan smectite is rather an interstratification of a di- and trioctahedral smectite, as this peak lies very close to the transition values. The Venetia red smectite could possibly be montmorillonite but microprobe work would be required to confirm the suggestion.

The Venetia red kimberlite was classified by different investigators as a typical Southern African TKB³. Apart from the red colour the general appearance of this kimberlite in hand specimen is typically kimberlitic. It is important to add some further observations as mentioned by Kurszlauskis³ about the origin of this unusual kimberlite sampled from the K1 pipe in the Venetia cluster.

Table VII

XRD results for Cullinan TKB, with estimated abundance

Mineral group name	Probable mineral	Estimated quantity
Chlorite	Chlinochlore	> 20
Smectite	Trioctahedral subgroup	10–20
Mica	Phlogopite	5–10
Talc	Talc	10–20
Amphibole	Tremolite	10–15
Kaolinite-Serpentine	Antigorite	10–15
Olivine	Forsterite	< 10
Pyroxene	Diopside	~ 5
Quartz	Quartz	< 5
Calcite	Dolomite	< 5
Spinel	Magnetite	< 10

Table VIII

Minerals identified in the in the Venetia red kimberlite, identified in the range 3–30° 2θ

Mineral name (mineral group name and probable identity)	Formula	d-spacing values (Å) of most prominent peaks	2θ (°) values of most prominent peaks	Symbol used
Smectite	(NaCaK)(MgAl ₂ Si ₄ O ₁₀)(OH) ₂ ·nH ₂ O	14.1	6.3	S
Quartz	SiO ₂	3.3	26.6	Q
Mica (phlogopite?)	KMg ₃ AlSi ₃ O ₁₀ (OH) ₂	10.1	8.8	M
Feldspar	CaAl ₂ Si ₂ O ₈	3.2	27.9	F
Amphibole (tremolite)	Ca ₂ Mg ₅ Si ₈ O ₂₂ (OH) ₂	8.4, 3.2	10.5, 27.9	A
Chlorite (clinochlore?)	Mg ₅ Al(Si ₃ Al)O ₁₀ (OH) ₈	14.3, 7.2, 4.7, 3.6	6.2, 12.3, 18.7, 24.7	C
Calcite	CaCO ₃	3.0	29.4	Ca

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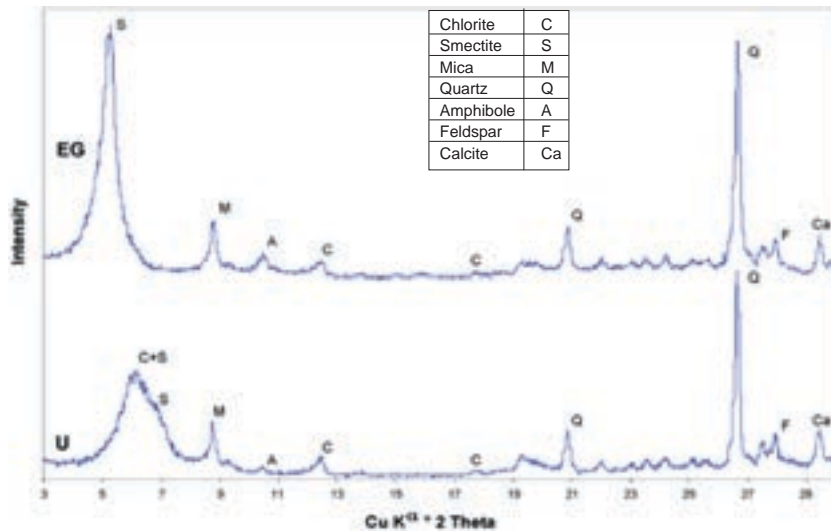


Figure 3—XRD scans on Venetia red kimberlite for the untreated (U) and ethylene glycol (EG) material, displaying the peak shift that characterizes smectites

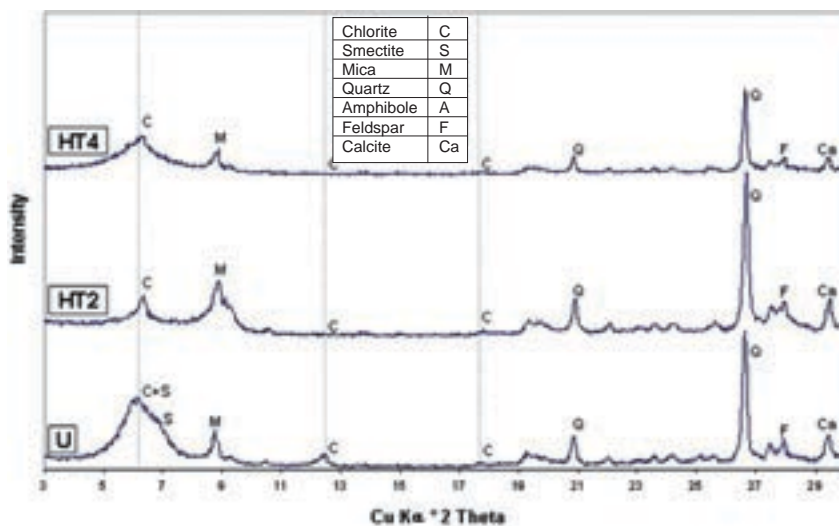


Figure 4—XRD scans of Venetia red kimberlite for the untreated (U), two-hour (HT2) and four-hour (HT4) heat-treated conditions, displaying the effect on chlorite peaks

Table IX
Estimated quantitative XRD results for Venetia red kimberlite

Mineral group name	Probable mineral	Estimated quantity
Smectite	Dioctahedral subgroup	~ 40
Quartz	Quartz	~ 25
Calcite	Calcite	~ 10
Feldspar	Albite	~ 10
Kaolinite-Serpentine	Lizardite	< 10
Mica	Phlogopite	~ 5
Spinel	Magnetite	< 5
Amphibole	Tremolite	< 5
Chlorite	Clinochlore	< 5

Certain observations were made about the volcanological and structural aspects of the different pipes exposed after mining. The mineralogy of the red kimberlite can most

probably be linked to its origin. He mentioned that the emplacement of K1 extended over time. The initial breccia was consolidated and cemented before renewed volcanic activity occurred, causing subsidence and re-brecciation of the material.

Another feature, which Kurszlauskis³ emphasizes, is bedding observed in open pits K1 and K2 at Venetia. Blocks of a red-brown colour are described that showed bedding. The red blocks are in contrast to the grey colour of the enclosing TKB. Bedding lamination as well as soft sedimentation deformation textures and even mud clasts are also referred to.

In drill cores sharp transitions are described from light olive to grey TKB to intensely red and brown coloured sections. This evidence indicates that crater blocks are thought to be not *in situ* but to have downrafted towards

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deeper levels of the pipe during ongoing volcanic eruptions, together with the hosting TKB. This material derived most probably from volcanoclastic material that originated from an intermediate period of relative low turbulence between eruptions where a more sedimentary regime prevailed.

Kurszlaukis³ also mentions that these isolated epiclastic blocks generally contain a high abundance of well-sorted, mostly angular to subrounded quartz grains. This is reflected in the diffractograms where prominent quartz peaks are present, which is unusual for a kimberlite (only if it can be linked to xenolithic material).

Although this was an investigation of mineralogical methods to characterize the clay components of the kimberlites, additional information obtained by chemical analysis (XRF) could be helpful in supporting certain mineralogical data. The chemistry of the two kimberlites are compared in Table X with the most prominent difference being the MgO and Al₂O₃ values.

The Cullinan sample is more Mg-rich than the Venetia. This could be attributed to a variety of Mg-containing minerals present; apart from smectite there are significant quantities of chlorite, talc, mica, amphibole and serpentine. Talc and serpentine could not be detected in the Venetia sample with certainty. Venetia contains higher Al₂O₃ values than Cullinan and that could possibly be linked to the high proportion of smectite and also the presence of feldspar that is different from the Cullinan sample. The presence of feldspar in Venetia red is possibly due to the presence of country rock and is confirmed by the presence of quartz, which is commonly associated with feldspar. The TiO₂ content of these kimberlites is also significantly different.

The identification of clay minerals in both kimberlites can not be narrowed down further by XRD. If required the qualitative composition of the clay fractions can be determined by electron beam methods with the subsequent better-defined classification of the clay minerals.

An investigation into the disintegration of kimberlites showed that the presence and abundance of smectite determines the degradation⁹. Therefore accurate determination of the presence and abundance of smectite is important in predicting the integrity/stability of kimberlite.

Characterization of more Venetia tuffisitic kimberlite breccias

More tuffisitic kimberlite breccia samples from Venetia were characterized to investigate the differences in mineralogy of

TKBs in the same region. The samples are named K1 East, K1 West, K2 North East, K2 South and K2 West. K1 and K2 refer to different kimberlite pipes of which the positioning and geological information are given in Kurszlaukis and Barnett³. K1 is the largest and central body with K2 the second largest kimberlite pipe. Most of K1 is described as two major units (eastern and western TKB) but hypabyssal intrusions occur³. Petrographic investigation by Kurszlaukis and Barnett consider differences in K1 East and K1 West to be minor. K2 is found west of K1 with the central part classified as TKB and hypabyssal kimberlite towards the southern and western regions. The western part of K2 breccias contains considerable proportions of country rock³.

The XRD results (5–80° 2θ) of these TKB samples are given in Figures 5–10. The estimated quantitative results from XRD are given in Table XII.

From an engineering point of view these kimberlites behaved very differently during weathering tests, indicating differences in mineralogical and chemical properties. Some of these results are reported by Morkel *et al.* The X-ray fluorescence data for these kimberlites are given in Table XI. Chemically the K1 samples are more Mg rich than the K2 samples except for K1 red that contain lower Mg. K2 generally contains more Ca than K1. The six TKB samples from Venetia show considerable differences, but also comparable mineralogical properties. Smectite is present in all the samples. The smectite content is the lowest for K2 West at ~ 30 %, the same for K1 East, K1 red and K2 South at ~ 40 %, ~ 45 % for K2 North East and ~ 50 % for K1 West. These differences seem small but alter the weathering properties considerably as shown by Morkel *et al.*⁹. The serpentine content is the highest in K1 East at 20–30 %, while K2 South show only trace quantities. The pyroxene content is very high in K2 West at ~ 30 % whilst absent in K2 South and K1 red. The magnetite content, on the other hand, is very high in K1 West at 10–20 % compared to less than 10% in all the other samples. The calcite is very high in K2 South at 30% whilst 10% and below in all the other samples. Quartz is present in only K2 South and very high in K1 red as discussed earlier. All the TKBs have no or very low dolomite content and very low chlorite values. Hypabyssal kimberlites, on the other hand, generally show considerably chlorite abundances. The chemical and mineralogical investigation shows that considerably differences exist between different TKB kimberlites from Venetia Mine.

Table X

Chemical XRF results for Cullinan and Venetia red kimberlites

Sample name	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃	MnO	SO ₂
	%	%	%	%	%	%	%	%	%	%	ppm
Cullinan TKB	0.80	29.1	4.08	52.6	0.12	1.19	5.15	1.29	9.47	0.15	368
Venetia red TKB	1.09	19.6	8.37	51.1	0.18	1.86	4.46	0.72	8.79	0.10	< 60

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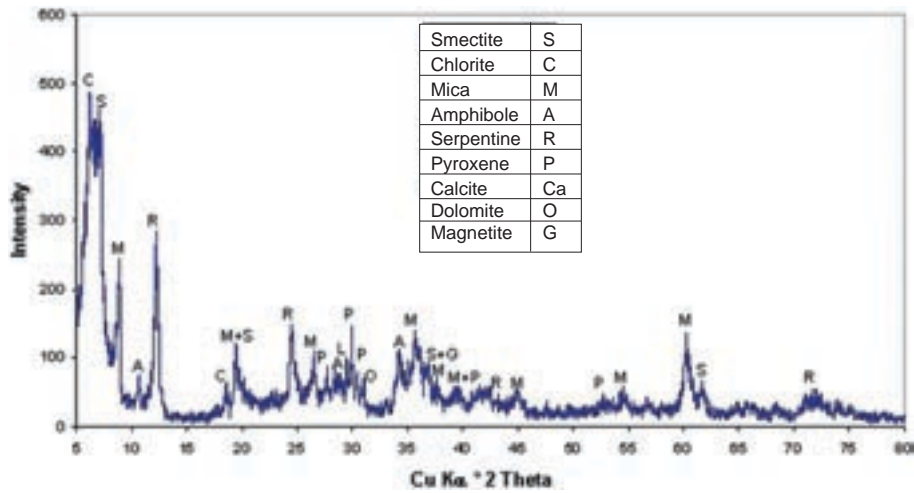


Figure 5—XRD scan of Venetia K1 East for the range 5–80° 2 Theta

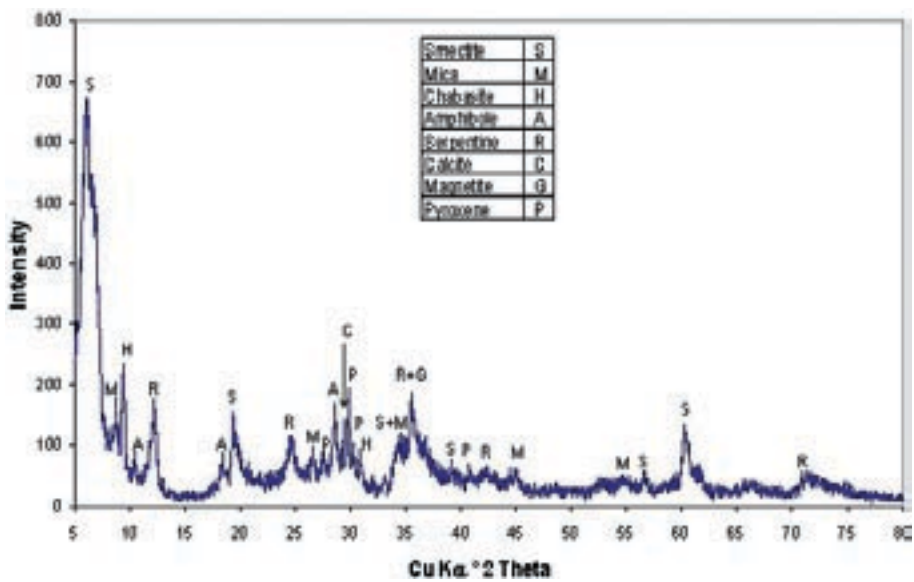


Figure 6—XRD scan of Venetia K1 West for the range 5–80° 2 Theta

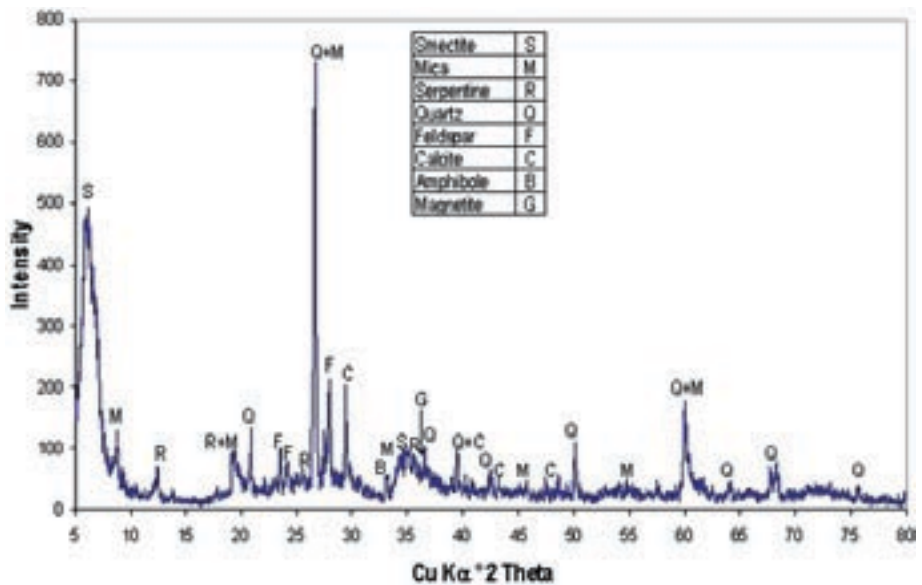


Figure 7—XRD scan of Venetia K1 Red for the range 5–80° 2 Theta

Characterization of clay mineral fractions in tuffisitic kimberlite breccias

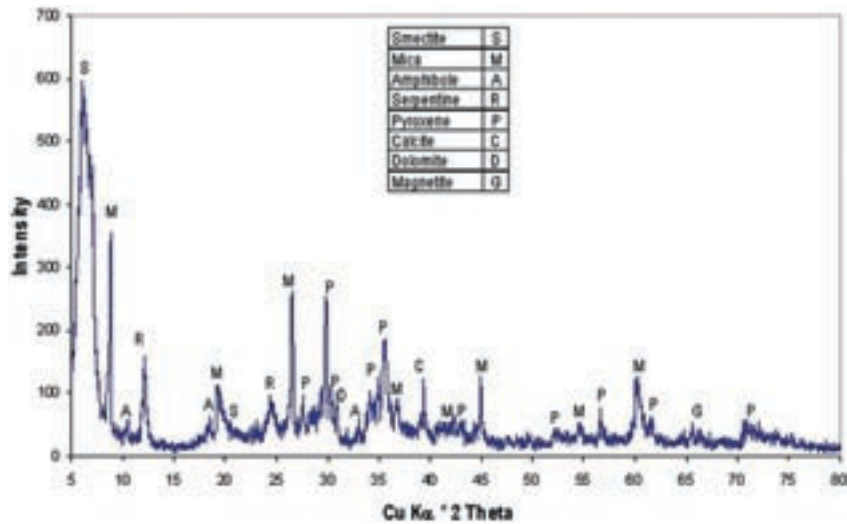


Figure 8—XRD scan of Venetia K2 North East for the range 5–80° 2 Theta

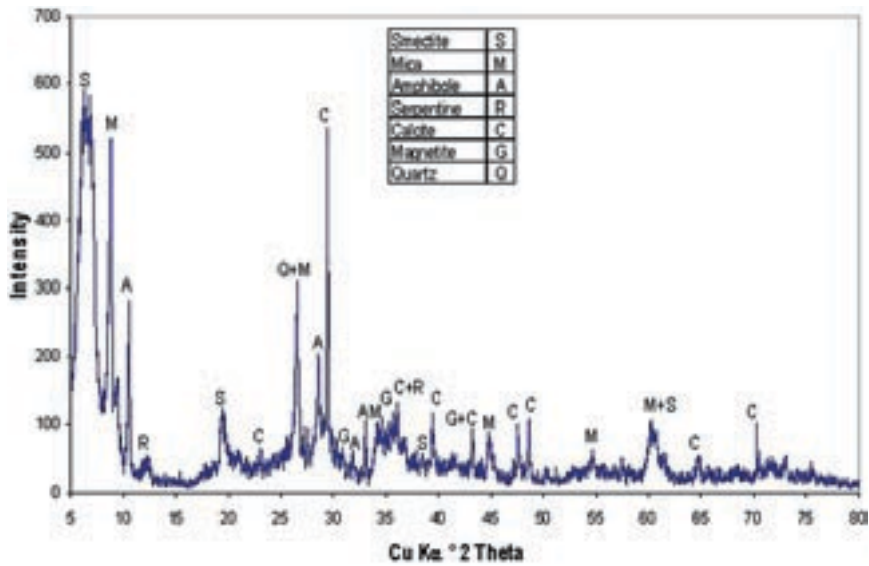


Figure 9—XRD scan of Venetia K2 South for the range 5–80° 2 Theta

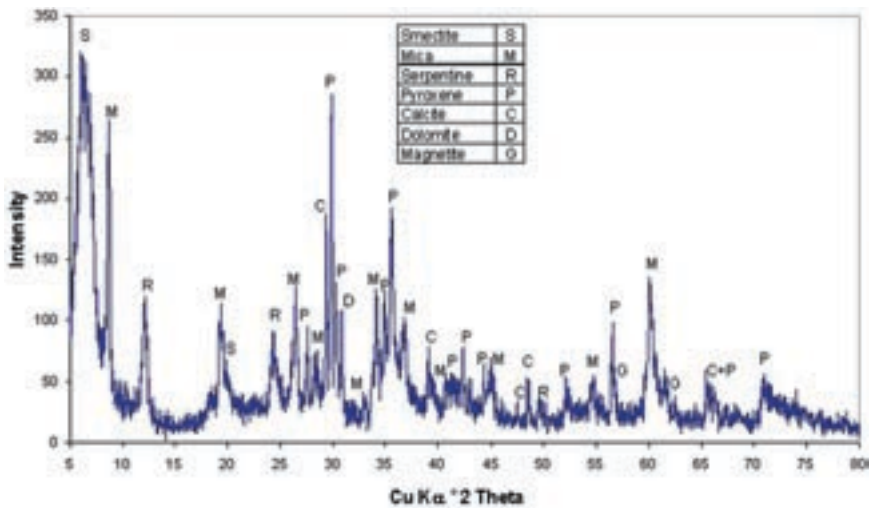


Figure 10—XRD scan of Venetia K2 West for the range 5–80° 2 Theta

Characterization of clay mineral fractions in tuffisitic kimberlite breccias

Table XI
Chemical XRF results for Venetia TKB kimberlites

Sample name	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃	MnO	SO ₂
	%	%	%	%	%	%	%	%	%	%	ppm
K1 East	0.82	29.0	5.26	47.8	0.15	1.58	3.90	0.50	9.44	0.12	0.1
K1 West	1.1	29.2	4.66	50.4	0.14	0.72	4.57	0.51	8.23	0.12	285
K1 Red	1.09	19.6	8.37	51.1	0.18	1.86	4.46	0.72	8.79	0.10	< 60
K2 North East	1.2	25.6	5.93	48.0	0.2	1.18	6.43	0.59	8.7	0.14	96
K2 South	0.6	21.7	5.78	46.5	0.28	1.69	9.88	0.76	8.68	0.19	509
K2 West	0.81	25.7	5.28	47.1	0.28	1.67	7.38	0.75	9.31	0.17	201

Table XII
Estimated quantitative XRD results for Venetia TKBs in mass %

Mineral	K1 East	K1 West	K1 Red	K2 North East	K2 South	K2 West
Amphibole	< 10	0	< 5	~ 5	10–20	0
Calcite	< 5	~ 5	~ 10	< 5	~ 30	~ 10
Chabasite	0	~ 5	0	0	0	0
Chlorite	< 5	0	0	0	0	0
Dolomite	~ 5	0	0	< 5	0	~ 5
Feldspar	0	0	~ 10	0	0	0
Magnetite	< 5	10–20	< 5	< 10	trace	< 10
Mica	10–20	10–20	~ 5	20–30	~ 20	~ 25
Pyroxene	< 10	~ 5	0	~ 10–20	0	< 30
Quartz	0	0	~ 25	0	~ 10	0
Smectite	~ 40	~ 50	~ 40	~ 45	~ 40	~ 30
Serpentine	20–30	< 10	< 10	~ 10	trace	~ 10

Conclusions

During research on mainly the weathering of kimberlite, it became evident that kimberlite mineralogy, especially the clay fractions is a very important but complex subject. Treatments of kimberlite with ethylene glycol and heat treatment as utilized in clay mineralogy and related scientific fields are shown to be very relevant and, in fact, a prerequisite when characterizing kimberlitic material. The importance of proper mineralogical work is emphasized to avoid substantial errors in the characterization of kimberlites.

During this investigation it was confirmed that substantial quantities of smectites are present in TKB samples that originate from both Cullinan and Venetia diamond mines. However, a much larger component of chlorite is present in the Cullinan TKB than in the Venetia sample. This fact could be established only with certainty after additional treatments of the two clays—this aspect was masked by peak overlap in untreated XRD scans.

The presence and abundance of smectite determines the degradation behaviour of kimberlite and therefore is an important subject in understanding kimberlite properties.

Further characterization of smectites and chlorites can be done by electron beam methods to verify their specific chemistry.

Comparison of different TKB samples from Venetia show considerably variation in mineralogical and chemical properties of these samples.

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