Lithogeochemical and Petrographic Features of some Archean Volcanic Rocks from the Kam-kotia Mine and Carsallen Township, Timmins Region, Ontario

for:
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Introduction

This report presents and interprets lithogeochemical and petrographic data for a small suite (6) of surface felsic and mafic rocks from the past-producing Kam-Kotia volcanogenic massive sulfide deposit. The objectives were to determine both the primary chemical composition of several lithological units immediately flanking the open pit, and the nature of alteration in these rocks. General views of the Kam-Kotia pit are shown in Fig. 1, and detailed views of an altered rhyolite and a stockwork pillow basalt in Fig. 2. In addition to the Kam-Kotia samples, two surface felsic rocks from the western part of Carscallen township were studied for comparison with regional rhyolite data.

Lithogeochemistry

General. The lithogeochemical data, including rare-earth element analyses, are given in Table 1, together with various elemental ratios (the analytical data were provided by XRAL in Toronto). Major and trace elements were analyzed by X-ray fluorescence, and rare-earth elements by neutron activation. The anhydrous sum is also listed because the data plotted in Figures 3 to 5 have been recalculated on an LOI-free basis.

Immobile element plots (Figures 3a and 3b) indicate that the rocks immediately surrounding the Kam-Kotia deposit include ferrobasalts (= Fe-rich tholeiites), icelandites, and two rhyolite types. The incompatible Zr-Y pair of elements (Fig. 4a) indicates that these rocks are of tholeiitic to transitional magmatic affinity. A plot of P_2O_5 versus TiO_2 (Fig. 4b) indicates that the mafic rocks can be divided into Fe-rich basalts and icelandites.

Kam-Kotia Rhyolites

One of the rhyolite types is a flow-banded rhyolite located next to the discovery outcrop of massive sulfide on the southeast side of the open pit. This rhyolite has normal TiO_2 and Al_2O_3 contents, high Zr (434 ppm) and Y (89 ppm), and a Zr/Y ratio of 4.9. Although it is somewhat altered in terms of alkali exchange and increased Fe-Mg contents, it shows no net mass change as indicated by its normal TiO_2 and Al_2O_3 contents (Fig. 3a). By contrast, the other sample, a perlitically cracked, chlorite-altered glassy rhyolite (Fig. 2a) from the 'island' that outcrops through the floor of the pit near its southern margin, has a higher TiO_2 content (0.39%). The original TiO_2 content would have been somewhat higher yet, as net mass gain of mobile elements has occurred, as shown by the sample's displacement towards the origin in the TiO_2 versus Al_2O_3 plot (Fig. 3a).

Fig. 1a

Fig 1b

Fig. 2a

Fig 2b

Kamiskotia and Carscallen volcanics

Fig. 3a

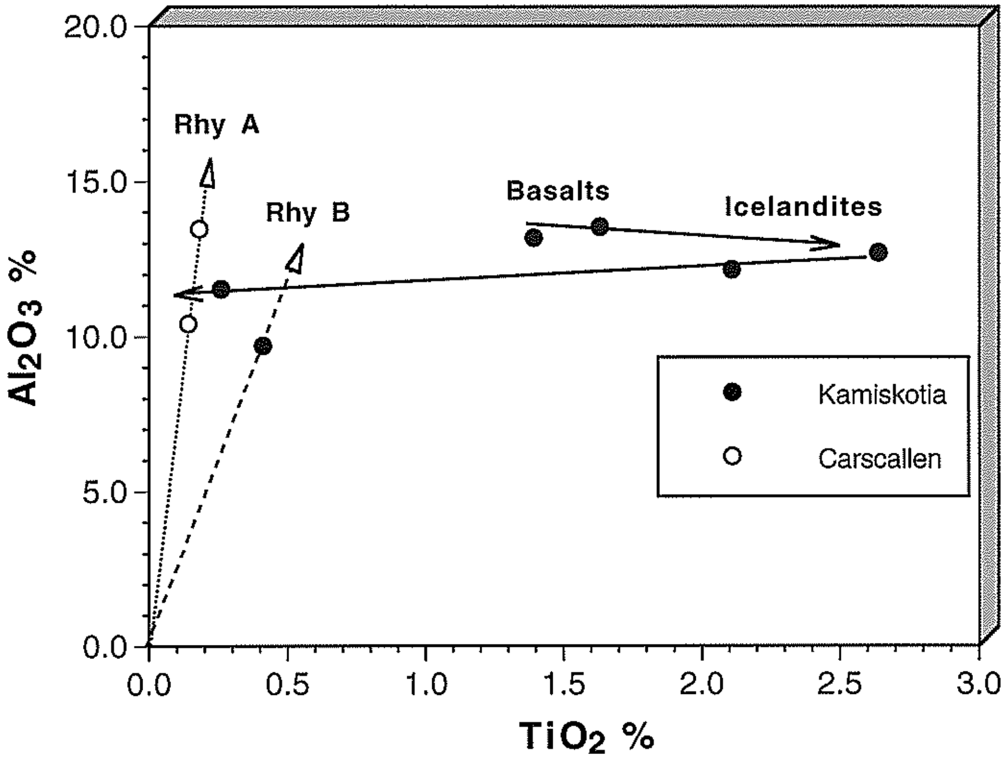
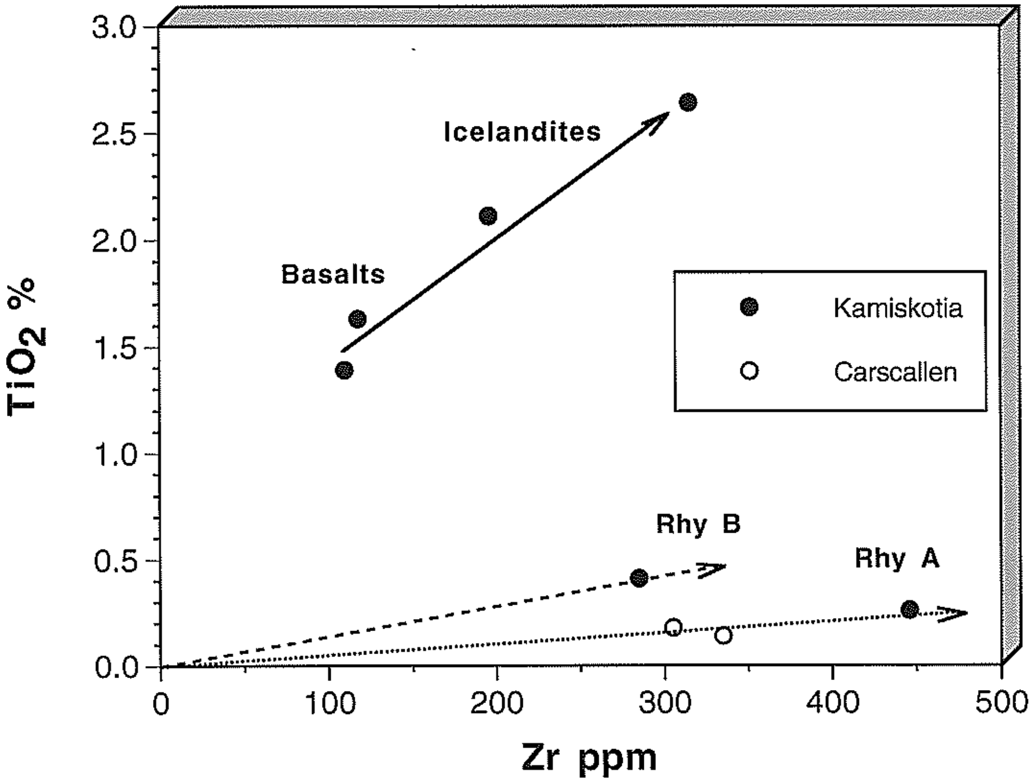


Fig. 3b



Kamiskotia and Carscallen volcanics

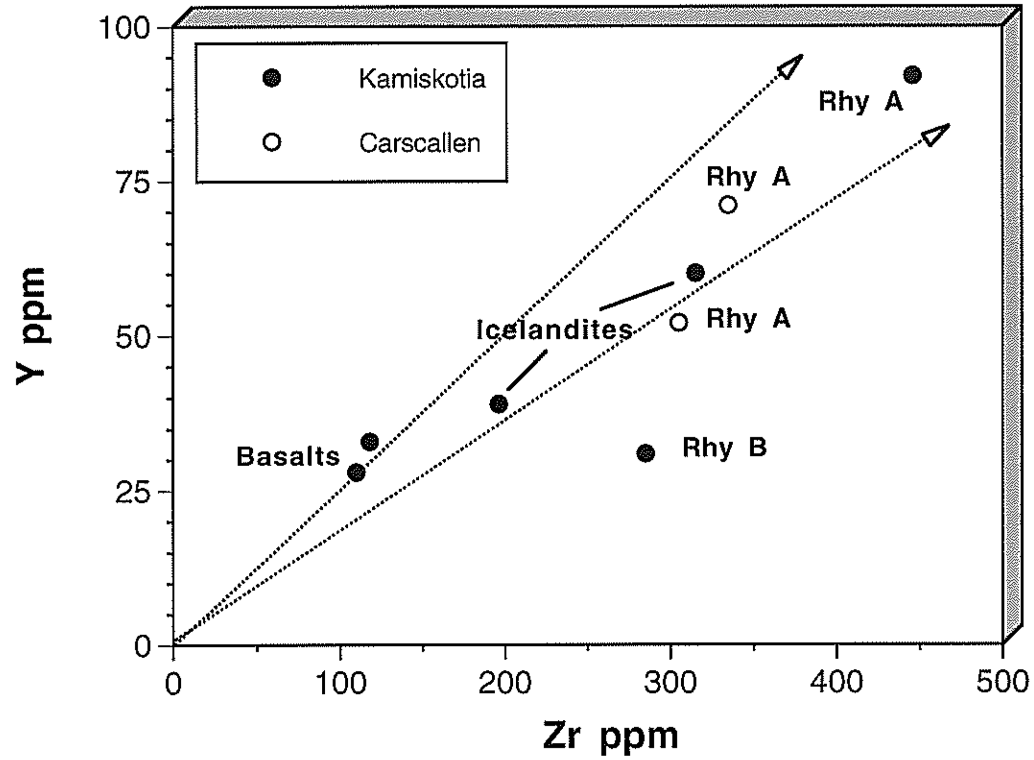


Fig. 4a

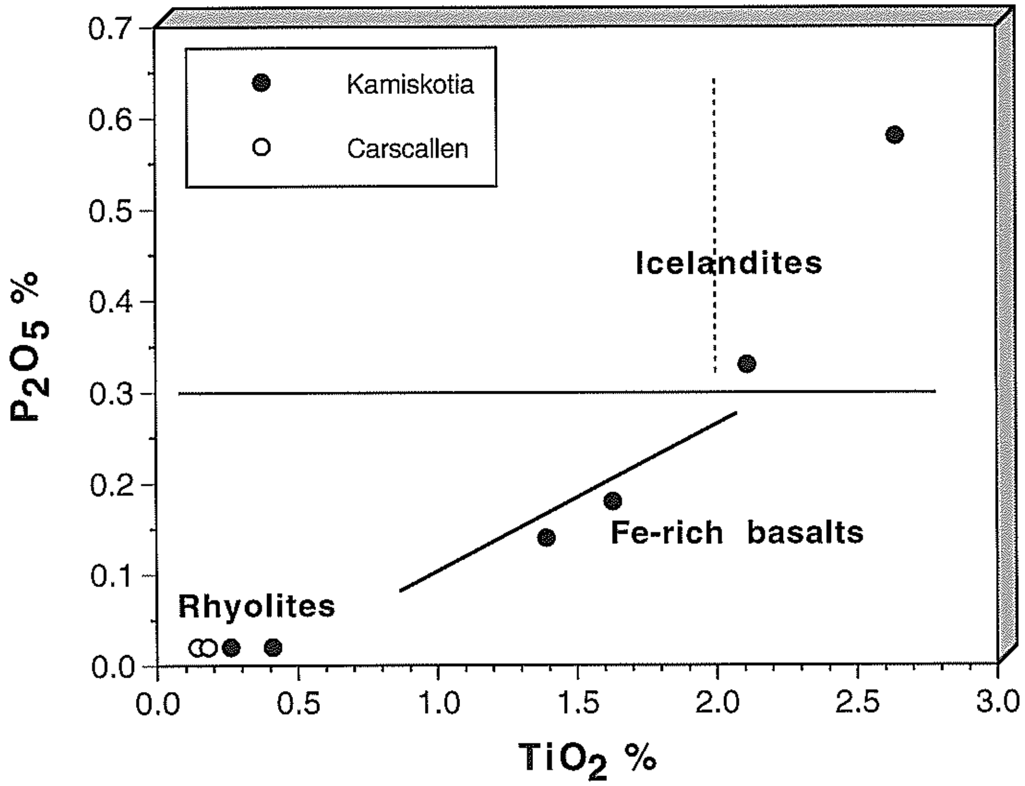


Fig. 4b

Relative to the flow-banded rhyolite, this perlitic rhyolite also has a notably higher Zr/Y of 9.3, as well as a distinctly different REE pattern (see later). Hence, it was clearly a compositionally different rhyolite prior to alteration. We term these two rhyolite types A and B; the flow-banded rhyolite is the more chemically evolved (A) and has a weakly tholeiitic magmatic affinity, whereas the perlitic rhyolite is less evolved (B) and in addition has a clearly calc-alkaline affinity. The fact that the perlitic rhyolite is very hydrothermally altered suggests that it is a syn-mineralization flow and not a later dyke. The existence of these two rhyolite types is of considerable interest; it would be worthwhile to further document their distribution.

Carscallen Rhyolites

The two Carscallen rhyolites are fractionated rhyolite A (Figures 3a and 3b), with estimated precursor Al_2O_3 and TiO_2 content of 12% and 0.15%, respectively. The rhyolites are of transitional affinity according to Zr/Y ratios (Fig. 4a). One rhyolite shows notable sericitization with moderate net mass loss as inferred from the Al_2O_3-TiO_2 plot, the other silicification with some mass gain.

Kam-Kotia Mafic Rocks

The mafic rocks around the pit fall into two distinct chemical and textural groups. One consists of altered, Fe-rich tholeiitic basalts. These are represented by pillow lava (#30213) in the immediate footwall on the south side of the open pit, and by massive vesicular lava (#30212) on the same side of the pit, but lying northwest of the pillow lava. These basalts have moderate contents of TiO_2 ($\approx$1.4 %) and Zr ($\approx$100 ppm). Their very high FeO contents ($\approx$20 %) probably reflect, in part, a primary iron-rich magma, but additionally also result from significant chlorite alteration and some addition of iron sulfide. That strong chloritic alteration has occurred is indicated by extreme depletion in all of the alkalis, i.e. Na_2O, CaO and K_2O. During this process, particularly in the upper parts of VMS feeder pipes, FeO + MgO can be added to the rocks from the same hydrothermal fluids that are leaching the alkalis.

In contrast, the second group of mafic rocks, here referred to as icelandite (this term is discussed in a later section), is almost chemically unaltered, with high contents of CaO (7.4 %) and Na_2O (1.5 %), consistent with the retention of the initial calcic plagioclase component of the rock.

The icelandites have notably higher contents of TiO_2 (1.9-2.5 %) and Zr (≈180-300 ppm) relative to the Fe-rich basalts (Fig. 3b); they also have elevated contents of P_2O_5 (0.30-0.55 %) (Fig. 3b). The icelandites therefore probably represent an evolved equivalent of the Fe-rich basalts, resulting from fractionation of a basaltic magma under low oxygen fugacity, which leads to the simultaneous enrichment in Ti-P-Zr and Fe (although Fe enrichment in this case cannot be demonstrated directly due to the alteration of the sampled basalts). Such tholeiitic Fe-enrichment magmatic trends are typical of rift-related (as opposed to subduction-related) environments, and have been documented from numerous large differentiated mafic intrusions and their volcanic equivalents.

The Zr/Y and Zr/Nb ratios for the Fe-rich basalts are slightly different from those of the icelandites, which could imply some mixing of contrasting types of mafic magma. Zr/Y ratios for the Fe-rich basalts are in the tholeiitic range (≈3.8), whereas those in the icelandites are of transitional affinity (≈5.2). This may indicate a small component of felsic composition in the melt. However, this is considered unlikely based on the similarity of REE patterns in the two mafic groups (discussed below). At present, it seems more likely that the two mafic groups are related primarily by fractionation.

Rare-Earth Elements

In chondite-normalized plots, the two Kam-Kotia rhyolites discussed above show contrasting REE patterns (Fig. 5a). The flow-banded rhyolite pattern parallels that of Kamiskotia rhyolite as previously reported by Lesher et al. (1986), and appears to be an FIIIb rhyolite. [The strongly negative Eu anlomaly reported by Lesher et al. (1986) is not present in the flow-banded rhyolite, probably because the latter is less altered.] In contrast, the perlitic rhyolite has a sloping pattern due to depletion in the heavy REE that is typical of FII-FI rhyolites. These inferences are supported by the Zr/Y ratios for the flow-banded and perlitic rhyolite, which are 4.9 and 9.3, respectively. It is unlikely that the stronger hydrothermal alteration in the perlitic rhyolite could have produced the large differences observed in both REE pattern and Zr/Y ratio, and at the same time also produced a more calc-alkaline affinity as inferred from each discriminant.

The Fe-rich basalts have near-flat REE patterns (Fig. 5b) that are identical to those of normal unaltered Kamiskotia basalt as reported by Barrie et al. (1991). The flat patterns of the Fe-rich basalts indicate a tholeiitic MORB-like affinity. As these basalts are also chloritized, their flat REE patterns support the above supposition that chloritization, as in the case of the perlitic rhyolite, does not cause steeper REE patterns.

Kamiskotia mine rocks

Fig. 5a

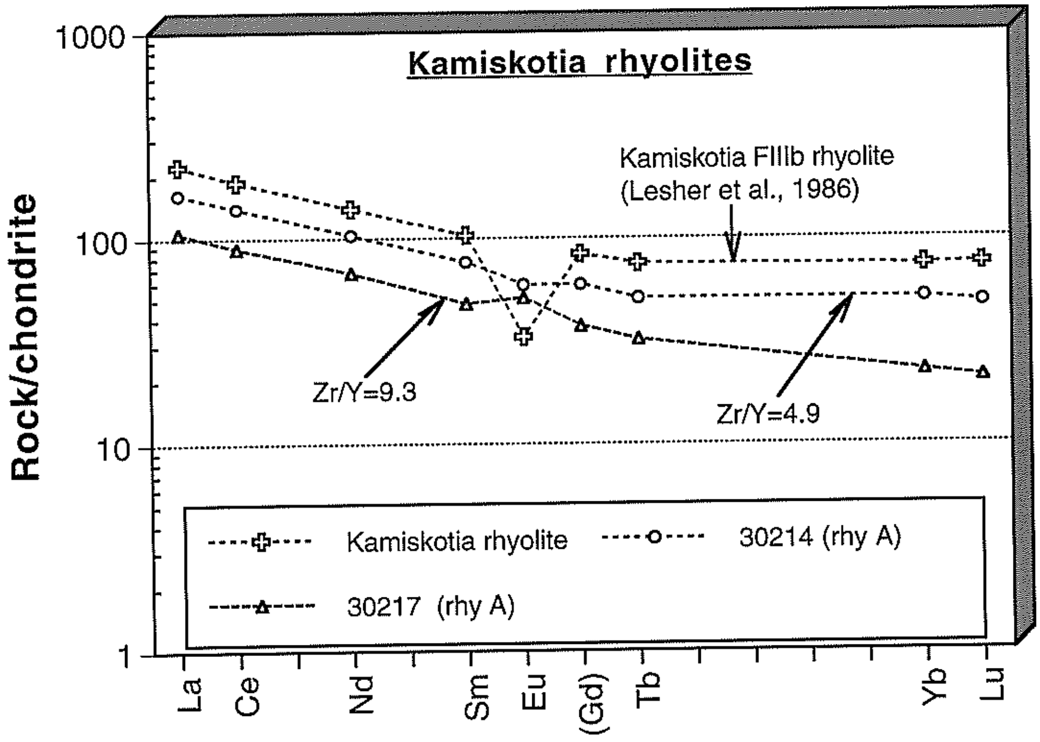
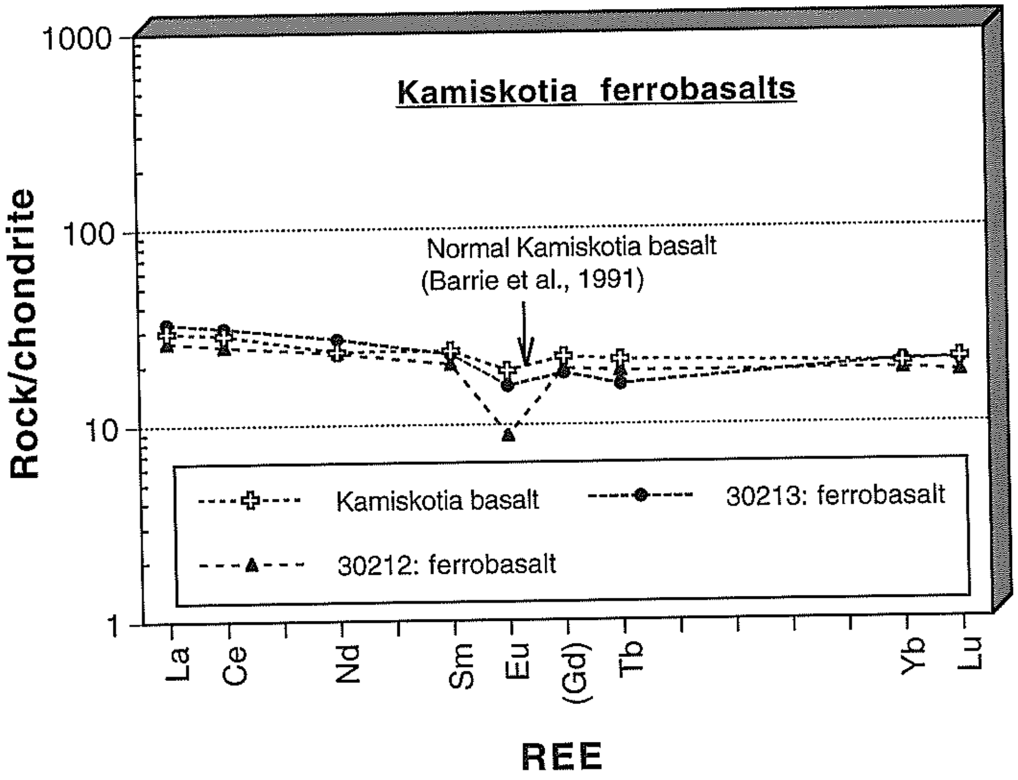


Fig. 5b



The Kamiskotia icelandites (Fig. 6a) have near-flat REE patterns but elevated REE contents relative to the Fe-rich basalts. This is consistent with their higher content of other incompatible trace elements (Zr, Y, Nb) relative to the basalts. Most likely, fractionation of Fe-rich basalt produced an increase in the concentration of the REE, but without a change in the relative proportion of light to heavy REE. The icelandite patterns are identical or similar to that of evolved Kamiskotia basalt as reported by Barrie et al. (1991).

As shown in Fig. 6b, the two Carskallen rhyolites have REE patterns and Zr/Y ratios typical of FIIa rhyolite (#30228) and FII rhyolite (#30227). However, these rhyolites represent only a small area of outcrop.

Alteration

Plots of K_2O-TiO_2 and FeO-TiO_2 (Figs. 7a, 7b) can be used to obtain a first-pass idea of alteration, although this is qualitative at best, as mass changes in other elements during alteration are not taken into account. For this brief report, it is sufficient to note that K addition in the three rhyolites is moderate to substantial, whereas the mafic rocks are essentially unaltered. Similarly, two rhyolites are significantly enriched in Fe (especially the perlitic rhyolite).

Additions of Fe in mafic rocks cannot be assessed readily using this plot because the precursor Fe-Ti values for the Fe-rich basalts have not been established. However, as noted earlier, the latter rocks are very depleted in all alkali elements; they are also enriched in Mg relative to unaltered equivalents elsewhere in the Timmins region. By contrast, Kamiskotia icelandites are essentially chemically unaltered, and therefore must represent eruptions or shallow level intrusions that were emplaced following hydrothermal activity.

Of the Carscallen rhyolites, one (#30227) shows significant sericitization and Na depletion, whereas the other (#30228) displays silicification with lesser sericitization. These chemical features reflects the petrographic observations outlined in a later section.

Fig. 6a

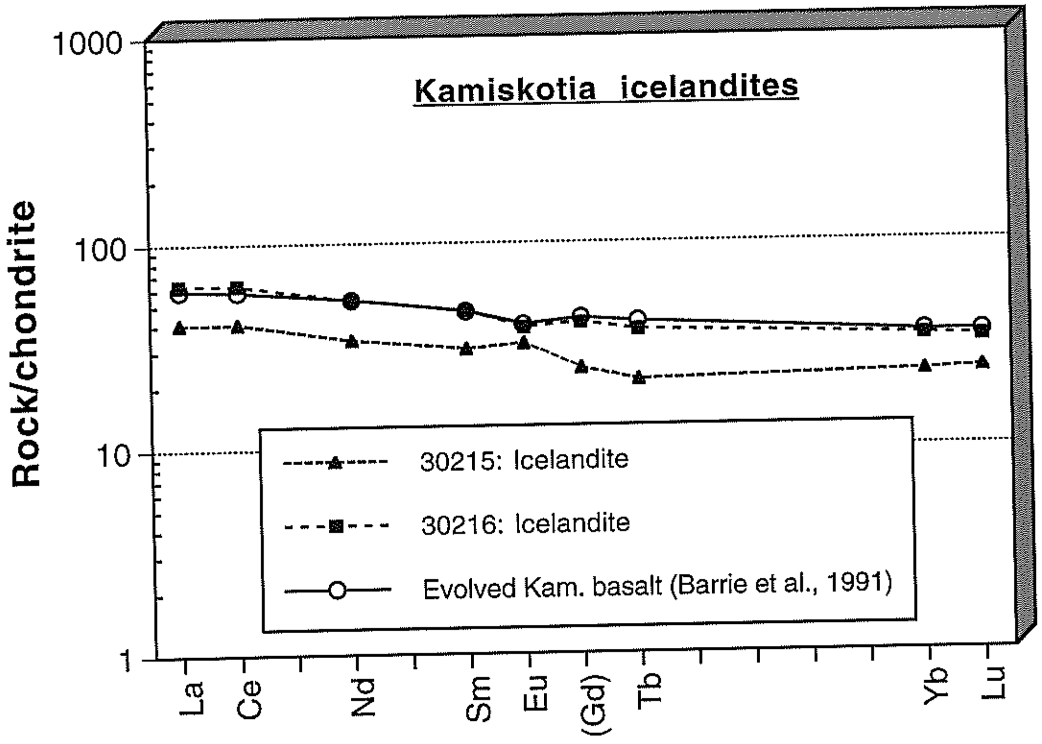
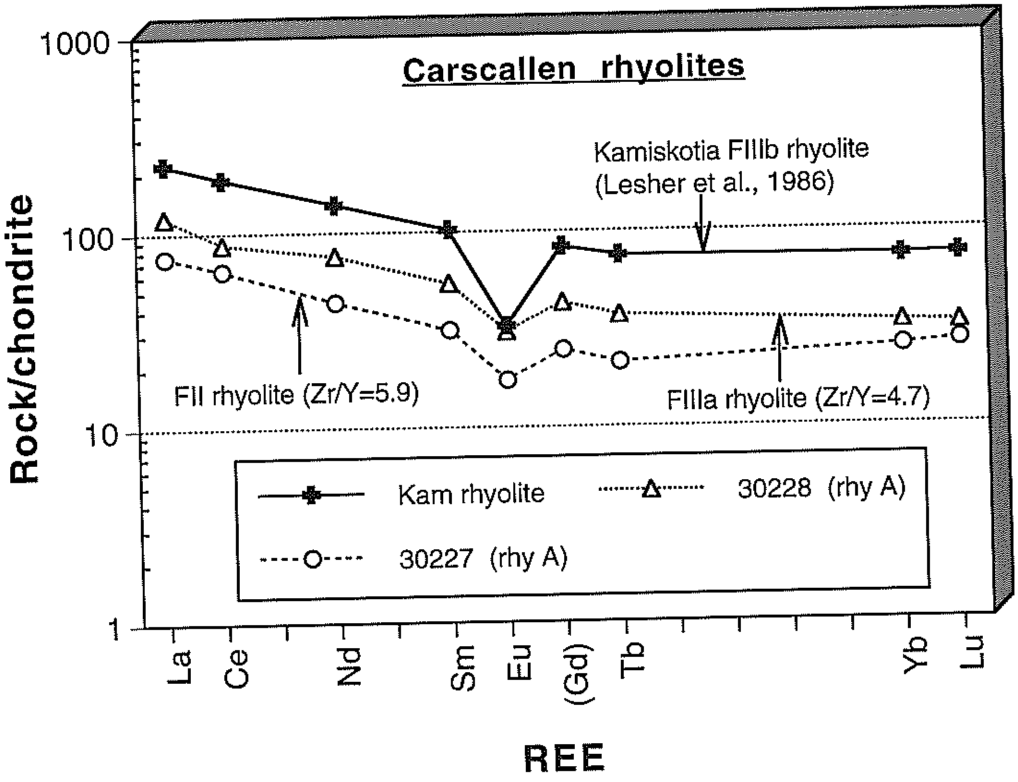

Kamiskotia icelandites
1000
100
10
1
Rock/chondrite
30215: Icelandite
30216: Icelandite
Evolved Kam. basalt (Barrie et al., 1991)
La
Ce
Nd
Sm
Eu
(Gd)
Tb
Yb
Lu

Fig. 6b


Carscallen rhyolites
1000
100
10
1
Rock/chondrite
Kamiskotia FIIIb rhyolite
(Lesher et al., 1986)
FII rhyolite (Zr/Y=5.9)
FIIIa rhyolite (Zr/Y=4.7)
Kam rhyolite
30228 (rhy A)
30227 (rhy A)
La
Ce
Nd
Sm
Eu
(Gd)
Tb
Yb
Lu
REE

Kamiskotia and Carscallen volcanics

Fig. 7a

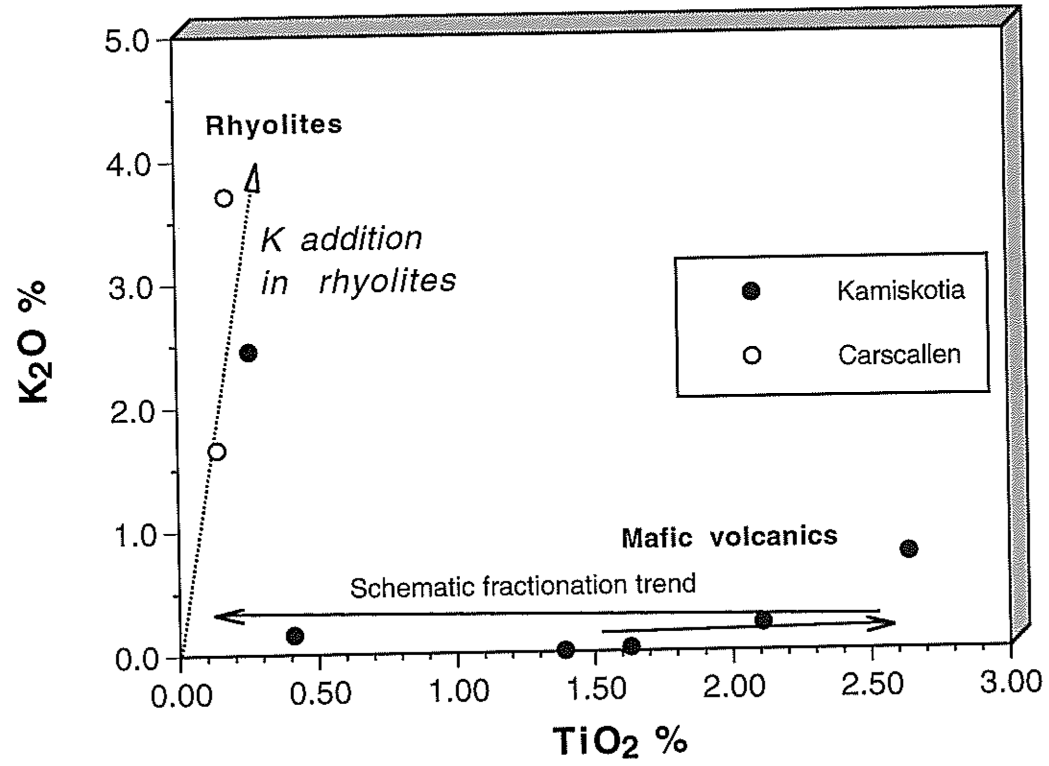
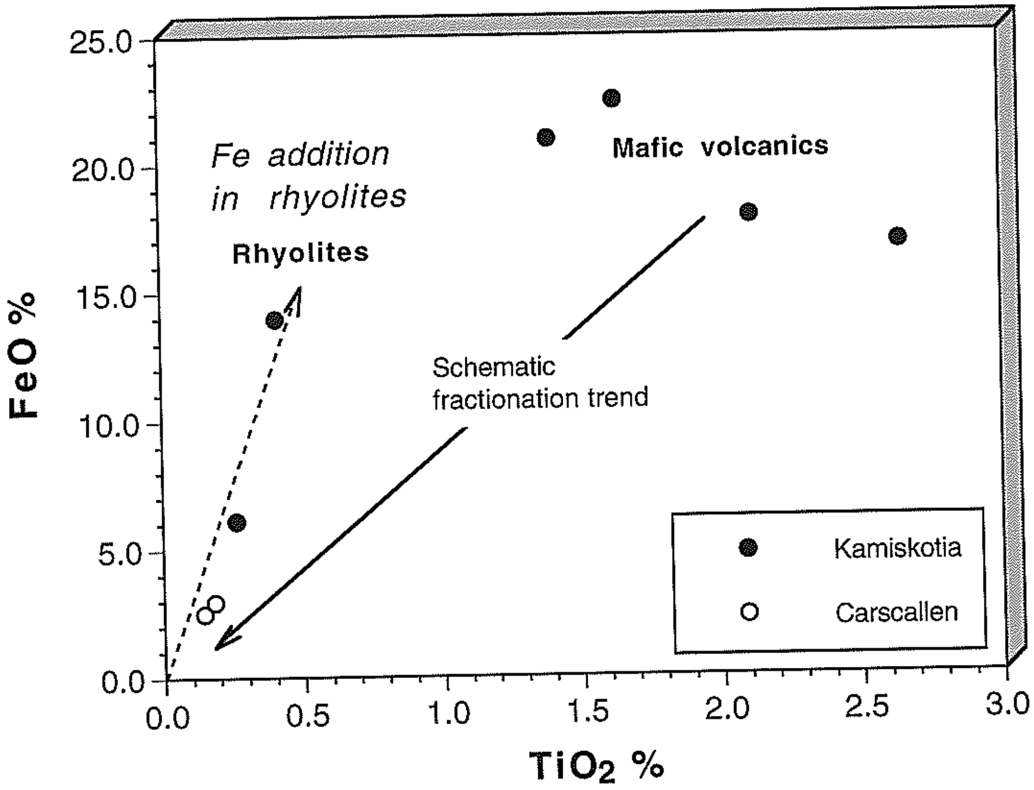


Fig. 7b



Petrography of some Rocks from the Kamiskotia Mine Area

Summary. The samples from Kamiskotia comprise four basalts (one probable a inrusion) and two rhyolites. Two of the basalts are strongly chloritized, with the chlorite having Berlin-blue birefringence typical of VMS-type hydrothermal alteration. The mafic intrusion (#30216) is little altered, as is basalt (#30215) that is veined by coarse carbonate and Berlin-blue chlorite.

One of the rhyolite samples (#30214) is a massive quartz-feldspar porphyry which is an extrusive unit. It has an altered, fine grained groundmass; veins of quartz and some carbonate also occur. Overall, alteration is moderate. The other rhyolite sample (#30217) is a perlitic glass replaced by chlorite (≈70%) and lesser fine-grained quartz; there are no phenocrysts. The circular perlite fractures have been filled in part with quartz, giving the hand specimen a pattern of white rings.

Further details are given in the captions of the following series of photographs.

Petrography of some Rocks from the Kamiskotia Mine Area

Quartz Feldspar Porphyritic Rhyolite

Flow-banded rhyolite next to massive pyrite outcrop (sample 30214)

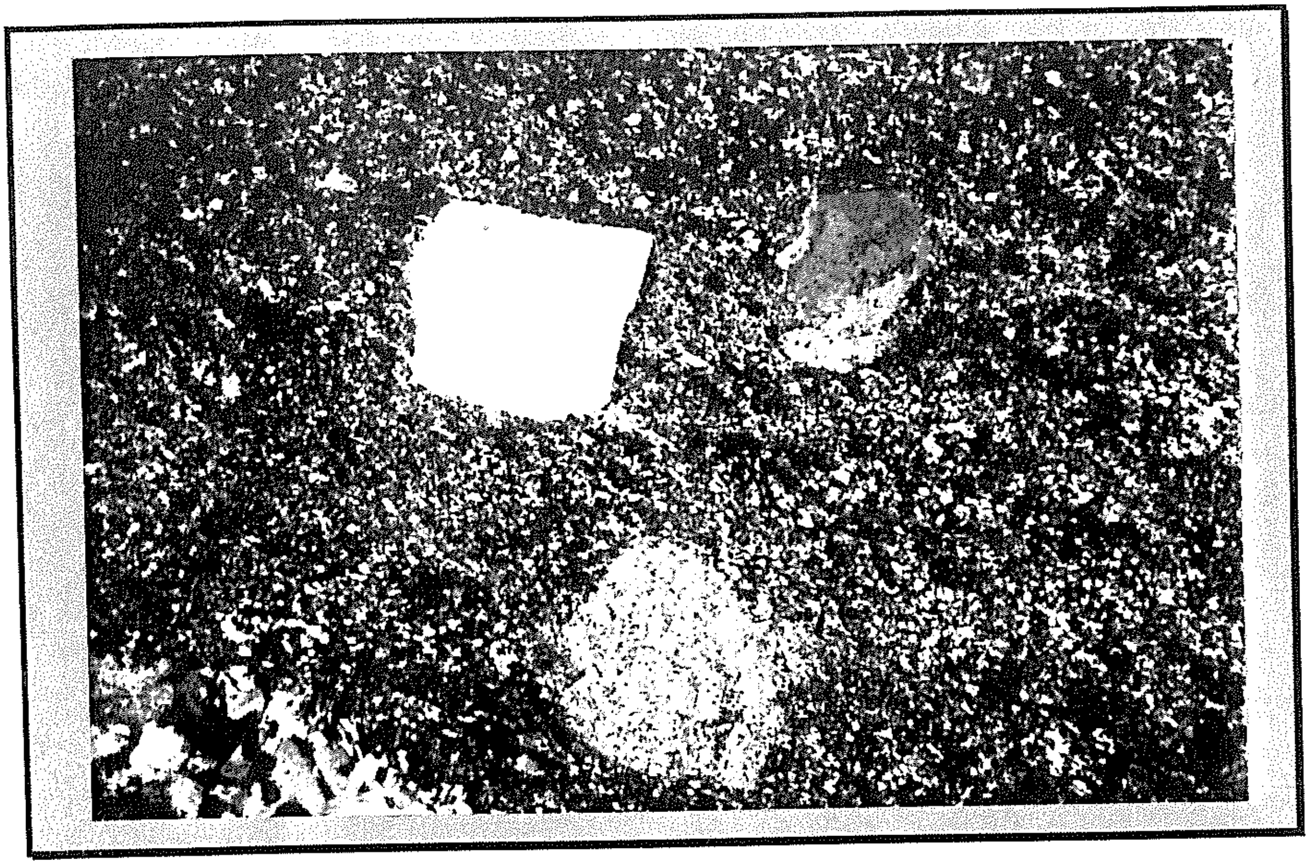
- Altered fine grained matrix: quartz + sericite+ biotite+ carbonate.
- Abundant quartz phenocrysts, and also feldspar phenos replaced by sericite.
- A volcanic rock with some banding; it may be a tuff; a few quartz - carbonate veins occur.

Figure 8a (facing upper photo)

Two quartz phenocrysts and one feldspar (?) pheno replaced by sericite. Biotite is the dark mineral. *Crossed nicols, 40X.*

Figure 8b (facing lower photo)

Quartz phenocryst in matrix of Qz-Ser-Biot-Lcx. *Crossed nicols, 40X*



Petrography of some Rocks from the Kamiskotia Mine Area

Altered Perlitic Rhyolite

From 'outcrop' near southern margin of pit (sample 30217)

-70% Berlin-blue chlorite, 25% quartz, 5% others.

- Very fine grained chlorite with rings and rounded masses of fine grained quartz.
- Pronounced round perlitic structures (not spherules) in chloritized rhyolite glass. Some perlitic fractures are filled with quartz. This produces the texture of white rings in the dark rock as seen in hand specimen.

Figure 9a (facing upper photo)

Perlitic structures in aphyric rhyolite glass replaced by chlorite and quartz. A few quartz amygdules are present. *Crossed nicols, 40X.*

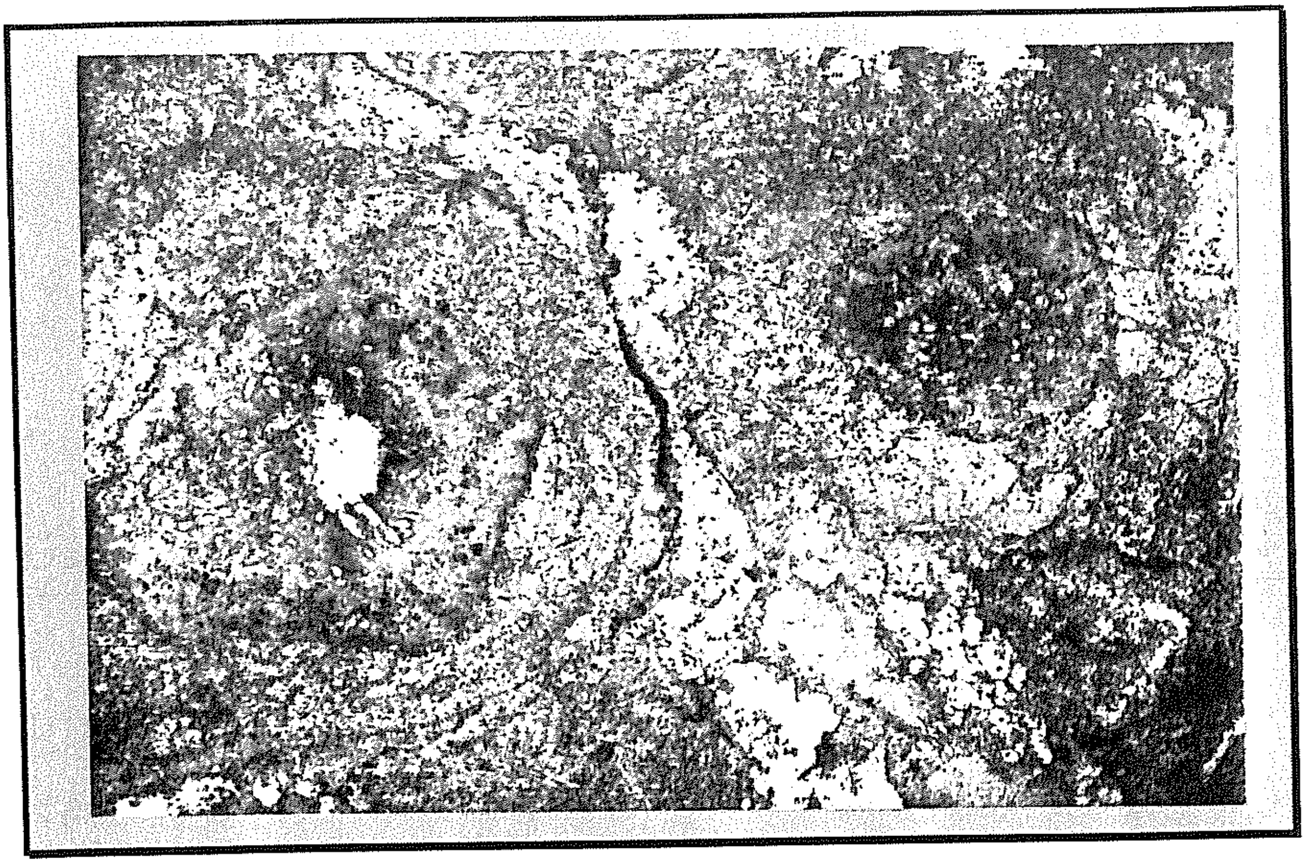
Chloritized Pillow Basalt

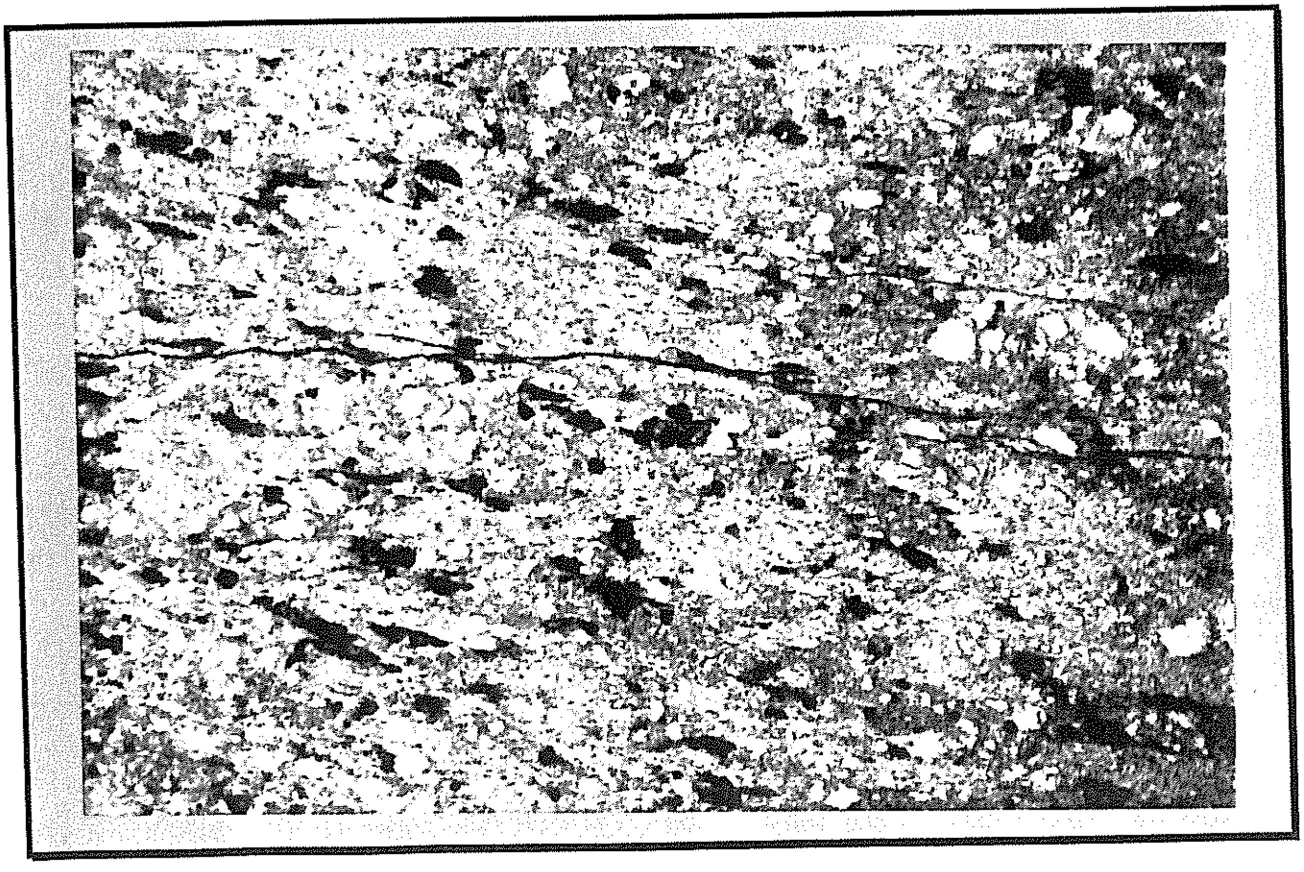
From southern margin of pit, near fence (sample 30213)

- Chlorite + quartz + leucoxene ± epidote; the chlorite has a burgundy birefringence colour.
- Large amount of leucoxene; relict plag (?) grains replaced by quartz; matrix is medium grained.
- Faint lenticular fabric, possibly shear related. Also a few schistosity or shear planes.

Figure 9b (facing lower photo)

General view: chlorite + quartz + leucoxene. *Plane light, 40X*





Petrography of some Rocks from the Kamiskotia Mine Area

Chloritized Amygdular Basalt

Mafic rock between pillow lavas and rhyolite on south side of pit (sample 30212)

- 50% chlorite, 35% quartz, 10% leucoxene (TiO_2-FeO mix), 5% opaques.
- Originally medium grained.
- The large amount of matrix quartz is produced during alteration, owing to the formation of chlorite, a low-SiO_2 mineral.
- Leucoxene is the mineral with high relief and a mix of transparent and opaque Fe-oxide.

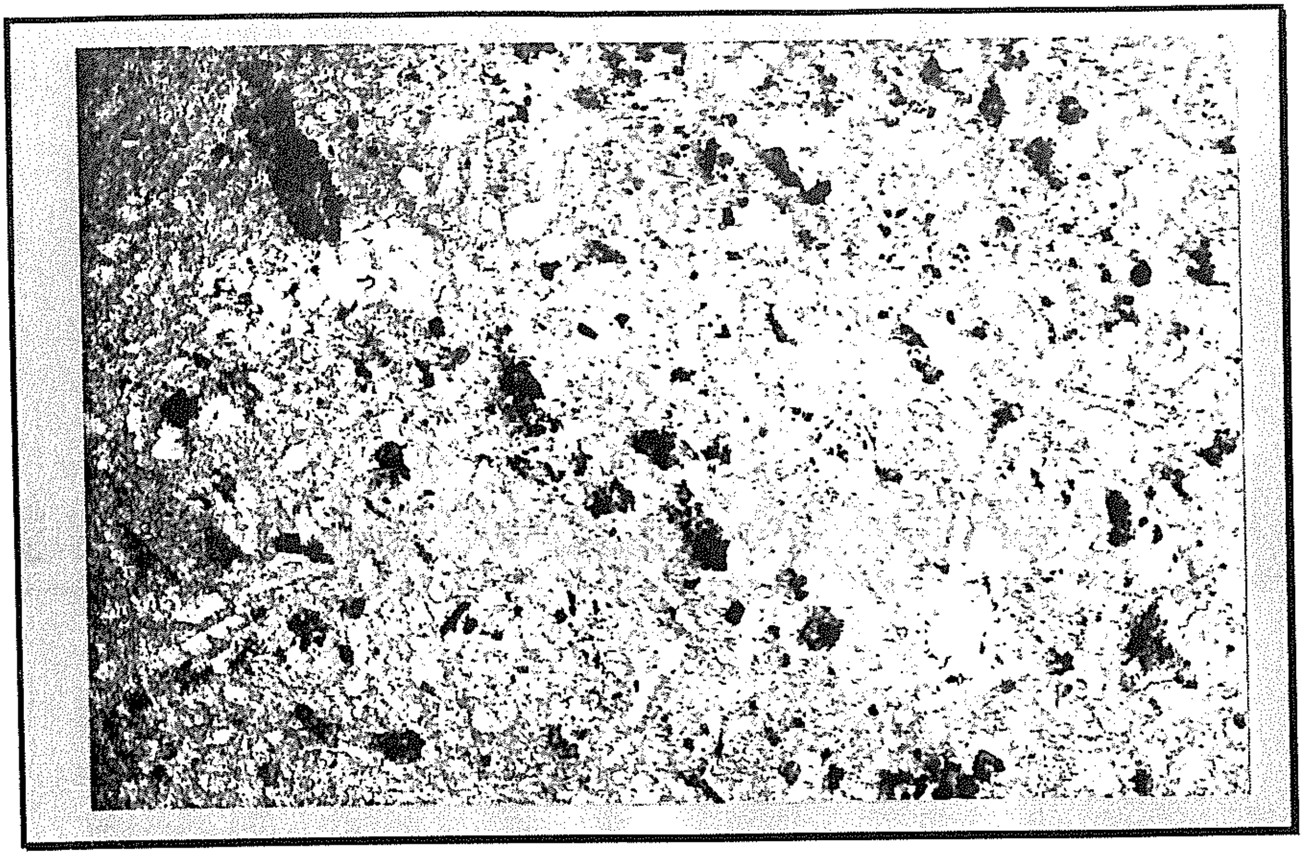
Note: the same view but in crossed polars is shown in **Photo 5a**.

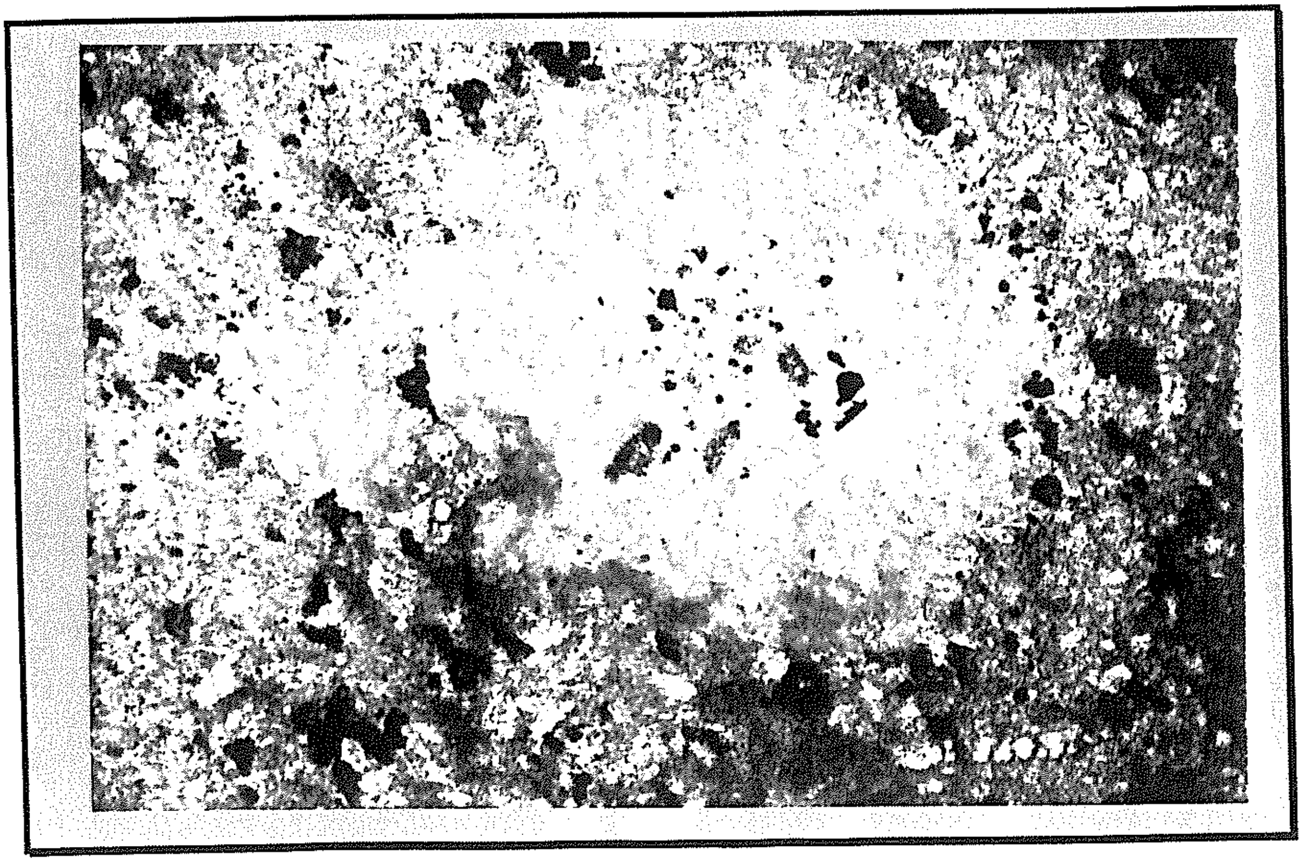
Figure 10a (facing upper photo)

Basalt texture, with dark leucoxene grains. The white mineral is Qz replacing Pl. Assemblage is chlorite + quartz + leucoxene. *Plane light, 40X*

Figure 10b (facing lower photo)

Chlorite in amygdule in basalt - note the dark leucoxene grains. Chlorite is Berlin-blue (Fe-rich) in crossed polars. *Plane light, 40X*





Petrography of some Rocks from the Kamiskotia Mine Area

Altered Basalt with Vein Carbonate

Massive 'icelandite' near massive pyrite outcrop (sample 30215)

- Chlorite + quartz + epidote + leucoxene + opaques ± carbonate.
- Few plagioclase (?) phenos replaced by quartz; 10% leucoxene and 5% opaques.
- The carbonate is coarse grained,with rhomb-shaped crystals, and contains fine grained quartz.
- Massive coarse-grained Berlin-blue chlorite along the basalt-carbonate boundary.

Figure 11a (facing upper photo)

Altered basalt with abundant leucoxene cut by coarse carbonate and green pleochroic chlorite. *Plane light, without blue filter. 40X.*

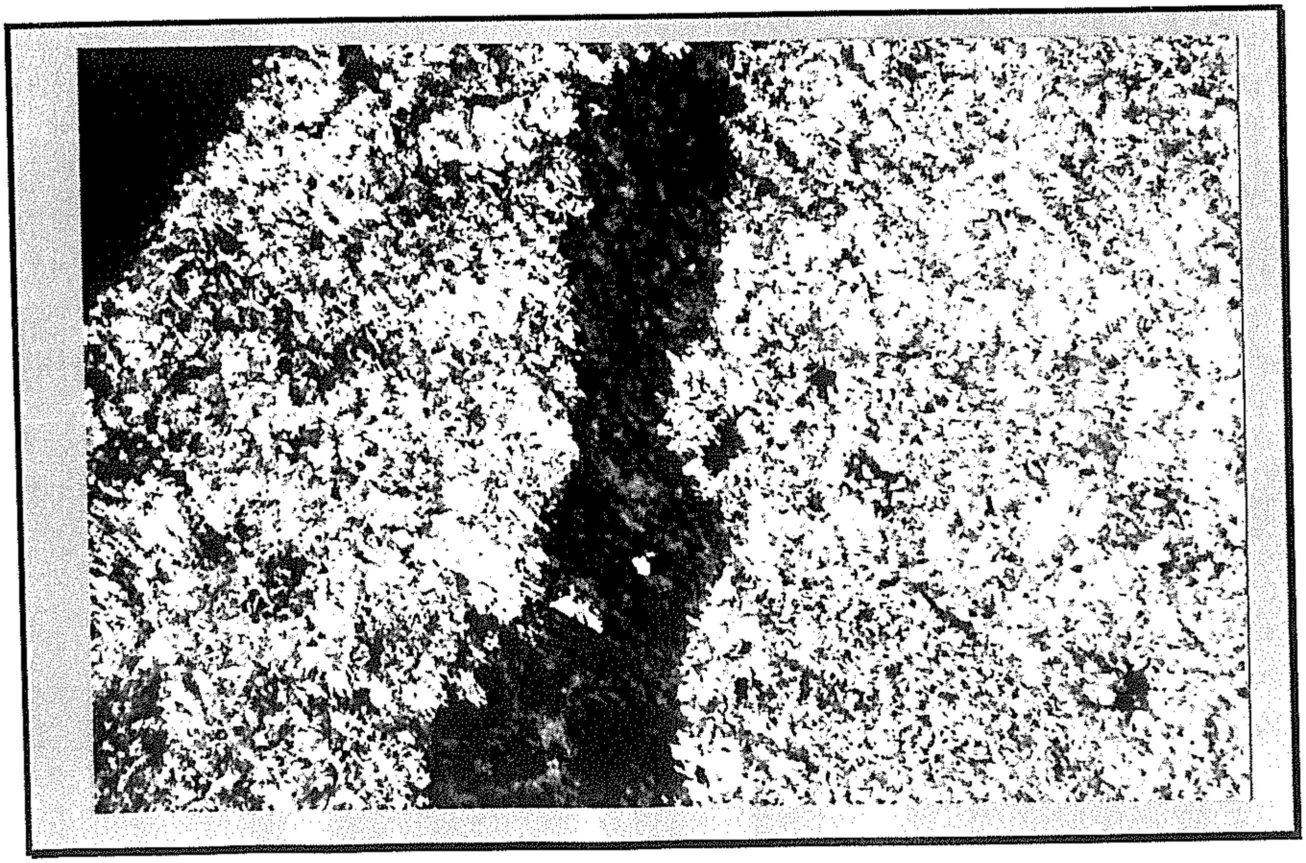
Basalt or Dolerite

Massive mafic intrusion? on north side of pit (sample 30216)

- Aphyric, with a good coarse interstitial (intersertal) texture. Rock is spilitized basalt or dolerite.
- Original minerals replaced by albite, epidote, actinolite, and minor quartz. 10-15% leucoxene.
- Large veins and spots of Berlin-blue chlorite containing few euhedral crystals of carbonate.
- Also some of the same blue chlorite in matrix.

Figure 11b (facing lower photo)

Basalt or dolerite cut by vein of Berlin-blue chlorite; the yellow acicular mineral is actinolite. *Crossed nicols, 40X.*



Petrography of a Kamiskotia Basalt and Carscallen Township Rhyolites

Kamiskotia: Chloritized Amygdular Basalt (see also Photo 3)

Mafic rock between pillow lavas and rhyolite on south side of pit (sample 30212)

Figure 12a (facing upper photo)

- This is the same thin section and view as in Photo 3a, but in crossed polars to show chlorite.
- 50% chlorite, 35% quartz, 10% leucoxene (TiO_2-FeO mix), 5% opaques.
- Burgundy to Berlin-blue birefringent chlorite in amygdules, veins and replaced phenocrysts. These bluish chlorites are commonly produced by Fe-rich ore-forming fluids, and are good indicators of VMS mineralization. Matrix chlorite is green-brown birefringent (medium Fe/Fe+Mg). *Crossed polars, 40X*

Carscallen: Quartz Porphyritic Rhyolite

Outcrop (sample 30228)

Figure 12b (facing upper photo)

- Small quartz phenocrysts are overgown by lacey quench quartz in optical continuity.
- Variable textures in the section:
  - (a) Quartz porphyritic with fine grained moderately altered (sericitic) groundmass;
  - (b) Coarse grained - mainly quartz (these represent areas of silicification).

Plane light, 40X

Carscallen: Sericitized Rhyolite Tuff (no photo)

Outcrop (sample 30227)

- Ranges from quartz-sericite-altered rock to sericitite. Fine-grained matrix.
- A few quartz phenocrysts (?) and minor quartz veining are present.

Acknowledgements

We would like to thank Lionel Bonhomme of Timmins for initiating this project, and for providing lithogeochemical data during the study. We are grateful to Falconbridge Limited for permission to visit and sample the Kam-Kotia deposit, and in particular to John Pattison for an informed geological tour and discussions.

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Table 1. Chemical composition of selected volcanic rocks from the Kam-Kotia mine, and some rhyolites from Carscallen Township, Ontario

No.	Lithology	SiO_2 %	Al_2O_3 %	TiO_2 %	Fe_2O_3 %	FeO* %	MnO %	CaO %	MgO %	K_2O %	Na_2O %	P_2O_5 %	LOI
Kamiskotia													
30212	Ferrobasalt	49.3	12.1	1.28	21.40	19.26	0.13	0.14	9.55	0.01	0.06	0.13	6.10
30213	Ferrobasalt	47.1	12.3	1.48	22.70	20.43	0.11	0.19	9.18	0.03	0.07	0.16	6.85
30214	Rhyolite A	73.1	11.2	0.25	6.62	5.96	0.07	0.13	1.97	2.38	2.11	0.02	2.00
30215	Icelandite	46.4	11.0	1.91	18.00	16.20	0.19	7.66	5.20	0.20	1.40	0.30	8.10
30216	Icelandite	49.5	12.0	2.50	17.70	15.93	0.25	7.20	4.10	0.74	1.74	0.55	3.95
30217	Rhyolite B	66.4	9.2	0.39	14.70	13.23	0.04	0.09	5.19	0.15	0.11	0.02	3.90
Carscallen													
30227	Rhyolite A	74.7	13.0	0.17	3.19	2.87	0.03	0.40	1.01	3.58	0.75	0.02	3.15
30228	Rhyolite A	79.5	10.2	0.14	2.74	2.47	0.05	1.68	1.24	1.63	1.15	0.02	2.10

No.	Lithology	Sum	Anh** sum	Ba ppm	Sr ppm	Y ppm	Zr ppm	Rb ppm	Nb ppm	Zr/Y	Zr/Nb	Al_2O_3/ TiO_2
Kamiskotia												
30212	Ferrobasalt	100.19	91.95	122	5	26	101	8	8	3.9	12.6	9.5
30213	Ferrobasalt	100.17	91.05	152	6	30	107	1	8	3.6	13.4	8.3
30214	Rhyolite A	99.85	97.19	357	24	89	434	67	22	4.9	19.7	44.6
30215	Icelandite	100.36	90.46	174	63	35	177	4	10	5.1	17.7	5.8
30216	Icelandite	100.23	94.51	412	106	57	298	31	13	5.2	22.9	4.8
30217	Rhyolite B	100.19	94.82	120	1	29	270	9	15	9.3	18.0	23.6
Carscallen												
30227	Rhyolite A	100.00	96.53	806	52	50	295	108	18	5.9	16.4	76.0
30228	Rhyolite A	100.45	98.07	218	106	70	329	57	29	4.7	11.3	74.5

Sample	Lithology	La ppm	Ce ppm	Nd ppm	Sm ppm	Eu ppm	Tb ppm	Yb ppm	Lu ppm	Th ppm	U ppm	(La/Yb)n
Kamiskotia												
30212	Ferrobasalt	6.5	16	11	3.1	0.51	0.7	3.09	0.46	.8	0.3	1.46
30213	Ferrobasalt	8.1	20	13	3.5	0.91	0.6	3.43	0.53	.9	0.1	1.58
30214	Rhyolite A	40	89	49	11.70	3.42	1.9	8.40	1.23	5.7	1.6	3.37
30215	Icelandite	10	26	16	4.7	1.87	0.8	3.79	0.6	.9	0.4	1.73
30216	Icelandite	15.4	40	25	7.2	2.24	1.4	5.66	0.85	1.9	0.5	1.88
30217	Rhyolite B	26	57	32	7.4	2.96	1.2	3.71	0.53	4.3	1.2	5.09
Carscallen												
30227	Rhyolite A	18.5	41	21	4.9	1.01	0.8	4.19	0.68	4.4	1.2	2.82
30228	Rhyolite A	29.4	56	36	8.42	1.79	1.4	5.56	0.84	4.7	1.3	3.63

chondrite#	0.245	0.638	0.474	0.154	0.058	0.038	0.17	0.025

#Evensen et al. (1978) values

*Calculated from Fe_2O_3. **Anhydrous sum based on calculated FeO.