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THE WAH WAH SPRINGS TUFF AND EFFECTS ON BULK  
ROCK CHEMISTRY,  
UTAH AND NEVADA

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SORTING OF COMPONENTS DURING EMPLACEMENT OF THE WAH WAH  
SPRINGS TUFF AND EFFECTS ON BULK ROCK CHEMISTRY, UTAH AND NEVADA

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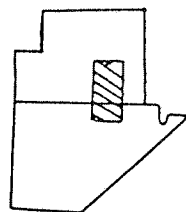
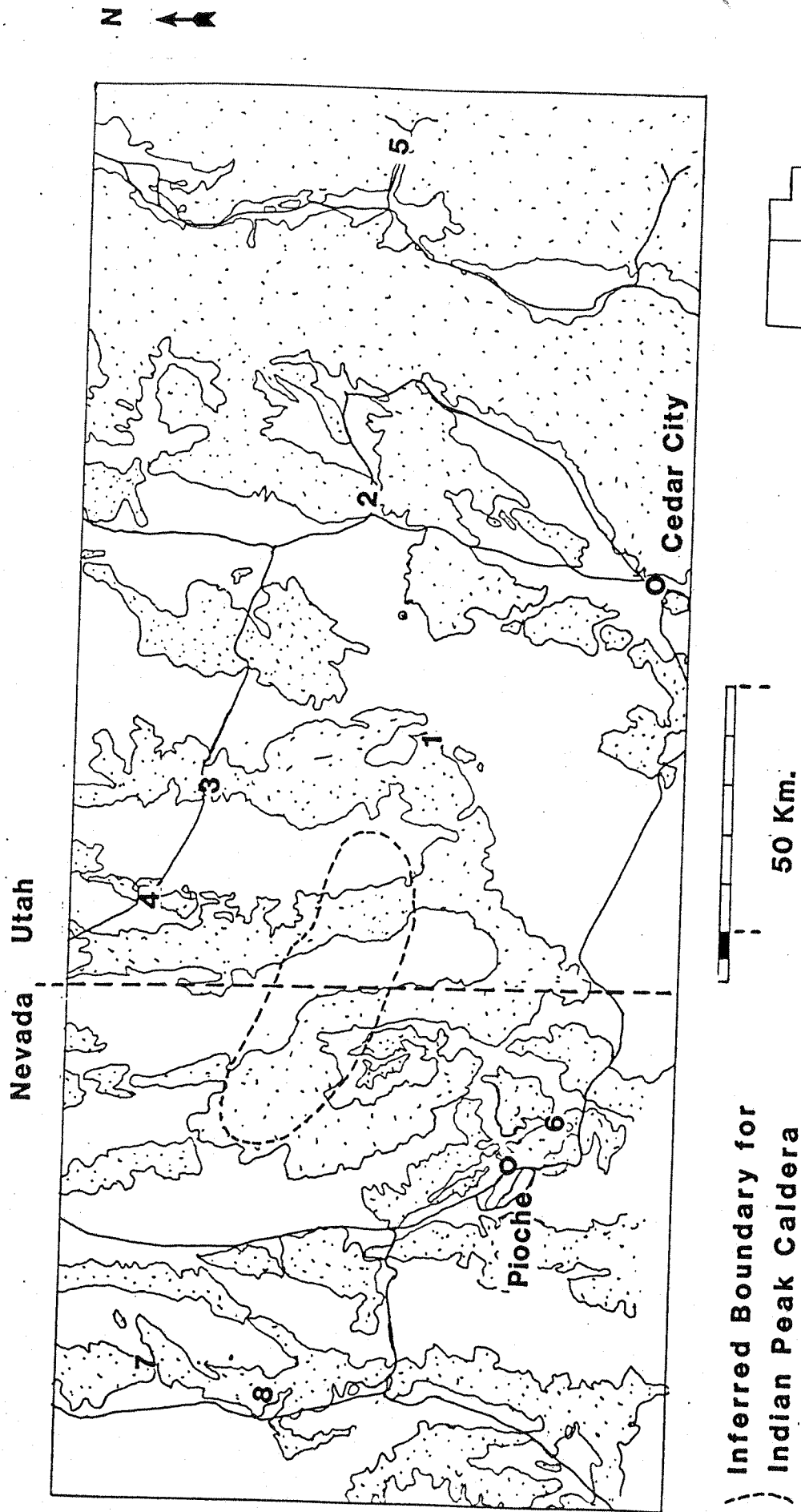
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## INTRODUCTION

The Wah Wah Springs Tuff Member of the Needles Range Formation was emplaced as a simple cooling unit about 30 mybp from the Indian Peak Caldera near the southern Utah-Nevada border. The tuff is crystal-rich, calc-alkaline, and rhyodacitic to quartz latitic in bulk composition (Nusbaum and Grant, 1985). Minimum volume estimates which have been corrected for Basin and Range extension indicate that the tuff is one of the largest currently recognized in the world with an estimated minimum volume of 3300 km<sup>3</sup>. Unlike many zoned tuffs, the conspicuous appearance, or disappearance of a mineral phase(s) does not occur within the Wah Wah Springs Tuff. Crystal size does not vary with stratigraphic position or lateral position at sites sampled radially and crudely equidistant from the source. The outflow tuff contains early-crystallized apatite, zircon, and pyrrhotite followed by magnetite, ilmenite, andesine, hornblende, biotite, clinopyroxene and quartz.

Numerous bulk rock chemical analyses have been performed for the Wah Wah Springs Tuff from sites surrounding the Indian Peak Caldera (Figure 1). Samples collected from the Kingston section are approximately three times the relative distance from the source of the tuff in comparison to other sections which are about equidistant from the Indian Peak Caldera. Its distal location allows sorting variability of components to be observed between the Kingston section and the others.

Sorting of physical components during emplacement is well documented in ash-flow tuffs (Fisher, 1966; Lipman, 1967, Sparks and Wilson, 1976; Sheridan, 1979; Caress and Walker, 1985; Izett, 1981). If one considers bulk rock analyses to represent a mixture of two mechanically separable components (minerals and glass), each of nearly fixed composition, then the total mineral content would control the variance in chemistry in the bulk rock.



**Fig. 1 Location of Sections**

- 1 - Lund Section
- 2 - Minersville Section
- 3 - Wallaces Peak Section
- 4 - Needle Range Sections

- 5 - Kingston Section
- 6 - Condor Canyon Section
- 7 - Shingle Spring Sections
- 8 - South Egan Range Section

## DISCUSSION OF RESULTS

The effects of differential sorting on the mineralogy are given in Table I. Loss of andesine, total crystals, and addition of biotite for Kingston samples are the most obvious differences between the groups based on comparison of Kingston samples to composite, unaltered samples from six stratigraphic sections. Student's t-test was employed at the 0.10 significance level to establish significant differences between groups.

To determine the effects of sorting on the REE, it is necessary to assess whether apatite and zircon are affected since they contain unusually high concentrations of some of the REE (Haskin and Paster, 1979; Hanson, 1980). Since the two minerals occur only in trace quantities, a statistically based comparison is not possible. Based on specific gravity considerations alone, it would not be surprising if apatite and zircon were also depleted in Kingston samples. Since apatite and zircon do occur as poikilitic inclusions in andesine, it seems likely that they would be depleted by the loss of andesine. The addition of biotite seems intuitively aerodynamically plausible considering the platy character of biotite crystals. Apatite and zircon would effectively be somewhat enriched by the addition of biotite to Kingston samples, however, the greater loss of andesine should overwhelm this effect. The decreased crystal content and increased glass (devitrified) content are also noteworthy.

As illustrated in Table II, qualitative explanations for variations in major element oxide chemistry for Kingston and combined sections samples reflect mineralogic differences and generally do not require glass compositional differences. Combined effects such as the addition of biotite and glass to Kingston samples and the loss of andesine can be used to explain the variations in most major element oxides. The loss of  $\text{TiO}_2$  for Kingston

TABLE I

## EFFECTS OF SORTING DURING EMPLACEMENT:

## MINERAL MODES

<u>MINERAL</u>	<u>MEANS AND ST. DEV.</u>	<u>MEANS AND ST. DEV.</u>	<u>T-TEST(0.10)</u>
	<u>KINGSTON, (n=3)</u>	<u>(6 sections)(n=38)</u>	
Quartz	2.3* $\pm$ 0.9	2.2 $\pm$ 1.1	H <sub>0</sub> : Accepted
Andesine	26.2 $\pm$ 3.1	31.1 $\pm$ 2.2	H <sub>0</sub> : Accepted
Hornblende	10.0 $\pm$ 0.3	10.8 $\pm$ 2.2	H <sub>0</sub> : Accepted
Biotite	5.1 $\pm$ 0.8	4.4 $\pm$ 0.8	H <sub>0</sub> : Rejected
Clinopyroxene	<1	<1	Not tested
Magnetite-ilmenite	1.2 $\pm$ 0.3	1.4 $\pm$ 0.4	H <sub>0</sub> : Accepted
TOTAL	45.3 $\pm$ 1.7	50.4 $\pm$ 3.6	H <sub>0</sub> : Rejected

\*Values given in area percent. See Nusbaum (1984) for individual sample analyses.

TABLE II

## EFFECTS OF SORTING DURING EMPLACEMENT: MAJOR ELEMENT OXIDES

OXIDE	MEANS AND ST. DEV.			POSSIBLE EXPLANATION
	KINGSTON (n=3)	(6 sections)(n=33)	t=TEST(0.10)	
SiO <sub>2</sub>	*65.71 ± 0.28	65.19 ± 1.16	H <sub>0</sub> : Accepted	No difference
Al <sub>2</sub> O <sub>3</sub>	15.22 ± 0.17	15.32 ± 0.77	H <sub>0</sub> : Accepted	No difference
**Fe <sub>2</sub> O <sub>3</sub>	4.62 ± 0.09	5.26 ± 0.29	H <sub>0</sub> : Rejected	-Magnetite? ‡
MgO	2.25 ± 0.61	2.52 ± 0.50	H <sub>0</sub> : Accepted	No difference
CaO	4.07 ± 0.31	4.52 ± 0.57	H <sub>0</sub> : Rejected	-Andesine
Na <sub>2</sub> O	3.10 ± 0.16	2.62 ± 0.27	H <sub>0</sub> : Rejected	+Glass (Devitrified in Kingston samples)
K <sub>2</sub> O	4.22 ± 0.20	3.60 ± 0.38	H <sub>0</sub> : Rejected	+Biotite
TiO <sub>2</sub>	0.58 ± 0.01	0.67 ± 0.04	H <sub>0</sub> : Rejected	-Ilmenite possible
P <sub>2</sub> O <sub>5</sub>	0.16 ± 0.01	0.18 ± 0.01	H <sub>0</sub> : Rejected	-Apatite possible
MnO	0.08 ± 0.01	0.08 ± 0.01	H <sub>0</sub> : Accepted	No difference

\* Values given in weight percent oxide. See Nusbaum (1984) for individual sample analyses.

\*\*Total iron content represented as Fe<sub>2</sub>O<sub>3</sub>.

‡ Addition (+) or subtraction (-) to Kingston section.

? Explanation not supported by mineralogic t-test results

samples may reflect a possible ilmenite reduction although this is not subject to statistical proof due to the trace abundance of ilmenite.  $\text{Fe}_2\text{O}_3$  reduction at Kingston may have resulted from possible reduction in magnetite (not supported at 0.10 significance level) and possible reduction of ilmenite. At first glance, the higher  $\text{Na}_2\text{O}$  content for Kingston samples is perplexing since lower plagioclase amounts are observed there. A possible explanation is that  $\text{Na}_2\text{O}$  is abundant in the glass (now devitrified products) which is enriched. Devitrified glass contains greater  $\text{Na}_2\text{O}$  than fresh glass according to Lipman (1965). Glass analyses show lower  $\text{Na}_2\text{O}$  contents than from those for plagioclase crystals by a factor of one half (Nusbaum, 1984). Alternatively,  $\text{Na}_2\text{O}$  leaching may have occurred within samples collected from the reference (proximal) sections. Many of these have less  $\text{Na}_2\text{O}$  than the microprobed glass alone; however, with sodium in the plagioclase, they should be richer than the reference glass. Leaching and alkali exchange is common in ash-flow ground masses. Increased  $\text{K}_2\text{O}$  for Kingston samples is most easily explained by an increase in biotite and glass.  $\text{P}_2\text{O}_5$  loss has probably resulted from an apatite reduction for Kingston samples due to the high specific gravity of the phase favoring deposition near the source.

The effects of sorting on bulk rock major element analyses appears to be significant on a qualitative basis. Employing compatible versus incompatible behavior for trace elements with respect to the various phases present in Wah Wah Springs Tuff samples allows a qualitative comparison of bulk rock trace element analyses and mineralogy. Since Ba behaves compatibly within the biotite structure (Arth, 1976) an approximate 10 percent addition of biotite to Kingston samples could conceivably account for approximately a 10 percent increase in Ba content (Table III). Comparison between volumetric equivalents



TABLE III

MINERAL	MEANS AND ST. DEV.			POSSIBLE EXPLANATION
	KINGSTON (n=3)	(6 sections)(n=32)	t=TEST(0.10)	
Ba	950* $\pm$ 40	870 $\pm$ 80	H <sub>0</sub> : Rejected	+ Biotite**
Sr	530 $\pm$ 180	560 $\pm$ 40	H <sub>0</sub> : Accepted	No difference
Rb	143 $\pm$ 5	120 $\pm$ 17	H <sub>0</sub> : Rejected	+ Biotite, + Glass
Cs	7.4 $\pm$ 2.0	3.1 $\pm$ 1.5	H <sub>0</sub> : Rejected	+ Biotite, + Glass
Th	22.0 $\pm$ 1.4	19.7 $\pm$ 0.7	H <sub>0</sub> : Rejected	+ Glass
U	5.3 $\pm$ 1.1	3.8 $\pm$ 1.0	H <sub>0</sub> : Rejected	+ Glass
Sc	12.3 $\pm$ 0.3	14.7 $\pm$ 1.0	H <sub>0</sub> : Rejected	- Zircon?
Cr	44 $\pm$ 1	49 $\pm$ 3	H <sub>0</sub> : Rejected	- Magnetite?
Co	15.3 $\pm$ 0.4	17.5 $\pm$ 1.3	H <sub>0</sub> : Rejected	- Magnetite? -Ilmenite?
Hf	4.9 $\pm$ 0.5	5.2 $\pm$ 0.5	H <sub>0</sub> : Accepted	No difference
Ta	0.95 $\pm$ 0.07	0.95 $\pm$ 0.06	H <sub>0</sub> : Accepted	No difference
La	48.7 $\pm$ 1.4	50.2 $\pm$ 2.8	H <sub>0</sub> : Accepted	No difference
Ce	78 $\pm$ 4	80 $\pm$ 8	H <sub>0</sub> : Accepted	No difference
Sm	5.3 $\pm$ 0.1	5.8 $\pm$ 0.4	H <sub>0</sub> : Rejected	Apatite?
Eu	1.00 $\pm$ 0.03	1.16 $\pm$ 0.07	H <sub>0</sub> : Rejected	Andesine
Tb	0.64 $\pm$ 0.02	0.74 $\pm$ 0.06	H <sub>0</sub> : Rejected	Zircon?, - Apatite?
Yb	1.4 $\pm$ 0.1	1.74 $\pm$ 0.1	H <sub>0</sub> : Rejected	Apatite?, Zircon?
Lu	0.32 $\pm$ 0.04	0.36 $\pm$ 0.03	H <sub>0</sub> : Rejected	Apatite?, Zircon?

\* Values in parts per million. See Nusbaum (1984) for individual sample analyses.

\*\*Addition (+) or subtraction (-) or to Kingston section.

? Explanation not supported by t-test results or modal data. See text for logic used for explanation.

and weight bases is generally unsatisfactory, however, in this case the assessment appears logical. Strontium is demonstrably compatible in the plagioclase structure (Dake and Weill, 1975) yet the null hypothesis is accepted for Sr. This is somewhat perplexing in light of the commonly observed compatibility of Sr in the plagioclase structure. Addition of biotite should necessitate an increase of Rb and Cs which substitute for K (Manhood and Hildreth, 1983). The increased Th and U contents for Kingston samples presumably reflect an increase in glass abundance coupled with incompatible behavior for these elements with large ionic radii. Incompatible behavior for these elements is described by Hart and Allegre (1980).

Scandium depletion is most easily explained by loss of zircon in which Sc is highly compatible (Manhood and Hildreth, 1983). It should be noted that Sc is compatible in biotite and hornblende, yet the compatibility in zircon reduction is an order of magnitude greater. Potential, yet unproven, zircon reduction should probably result in a reduction of Hf in Kingston samples since Hf substitutes for Zr in the mineral structure, yet the null hypothesis was accepted.

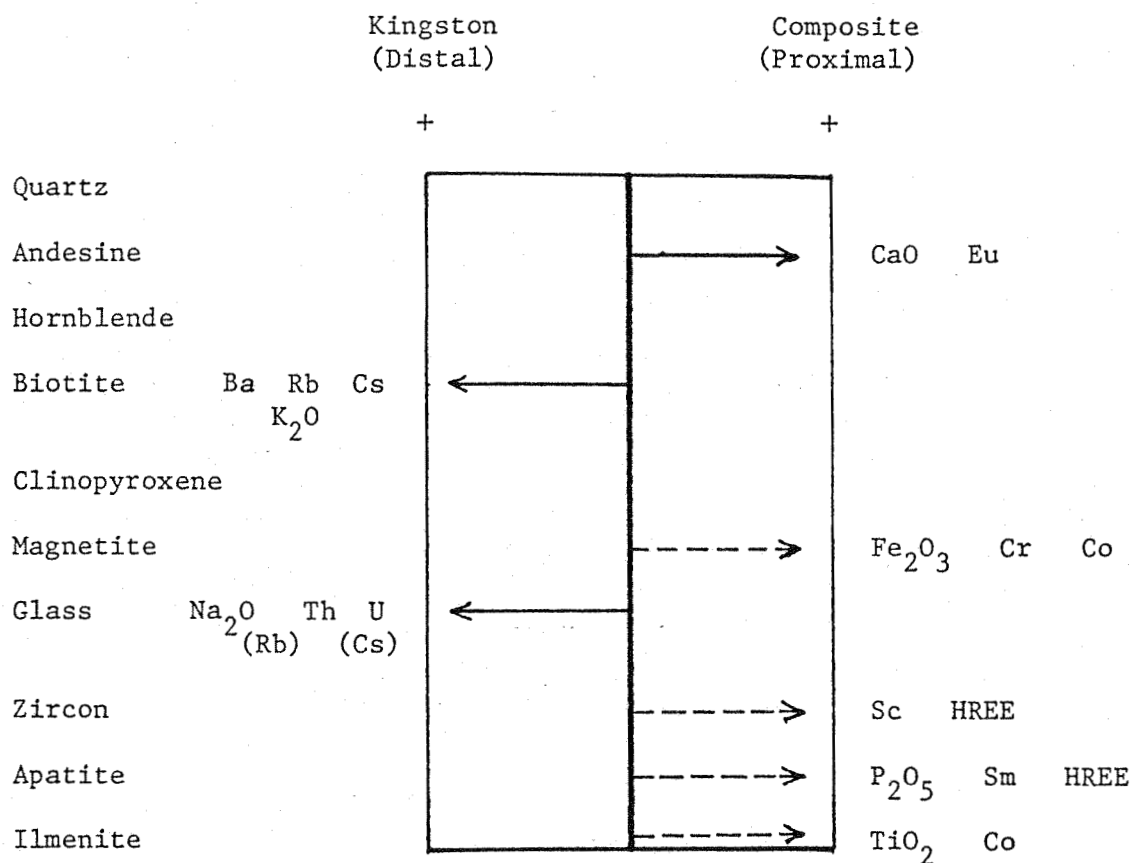
Chromium and Co reductions at Kingston probably have resulted from a statistically unfounded reduction in magnetite (and probably ilmenite) since the compatibility is significant compared to compatibility with biotite and hornblende (Manhood and Hildreth, 1983). Tantalum values are seemingly unaffected by sorting effects, however, this has probably resulted from combined effects of mineralogic differences for Kingston samples. Tantalum is most likely to be affected by ilmenite and zircon contents (Manhood and Hildreth, 1983) since the element behaves compatibly with these, however, the effect of increased glass content may be the equalizing factor if Ta is concentrated in the glass (Hildreth, 1981).

In general HREE have lower contents for Kingston samples. A decrease in apatite could explain this based on studies by Haskin and Paster (1979); however the same effect should be observed for the LREE. It is possible that loss of apatite and addition of glass may be used to explain the insignificant differences for LREE between the groups. A reduction in zircon could account for additional depletion of HREE (Manhood and Hildreth, 1983).

#### SUMMARY

The Wah Wah Springs Tuff is one of the largest currently recognized tuffs in the world with an estimated minimum volume of  $3300 \text{ km}^3$ . Samples collected from distal portions of the tuff (Kingston section) have experienced a reduction in total crystals and andesine, with an addition of biotite compared to a composite of six closer sample sections (Figure 2). Zircon, apatite and ilmenite occur in trace quantities and cannot be tested statistically. We propose that they are depleted distally since (1) they commonly exhibit a poikilitic relationship with larger crystals which generally diminish in abundance with distance from the Indian Peak Caldera, and (2) they have anomalously high specific gravities. A reduction in magnetite is not supported at the 0.10 significance level, however, poikilitic magnetite must be depleted.

FIGURE 2. BULK CHEMICAL COMPONENTS AFFECTED BY MINERAL/GLASS VARIATIONS \*



\* Solid lines = statistically significant mineral phase enrichment at 0.10 level; Dashed lines = unstatistically supported (see text for logic); Elements in parentheses may be explained by biotite compatibility alone.

Variations in bulk rock chemistry between distal portions and proximal facies of the tuff are explained in terms of a mixture of physically separable components (minerals and glass), each of nearly constant composition. Reduced CaO and Eu contents for Kingston samples are explained by a decrease in andesine, however expected reductions for Na<sub>2</sub>O and Sr were not detected. Increased Na<sub>2</sub>O may have resulted from devitrified glass enrichment for distal samples. Alternatively, small Na<sub>2</sub>O contents for proximal samples may have resulted from leaching and alkali exchange not evident in distal samples. Biotite is enriched for Kingston samples and is partially responsible for increased K<sub>2</sub>O, Ba, Rb and Cs contents. Reduction of total crystals or an increase in glass content at Kingston accounts for augmentation of Th, U, and perhaps Rb and Cs values. Depletion of zircon probably resulted in decreased HREE and Sc for distal samples, while apatite losses could also explain diminished HREE contents in addition to lower Sm and P<sub>2</sub>O<sub>5</sub> values. Reduced ilmenite is probably responsible for lower TiO<sub>2</sub>. A statistically unproven magnetite reduction for distal samples could account for lower total Fe, Cr and Ca.

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