The Distribution of Indium among Minerals in a Granitic Suite of Rocks

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Objective and Project Overview

Goal: Evaluate the distribution of indium among select minerals from four samples of granitic rocks

- **My hypothesis: The highest concentrations of indium will be found among the ferromagnesian minerals**

EPMA analysis was used to identify the chemical composition of the samples and to characterize the needed standards for use with the LA-ICP-MS analysis .
LA-ICP-MS analysis was performed to evaluate this hypothesis and measure indium concentrations.

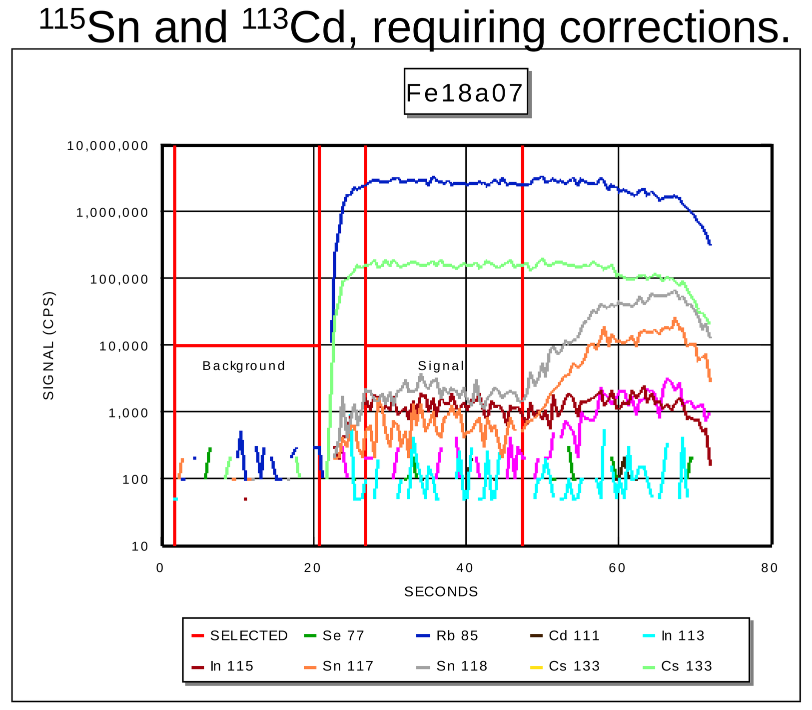
The scope of analyses included samples from each of the four discrete, intrusions known collectively as the Tuolumne Intrusive Suite (TIS), Sierra Nevada Batholith, California

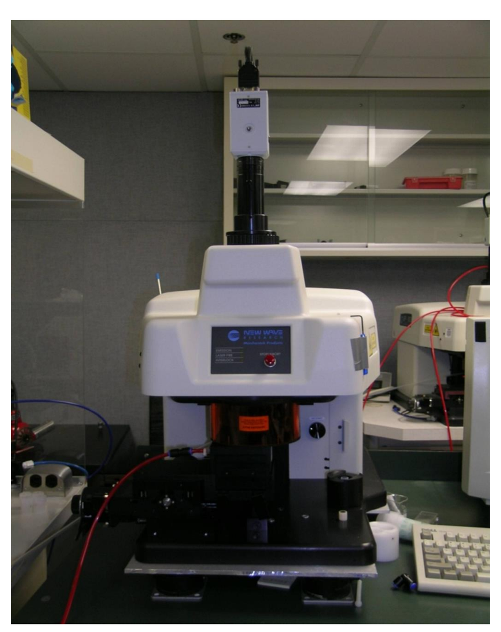
Geology

The four samples used in this study represent the TIS members (in order of emplacement and increasing felsic composition) the Kuna Crest (May Lake Granodiorite; MLG), the Half Dome Granodiorite (HDG), the Cathedral Peak Granodiorite, and the Johnson Granite Porphyry, thought to be associated with volcanic activity. The TIS formed between 95 and 85 Ma, by incremental, pulsed intrusions inferred to have originated from the same magma source (Coleman et. al, 2009)

LA-ICP-MS Analysis

LA-ICP-MS analysis was used to measure the trace concentrations of indium found in the granitic samples, but not without complications. Indium is the only element to have no isotopes free from isotopic inferences. The mass spectrometer cannot differentiate isotopes of similar mass; detected signal intensities for indium overlap with both ^{115}Sn and ^{113}Cd, requiring corrections.



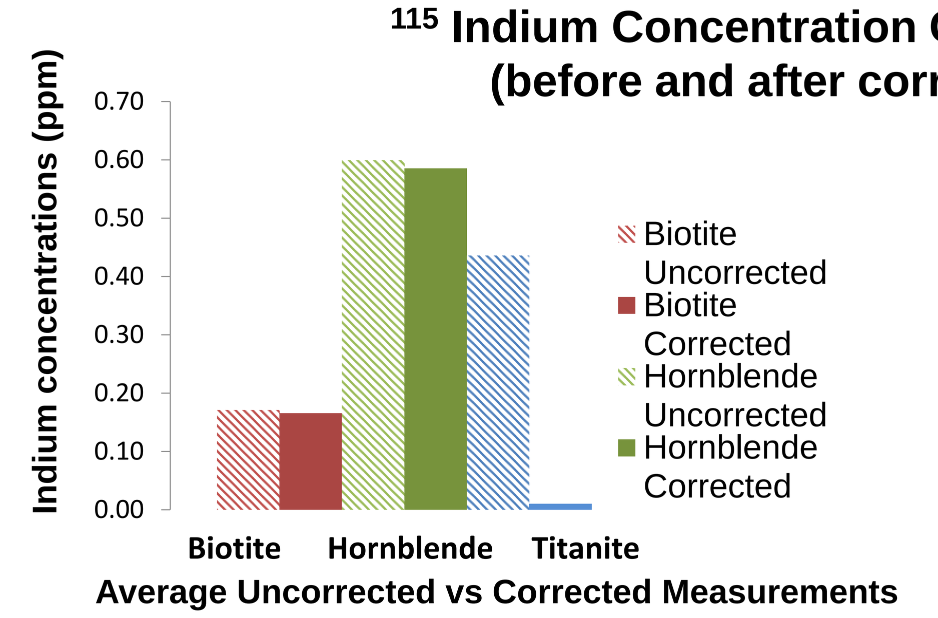


Low concentrations of indium require low limits of detection (LOD) and sufficient signal counts (cps) to obtain measurements; increasing the ablation spot size and laser / time parameters can increase signal intensities and decrease LOD settings but only within limitations determined by the mineralogy and/or grain size of the analyte.
Internal and external standards are used for reference, enabling both accuracy and precision when properly matched with the samples
(external standards: NIST610 and BHVO2G, internal standard (IS): used was aluminum).

Correction calculations

Both ^{113}In and ^{115}In have isotopic interferences caused by the ^{113}Cd and ^{115}Sn respectively. Using isotopic ratios in the following calculations were required to remove these interferences from the measured indium signal intensities.

^{115} Indium Concentration Comparisons (before and after corrections)



Both biotite and hornblende had very little ^{115}Sn interference
Titanite contained a very high count of ^{115}Sn relative the ^{115}In; after subtracting out the ^{115}Sn interferences, the indium concentration was ~ 0.01 ppm or below detection (b/d)

Isotopic ratios were used to determine and subtract interferences from the overall signal intensities measured for indium. (cps = counts per second)

- Corrected ^{115}In = ^{115}In (total uncorrected cps) – ($Sn^{115}/_{118}$)*(^{118}Sn cps)
- Corrected ^{113}In = ^{113}In (total uncorrected cps) – (^{111}Cd cps / Cd $^{113}/_{111}$)

Calculating the concentrations of indium (example shown with biotite)

- $C^{Bt}_{In} = (C^{Bt}_{IS\,Al} \times I^{Bt}_{In} / I^{Bt}_{IS\,Al}) \times (C^{ratio}_{In} / C^{ratio}_{IS\,Al}) \times (I^{ratio}_{IS\,Al} / I^{ratio}_{In})$

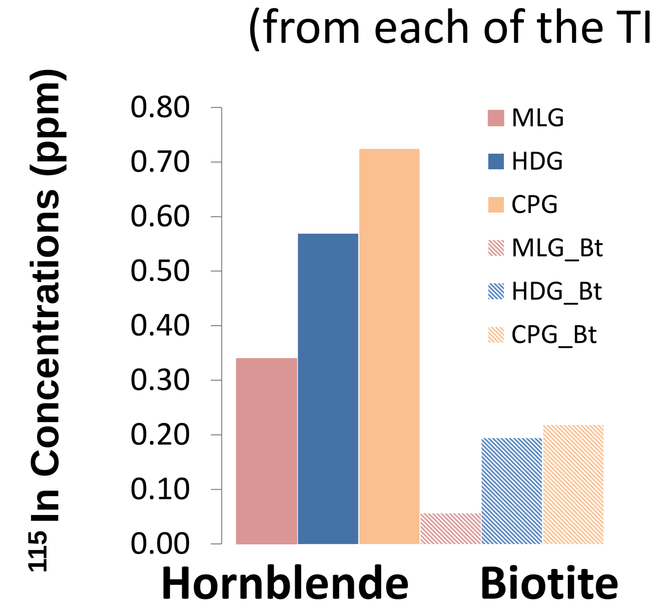
Limit of Detection

- $LOD^{Bt}_{In} = C^{Bt}_{IS} * (3 * \sigma BG_{In}) / \text{avg } I\,Bt_{IS} * (C^{ratio}_{In} / C^{ratio}_{IS}) * (I^{ratio}_{IS} / I^{ratio}_{In})$

Al = (IS) internal standard, Bt = biotite, BG = background signal, In = indium, C = concentration, I = signal intensity

^{115} Indium Concentrations in Hornblende and Biotite

(from each of the TIS members)



Hornblende was the dominant mineral to sequester indium (avg 0.54 ppm, 0.00054 mg/g). Hornblende from the CPG had the highest indium concentrations averaging 0.72 ppm (0.00072 mg/g) and the highest recorded measurement of any sample at 1.1 ppm (0.0011 mg/g); this is approximately 20 times more indium than the avg. concentrations found in the upper continental crust (0.056 ppm).

References:

Bateman, P. C., & Chappell, B. W. (1979). Crystallization, fractionation, and solidification of the Tuolumne Intrusive Series, Yosemite National Park, California. *Geological Society of America Bulletin*

Coleman, D. S., Gray, W., & Glazner, A. F. (2004). Rethinking the emplacement and evolution of zoned plutons; geochronologic evidence for incremental assembly of the Tuolumne Intrusive Suite, California. *Geology [Boulder]*, *32*(5), 433-436.

Longerich, H. P., Jackson, S. E., & Günther, D. (January 01, 1996). Inter-laboratory note. Laser ablation inductively coupled plasma mass spectrometric transient signal data acquisition and analyte concentration calculation. *Journal of Analytical Atomic Spectrometry, 11*, 9, 899-904.

Data and Results

	MLG		Std. Dev.	# of trials	Sample range per mineral
	Vol. %	ppm			
Quartz	18.0%				
Biotite	10.6%	0.06	0.01	3	0.05-0.06
Hornblende	10.9%	0.34	0.05	3	0.30 - 0.40
Plagioclase	48.4%	ins/d	ins/d	2	b/d - 0.05
Alkali Feldspar	10.6%	n/d	n/d	0	n/d
Titanite	0.4%	b/d	ins/d	2	b/d
Magnetite	0.5%	n/d	n/d	0	n/d
Chlorite	n/d	n/d	n/d	0	n/d
Apatite	0.2%	n/d	n/d	0	b/d - 0.19
	HDG		Std. Dev.	# of trials	
	Vol. %	ppm			
Biotite	3.7%	0.19	0.04	8	0.12 - 0.23
Hornblende	2.3%	0.57	0.01	6	0.38 - 0.71
Plagioclase	43.5%	b/d	ins/d	5	b/d
Alkali Feldspar	23.4%	b/d	ins/d	4	b/d
Titanite	0.6%	0.01	0.01	5	b/d - 0.03
Magnetite	1.0%	b/d	ins/d	2	b/d - 0.02
Chlorite	n/d	0.14	ins/d	1	0.14
Apatite	0.6%	n/d	n/d	0	n/d
	CPG		Std. Dev.	# of trials	
	Vol. %	ppm			
Biotite	3.8%	0.22	0.12	2	0.13 - 0.31
Hornblende	0.4%	0.72	0.25	6	0.48 - 1.13
Plagioclase	47.7%	b/d	ins/d	2	b/d
Alkali Feldspar	20.8%	ins/d	ins/d	3	b/d - 0.33
Titanite	0.5%	0.01	0.01	4	b/d - 0.03
Magnetite	0.7%	b/d	ins/d	3	b/d - 0.02
Chlorite	n/d	ins/d	ins/d	2	b/d - 0.34
Apatite	0.2%	n/d	n/d	0	n/d
	JGP		Std. Dev.	# of trials	
	Vol. %	ppm			
Biotite	1.5%	n/d	n/d	0	n/d
Hornblende	0.0%	n/d	n/d	0	n/d
Plagioclase	41.1%	b/d	n/d	2	b/d
Alkali Feldspar	29.0%	b/d	n/d	2	b/d
Titanite	0.1%	b/d	n/d	2	b/d
Magnetite	0.3%	0.04	0.02	2	0.03 - 0.06
Chlorite	n/d	ins/d	n/d	4	b/d - 0.23
Apatite	b/d	n/d	n/d	0	n/d

Table 2 Summary of mineralogy and concentrations of indium measured among each sample from the TIS.
<u>**Legend**</u> n/d: *no data,* Ins/d: *insufficient data,* b/d: below detection

Project Conclusions

As the abundance of ferromagnesian minerals decreased, their concentrations of indium increased; most notably with the hornblende in the first 3 TIS members. The first TIS intrusion (MLG) had indium concentration averages in biotite 3 x less than biotite in proceeding emplacement (HDG). The last TIS member to form (JGP) had no observed hornblende and was the only sample to successfully measure indium in the magnetite at 0.04 ppm. All the biotite sampled from the JGP had undergone chloritization with indium concentrations in some samples between 0.17 - 0.23 ppm (similar to levels found in the biotite from HDG and CDG), while others were b/d (therefore not in data averages). The later stages of crystallization had fewer ferromagnesian minerals yet hosting high concentrations of indium; this might result from the incompatible nature of indium with quartz, plagioclase and alkali feldspar and the decreasing melt phase as opposed to any appreciative increases with the concentration of indium.