Vein Related Mass Transport in the Ritter Range Roof Pendant During Late Cretaceous Contact Metamorphism

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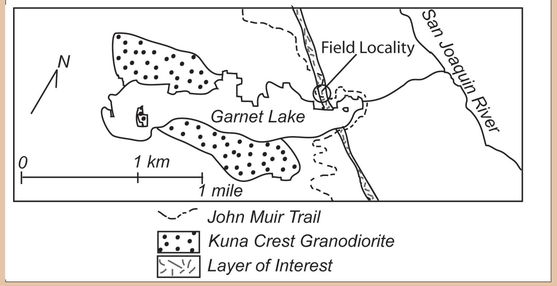
Abstract

A mass balance consideration of quartz-amphibole veins interpreted to have formed during peak metamorphic conditions (~2 kbar and 500 °C) in an andesitic meta-volcanic layer in the Ritter Range Roof Pendant suggests that vein material was derived both from cm-scale diffusion from the surrounding wall rock and from deposition of material from a far-field source. Changes in the mineralogy and mineral chemistry of phases in the altered region surrounding the veins, referred to as selvages, relative to unaltered wall rock suggest that selvages experienced mainly mass loss. The vein and selvage assemblage experienced a net gain of material relative to the unaltered wall rock. Application of the mass balance equation to individual elements provides a minimum constraint to the amount of that element that is derived from far-field sources.

Map of Field Locality



Mathematical Background

$$\Delta C_i * x^{sel} * \rho^{sel} + C_i^{vein} * x^{vein} * \rho^{sel} = C_i^{ext}$$

$$\Delta C_i = \left[\left(\frac{C^{wr}}{C^{sel}} \right)_{ref} \left(\frac{C^{sel}}{C^{wr}} \right)_i - 1 \right] C_i^{wr}$$

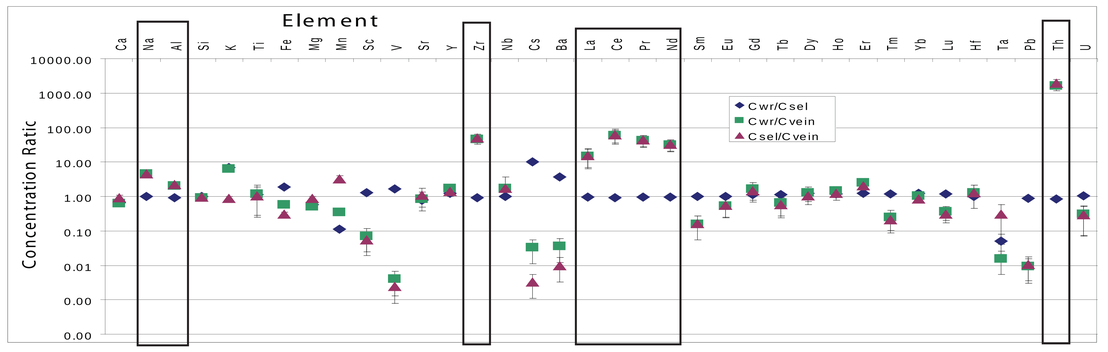
x **is thickness**
ρ **is density**
C **is concentration in mass element/mass rock**
$*C_i^{ext}$ **is mass element/area rock**
wr **denotes the wall rock region**
sel **demotes the selvage region**
vein **denotes the vein region**
i **is an element of interest**
ref **is an immobile reference element**

(Gresens, 1966; Grant 1986; Ague, 1994; Penniston-Dorland and Ferry, 2008)

Element Concentrations

	Wall Rock			Selvage			Vein		
	In Situ	2σ	Bulk Rock	2σ	In Situ	2σ	Bulk Rock	2σ	In Situ	2σ	
Ca	0.045	0.003	0.0467	0.0005	0.10	0.01	0.070	0.006	0.08	0.01	g / g
Na	0.020	0.001	0.0181	0.0002	0.021	0.001	0.018	0.002	0.004	0.001	g / g
Al	0.052	0.003	0.050	0.001	0.071	0.004	0.055	0.005	0.025	0.003	g / g
Si	0.26	0.01	0.258	0.003	0.29	0.02	0.26	0.02	0.28	0.02	g / g
K	0.0047	0.0002	0.0058	0.0001	0.0006	0.0001	0.0008	0.00001	0.0009	0.0001	g / g
Ti	0.0055	0.0002	0.0061	0.0001	0.01	0.01	0.0054	0.0005	0.005	0.004	g / g
Fe	0.058	0.002	0.059	0.001	0.05	0.01	0.031	0.003	0.10	0.01	g / g
Mg	0.014	0.001	0.0156	0.0002	0.011	0.002	0.027	0.002	0.030	0.003	g / g
Mn	0.00080	0.00003	0.00106	0.00001	0.001	0.001	0.010	0.001	0.003	0.001	g / g
Sc	10	1	23.3	0.2	11	3	18.0	0.2	323	210	μg / g
V	144	14	254	3	144	29	155	2	64040	42874	μg / g
Sr	625	74	650	7	848	93	851	9	767	423	μg / g
Y	4.4	0.5	23.1	0.2	25	7	18.5	0.2	13	4	μg / g
Zr	2.1	0.2	103	1	60	11	111	1	2	1	μg / g
Nb	0.45	0.04	4.00	0.04	8	5	4.00	0.04	2	3	μg / g
Cs	0.00	0.00	4.00	0.04	1.2	0.1	0.400	0.004	121	81	μg / g
Ba	242	26	576	6	149	16	159	2	15912	10653	μg / g
La	0.43	0.05	15.3	0.2	37	17	16.2	0.2	1	1	μg / g
Ce	0.79	0.08	30.9	0.3	74	35	33.1	0.3	0.5	0.2	μg / g
Pr	0.10	0.01	4.08	0.04	9	4	4.29	0.04	0.10	0.04	μg / g
Nd	0.64	0.05	17.5	0.2	41	19	18.1	0.2	0.6	0.2	μg / g
Sm	0.24	0.02	4.10	0.04	9	4	4.15	0.04	26	17	μg / g
Eu	0.26	0.02	1.27	0.01	3	1	1.29	0.01	2	1	μg / g
Gd	0.33	0.03	4.85	0.05	7	3	4.30	0.04	3	2	μg / g
Tb	0.08	0.01	0.75	0.01	0.9	0.4	0.650	0.007	1	1	μg / g
Dy	0.65	0.07	4.39	0.04	5	2	3.59	0.04	3	2	μg / g
Ho	0.15	0.02	0.88	0.01	0.9	0.3	0.735	0.007	0.6	0.2	μg / g
Er	0.44	0.05	2.56	0.03	2	1	2.05	0.02	1.0	0.2	μg / g
Tm	0.08	0.01	0.373	0.004	0.3	0.1	0.310	0.003	1	1	μg / g
Yb	0.56	0.06	2.50	0.03	2.3	0.5	2.00	0.02	2.4	0.5	μg / g
Lu	0.08	0.01	0.357	0.004	0.3	0.1	0.305	0.003	1.0	0.4	μg / g
Hf	0.08	0.01	3.00	0.03	1.9	0.4	3.00	0.03	2	2	μg / g
Ta	0.014	0.002	-	-	0.3	0.2	-	-	1	1	μg / g
Pb	18	2	14.0	0.1	19	2	16.0	0.2	1506	1009	μg / g
Th	0.030	0.003	2.30	0.02	6	3	2.70	0.03	0.0014	0.0004	μg / g
U	0.028	0.003	0.920	0.009	1.1	0.4	0.875	0.009	3	2	μg / g

Concentration Ratios for Elements Studied

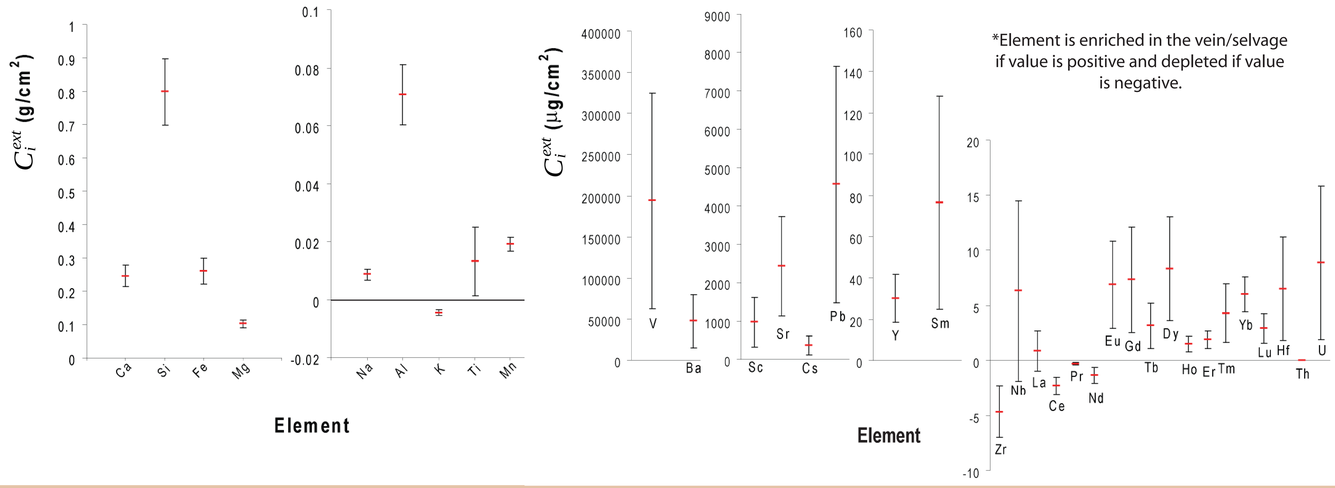


*Boxed elements have concentration ratios characteristic of low mobility elements. Thorium is used as the immobile reference in this study.

Phase Abundances

	Selvage (n = 587)		Wall Rock (n = 826)		Vein (n = 748)	
Selvage	Volume %	2σ error	Volume %	2σ error	Volume %	2σ error
Amphibole	17	4	17	3	52	5
Plagioclase	75	4	68	5	10	3
Biotite	0	-	11	3	0	-
Quartz	0.5	0.7	4	2	28	4
Ilmenite	0.6	0.8	0.8	0.9	0.6	0.8
Apatite	0.5	0.7	0.2	0.5	0	-
Calcite	0.7	0.8	0	-	2	2
Titanite	2	1	0	-	0.6	0.8
Epidote	4	2	0	-	3	2
Pyroxene	0	-	0	-	2	1
Chalcopyrite	0	-	0.1	0.4	0	-
Chlorite	0	-	0	-	1	1

Mass Balance Results



*Element is enriched in the vein/selvage if value is positive and depleted if value is negative.

Indicates Field Locality

Image of field locality taken from across Garnet Lake looking Northwest nearly parallel to the strike of layering

Image of an in place vein with selvage. Pocket knife for scale.

Image of hand sample RQ0853. This is the primary sample for vein and selvage material in this study.

Methods

Instrumentation
- Point counting - EDS and BSE on an EPMA
- Phase chemistry - WDS-EPMA and LA-ICP-MS
- Bulk rock chemistry - pressed pellet XRF* and ICP-MS*

Density Determination
- Vein - average phase densities weighted by phase abundance
- Selvage and wall rock - mass and volume measured

Thickness Measurements
- Average thickness calculated by repeated measurement across sample

Immobile Reference Frame Determination
- Suggested to be immobile in metamorphic environments (Zr, Th, REEs)
- Look for Cwr/Csel < 1, high Cwr/Cvein, and high Csel/Cvein
- Thorium used as IRF in this study.

Major Sources

Ague, J (1994).Mass transfer during barrovian metamorphism of pelites, south-central conneticut. 1: evidence for changes in composition and volume. *American Journal of Science, 294*, 989-1057.

Ague, J (2003).Fluid Flow in the Deep Crust. *Treatise on Geochemistry, 3*, 195-228.

Baumgartner, L and Olsen, S (1995). A least-squares approach to mass transport calculations using the isocon method. *Economic Geology, 90*, 1261-1270.

Grant, J (1986).The isocon Diagram – a simple solution to Gresens' Equation for Metasomatic Alteration. *Economic Geology, 81*, 477-1976-1982.

Gresens, R (1966).Composition-Volume relationships of metasomatism. *Chemical Geology, 2*, 47-65.

Hanson, B (1993).Long term evolution of fluid-rock interactions in magmatic arcs:evidence from the Ritter Range pendant, Sierra Nevada, California and numerical modeling. *Journal of Petrology, 34*, 23-62.

Holland, T and Powell, R (1998).An internally consistant thermodynamic data set for phases of petrological interest. *Journal of Metamorphic Geology, 16*, 309-343.

Masters, R and Ague J (2005).Regional-scale fluid flow and element mobility in Barrow's Metamorphic zones, Stonehaven, Scotland. *Contributions to Mineral and Petrology. 150*, 1-18.

Oliver, N and Bons, P (2001).Mechanisms of fluid flow and fluid-rock interaction in fossil metamorphic hydrothermal systems inferred from vein-wallrock patterns, geometry and microstructure. *Geofluids. 1*, 137-162.

Oliver, N (1996).Review and classification of structural controls on fluid flow during regional metamorphism. *Journal of Metamorphic Geology, 14*, 477-492.

Penniston-Dorland, S and Ferry, J (2008).Element mobility and scale of mass transport in the formation of quartz veins during regional metamorphism of the Waits River Formation, east-central Vermont. *American Mineralogist. 93*, 7-21.

Pyle, J., Spear, F., Rudnik, R., McDonough, W., (2001). Monazite-xenotime-garnet equilibrium in metapelites and a new monazite-garnet thermometer. *Journal of Petrology. 42*, 11, 2083-2107.

Sorensen, S Dunne, G, Hanson, RB, Barton, M, Becker, J, Tobisch, O, Fiske, R (1998). From Jurassic shores to Cretaceous plutons: geochemical evidence for paleoalteration environments of metavolcanic rocks, eastern California. *GSA Bulletin*. 110, 326-343.

Van Der Plas and Tobi (1965).A chart for judging the reliability of point counting results. *American Journal of Science. 263*, 87-89.

Conclusions

1) Ca, Si, Fe, Mg, Na, Al, Ti, Mn, V, Ba, Sc, Sr, Cs, Pb, Y, Hf, and U are ENRICHED in the vein/selvage relative to the wall rock.

2) K is DEPLETED in the vein/selvage relative to the wall rock.

3) Nb and La adhere to mass balance within error.

4) Ce,Pr, Sm, Nd, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, and Zr are suggested to have been mobilized, however, this is inconsistent with Ague (2003) and the concentration ratios of some of these elements suggest that they were not mobilized. Better characterization of the vein may negate this discrepency.

5) Silicon and calcium enrichment is consistent with studies of veins in metapelitic rocks (Ague, 1994, Masters and Ague, 2005; Penniston-Dorland and Ferry, 2008). Potassium depletion is consistent with Ague (1994) and Penniston-Dorland and Ferry (2008).

6) Na and K suggest that sodium metasomatism may be occuring suggesting that an infiltrating metamorphic fluid may have been traveling up temperature gradients.

Acknowledgements

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