Measuring host rock volume changes during magma emplacement: Reply

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We thank Dr. W.H. Owens for providing us this opportunity to discuss further our results on host-rock volume changes during magma emplacement and highlight some of our more recent work on the statistics behind estimating mass change associated with contact metamorphism. Owens is correct to point out the errors in the statistical analysis of the confidence limits as presented in our paper (Yoshinobu and Girty, 1999). Simply stated, we regret not including a more rigorous statistical approach while analyzing the data and writing the original manuscript. However, it is important to note that the following discussion and that by Dr. Owens do not change any of the conclusions presented in our original paper. In fact, we were surprised upon reviewing the literature how few studies actually deal with the problem of multivariate statistics and other statistical issues involving chemical compositional data such as closure and the 'constant sum problem' (for a notable exception, see Rollinson, 1993; Ague, 1994).

Excuses aside, it is important that the uncertainties in the chemical data under discussion be understood and well documented for the reader, which we apparently did not do! Therefore, we have recalculated Table 1 from Yoshinobu and Girty (1999) using the more rigorous statistical procedures outlined in Owens' Discussion and in Warren and Girty (1999). Included in the accompanying revised Table 1 are the 95% confidence intervals for density measurements (which were not included in our original paper) as well as corrected 95% confidence bands for all key chemical parameters. In addition, we have recalculated T_{Al}, and the mass redistribution of silica using both τ_{Al}^{Si} and equations discussed in Warren and Girty (1999). The results show T_{Al} to be $11.1 \pm 8.4\%$. In contrast, τ_{Al}^{Si} is recalculated to be $16.0 \pm 8.9\%$ while the slightly different procedure given in Warren and Girty (1999) for calculating mass change for a mobile species indicates a value of $16.0\%^{+12\%}_{-10.5\%}$ for SiO_2. Finally, the volume strain, ε, is recalculated to be $-12.5 \pm 8.3\%$. All uncertainties for estimates of ε, T_{Al}, and τ_{Al}^{Si} are given as 2σ values, and were calculated utilizing standard error propagation models following methods outlined in Warren and Girty (1999), and discussed by Dr. Owens. As noted in our introductory comments, none of these recalculated values differ significantly from the original values cited in our paper, and thus change none of our conclusions. Therefore, we conclude that silica mass may have been removed from the aureole of the Emigrant Gap pluton allowing volume strains to occur during the construction of the magma chamber. Given that many shallow-crustal pluton–host rock systems in a variety of fossilized arcs display features similar to those described in our paper, we wonder whether mass transfer and volume changes of varying magnitudes may be common phenomena during magma emplacement.

References

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Table 1
Recalculated mean values of major oxide abundances[a]

	Chlorite-grade belt		Andalusite ± cordierite belt		K-feldspar ± sillimanite belt		Aureole[b]	
	Mean (n = 13)	95% uncertainty	Mean (n = 17)	95% uncertainty	Mean (n = 9)	95% uncertainty	Mean (n = 26)	95% uncertainty
SiO_2	63.5	2.85	60.0	2.87	60.0	3.47	60.0	1.64
Al_2O_3	20.0	1.79	23.0	1.77	22.3	2.98	22.5	1.15
TiO_2	0.92	0.10	1.04	0.07	1.03	0.14	1.03	0.06
FeO^c	6.42	0.83	6.82	1.48	6.06	0.61	6.85	0.75
MnO	0.07	0.02	0.09	0.02	0.08	0.02	0.08	0.01
CaO	0.58	0.27	0.34	0.14	0.77	0.65	0.52	0.22
MgO	2.18	0.34	2.18	0.34	2.47	0.66	2.25	0.27
K_2O	4.68	1.29	5.82	0.47	5.95	0.59	5.86	0.30
Na_2O	1.49	1.50	0.59	0.27	1.15	0.39	0.82	0.20
P_2O_5	0.12	0.03	0.14	0.02	0.14	0.02	0.15	0.05
Density[d]	2.59	0.02	2.63	0.03	2.62	0.04	2.63	0.02

[a] Mean compositions were normalized on a volatile- and LOI-free basis.

[b] Student's t test indicates no difference between the andalusite ± cordierite and potassium feldspar ± sillimanite belts with the exception of Na_2O; therefore data were combined to form the aureole mean. Student's t test indicates that there is some likelihood that silica mass was removed during development of the aureole.

[c] Total iron as FeO.

[d] Bulk density measured in g/cm^3. All uncertainties are calculated on the basis of $t_{\alpha/2} * s_{\bar{x}}$, where $t_{\alpha/2}$ represents the Student's t value for 95% confidence, and $s_{\bar{x}}$ is the standard error of the mean calculated as $s/\sqrt{n}$, where s is the sample standard deviation and n is the number of specimens in the sample.