

## Time scales of metamorphic processes: Records in diffusion modification of mineral compositions and ages

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Diffusion in minerals could induce or modify compositional zoning, and also reset mineral ages during the thermal evolution of rocks. These diffusion modified properties provide important records of the time scales of metamorphic processes. We critically summarize here the available diffusion data in garnet, which is the most commonly used mineral to recover these time scales from diffusion-kinetic modeling, along with new experimental data from our on-going research program. These data are applied to retrieve the time scales of pro- and retro-grade metamorphic processes and exhumation velocities in selected metamorphic terranes.

Recent developments on the theory of closure temperatures and closure ages [1,2], which build on Dodson's seminal works on this subject, permit determination of cooling rate of metamorphic rocks from the extent of resetting of bulk mineral age or from the difference between the core and bulk ages of a mineral, as determined by a single decay system. This method has been applied to a garnet sample from the Valhalla complex, British Columbia, using the Sm-Nd decay system, to simultaneously retrieve both the peak metamorphic age (67±3 Ma) and the high temperature cooling rate. The latter is compatible with the cooling rate derived from the retrograde Fe-Mg zoning of the same crystal and earlier geochronological data [3].

We have recently determined the Fe-Mg interdiffusion in spinel [4] by diffusion couple experiments, and have now extended the program to study the coupled Fe-Mg and Cr-Al interdiffusion kinetics. Cr/(Cr+Al) ratio is found to strongly enhance Fe-Mg interdiffusion, whereas Cr-Al interdiffusion is much slower than the latter. These data permit modeling of compositional zonings in natural spinels, especially in the ultramafic rocks, to retrieve their cooling rates, which are illustrated by applications to selected samples.

### References

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## Analysis of Forty-Two Major and Trace Elements in USGS and NIST SRM Glasses by LA-ICPMS

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Forty-two major (Na, Mg, Ti and Mn) and trace elements covering the mass range from Li to U in three USGS basalt glass standards BCR-2G, BHVO-2G, and BIR-1G were analyzed using laser ablation-inductively coupled plasma mass spectrometry. Calibration was performed using NIST 610 as external standard in conjunction with internal standardization using Ca. Analysis was also done on NIST 612 and NIST 614 as well as NIST 610 as unknown and includes forty-five major (Al and Na) and trace elements. Relative standard deviation (RSD) of the analysis is below 10% for most elements in all these glasses under investigation. Consistent exceptions are Sn and Sb in BCR-2G, BHVO-2G, and BIR-1G. For BCR-2G, BHVO-2G, and BIR-1G, clear negative correlations on a logarithmic scale exist between RSD and concentration for elements lower than 1500 µg g<sup>-1</sup> with logarithmic correlation coefficient being -0.75 to -0.86. There is also a clear trend of increasing RSD with decreasing concentration from NIST 610 through NIST 612 to NIST 614. These suggest that the difference in the scatter of apparent element concentrations is not due to chemical heterogeneity but reflects analytical uncertainty. It is concluded that all these glasses are overall homogeneous on a scale of 60 µm.

Our first results on BHVO-2G and BIR-1G show that they generally agree with BHVO-2/BHVO-1 and BIR-1 within 10% relative. Exceptions are Nb, Ta and Pb in BHVO-2G, which are 14-45% lower than reference values for BHVO-2 and BHVO-1. Be, Ni, Zn, Y, Zr, Nb, Sn, Sb, Gd, Tb, Er, Pb, and U in BIR-1G are also exceptions. However, of them, Be, Nb, Sn, Sb, Gd, Tb, Pb, and U are consistent within 2s errors between our data and BIR-1 reference values. Results on NIST 612 agree well with published data except for Mg and Sn. This is also true for elements with m/z ≥85 (Rb) in the case of NIST 614.

The good agreement between measured and reference values for Na and Mg in BCR-2G, BHVO-2G, and BIR-1G and for Al and Na in NIST 610, NIST 612, and NIST 614 up to concentrations of at least several weight percent (possible to analyze due to a dynamic range of 10<sup>8</sup>) indicates the suitability of this technique for major, minor and trace element analysis.