Goldschmidt 2000
September 3rd–8th, 2000
Oxford, UK.

Journal of Conference Abstracts
Volume 5(2), 573

An Experimental View of the Behaviour of Noble Gases During Mantle Melting

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For many years experimental studies seemed to show that noble gases were quite compatible with partition coefficients in the range 0.01 to 1, while evidence from natural occurrences strongly indicated a much more incompatible nature. Thus while noble gas isotope ratio studies have made an important contribution to mantle models, the lack of reliable experimental partition coefficients prevented modelling of noble gas elemental ratios. Precise noble gas partition coefficients were not critical to box models for simple two layer mantle, crust and atmosphere. However, understanding dynamic processes such as the demonstrated interchange of material between the upper and lower mantle, whole mantle convection and mantle over-turn require a better understanding of noble gas behaviour. Our earliest experiments using an ultra-violet laser to extract argon from single crystals of clinopyroxene and olivine demonstrated that argon is incompatible at 1 bar, yielding partition coefficients as low as 0.0016 (Brooker et al. 1998). Though this was the first experimental evidence that noble gases were truly incompatible, it represented only a value at the earth's surface. In more recent experiments on clinopyroxene/melt partitioning of Ar we found no change in compatibility between 1 bar and 8 GPa. The experiments proved to be easier at higher pressures where the crystals were easier to grow and could dissolve 10000 times as much Ar as at 1bar. Partition coefficients did not change significantly from 1 bar to 8 GPa and centred around a value of 0.001. More important to mantle evolution than variations with pressure is the variation of partition coefficients between noble gases. Such differences have been evoked to explain differences in efficiency of extraction from the mantle and differences in recycling at subduction zones. Multi-gas experiments on noble gas partition between clinopyroxene and melt have been undertaken at Bristol and analysed at the Open University, using a gas mixture including He, Ne, Ar and Kr. Though there have been difficulties resulting from outgassing of helium from the melt glasses, initial data show a gradual trend to greater incompatibility with atomic radius. Coefficients vary from around 0.007 for helium to around 0.0004 for Kr. The new noble gas data parallel trends in other elements predicted by Blundy and Wood (1994) using lattice strain theory. In contrast to the large variations (orders of magnitude) observed within suites of 3+ and 2+ elements substituting in clinopyroxene, however, a total variation of only around 20 is observed for the noble gases. Further, the value for helium is very much lower than any other element of similarly small radius. Several interesting predictions flow from these preliminary data and more data will obviously lead to further insights. Firstly, all the noble gases are incompatible and thus some form of mid-ocean ridge process would be an effective method of extracting noble gases from the primordial mantle. If other parameters were equal, xenon might have been extracted more efficiently than the other noble gases in this regime. Small degree melts in the present day should result in helium depletion relative to the other noble gases, but this is in contrast to measurements of natural MORB basalts which have enhanced He/Ar ratios.

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