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Identifying the Mechanism and Character of Magmatic CO_2 Emplacement into Sedimentary Structures II: Resolving Magmatic He, Ne and Ar in Harding County (New Mexico) CO_2 Well Gases

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Identifying and tracing magmatic CO_2 emplacement in crustal systems remains a fundamental problem in hydrocarbon and mineral exploration. However, ^{3}He is an unambiguous tracer of magmatic fluid input into shallow crustal fluids (Oxburgh et al., 1986). The relationship between CO_2 and ^{3}He in mid-ocean ridge settings is well defined, with a $CO_2/^3$He range of ~1-7x10^9. This is small compared with continental fluid systems, which range between 10^5-10^{13}. Crustal fluids with $CO_2/^3$He in the magmatic range clearly contain a magmatic CO_2 component, although varying values of $CO_2/^3$He can still be ascribed to a significant crustal CO_2 admixture or reactive loss (Sherwood, Lollar et al., 1997).

Magmatic ^{3}He/^{22}Ne resolved in basinal fluids is fractionated from mid-ocean ridge source values and is accounted for by melt/gas fractionation during partial degassing of deep magmas (Ballentine, 1997). Partial magmatic degassing accounts for observed systematic spatial variation in $CO_2/^3$He in CO_2 rich gas fields in the Permian Basin, SW Texas, USA. In this case, the highest $CO_2/^3$He values are produced by the first stages of outgassing. This variation therefore, preserves a record of flow direction and reservoir filling history (Ballentine et al., 2000). Quantifying the magmatic CO_2 contribution or identifying the magmatic fluid flow direction where the CO_2 record has been perturbed by crustal addition or reaction is only possible by extension of this technique to other inert magmatic tracers. Mantle Ne and Ar can be resolved using their respective isotope systematics. Nevertheless, we need to be able to demonstrate that the magmatic Ar/^{3}He and Ne/^{3}He fractionation behaves coherently with $CO_2/^3$He, and that a melt/gas solubility model can reasonably describe the fractionation.

We present here results from a study of a classic CO_2 well gas system to address this. The Bueyeros field (Phinney et al., 1978, Caffee et al., 1999) is a small section of the Bravo Dome gas field, which covers an area of some ~2400km^2 and contains an estimated 2.3x10^{11}m^3 (STP) of 99%+ pure CO_2. The field is located in Harding and Union Counties, New Mexico, 35 km to the South of the Cenozoic volcanism (Raton-Clayton field) related to the Sierra Grande uplift. The field is a structural-stratigraphic trap of a faulted southeast plunging nose producing from feldspathic Permian sandstone sealed above by anhydrite and pinching out Northeast on Precambrian basement at 600-1000 m depth.

We have determined the He, Ne and Ar isotopic composition and abundance of samples collected from 14 producing wells across the field. ^{3}He/^{4}He, ^{20}Ne/22Ne and ^{40}Ar/^{36}Ar vary coherently between 0.76-3.78 Ra, 9.93-11.88 and 4,653-22,491 respectively. ^{21}Ne/^{22}Ne vary between 0.0515-0.0583. ^{4}He, ^{20}Ne and ^{40}Ar vary between 0.4-4.4x10^{-4}, 1.2-7x10^{-9} and 2.4-6.5x10^{-5} cc(STP)/cc respectively and are all anti-correlated with ^{3}He/^{4}He. ^{3}He/^{4}He are a two component mixture of mantle and crustal-derived He. Ne and Ar isotopes are a result of varying proportions of crustal, mantle and water (dissolved air)-derived noble gases. Three components and three isotopes enables the air-Ne contribution to be calculated and removed to give 21Ne* (Ballentine, 1997). Similarly, all ^{40}Ar contributing to ^{40}Ar/36Ar ratios greater than the air value of 295.5 are due to a two component mixture of mantle and crustal ^{40}Ar, or ^{40}Ar*. Plots of ^{21}Ne*/^{4}He and ^{40}Ar*/^{4}He vs. ^{3}He/^{4}He therefore represent two component mixtures of mantle and crustal end-members. Extrapolation to the crustal value of ^{3}He/^{4}He=0.02Ra defines the crustal ^{4}He/^{40}Ar and ^{4}He/^{21}Ne to be 16.01 and 3.53x10^7 with correlation coefficients of 0.993 and 0.966 respectively (Figure). Individual samples are corrected for the crustal contribution, assuming that mantle ^{3}He/^{4}He=8Ra, to determine the mantle ^{21}Ne and ^{40}Ar. Mantle ^{3}He/^{4}He values of between 4.5Ra and 8Ra (MOR Source) have been used to test model sensitivity.

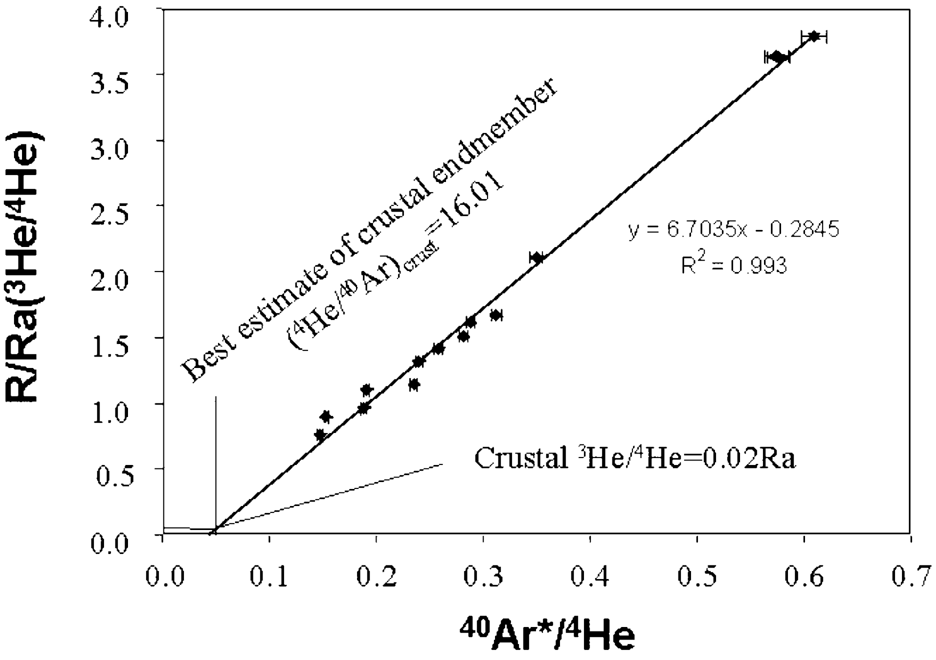

Figure 1: Resolving magmatic ^{40}Ar: Plot of ^{3}He/^{4}He(R/Ra), against ^{40}Ar*/^{4}He. Both axes represent two component mixtures of crustal and magmatic end-members. Interception of the mixing line with the crustal ^{3}He/^{4}He gives the crustal ^{40}Ar/^{4}He end-member. Assuming a mantle ^{3}He/^{4}He value (8Ra), enables the crustal ^{4}He and therefore crustal ^{40}Ar to be determined. The residual is magmatic ^{40}Ar.

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