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Identifying the Mechanism and Character of Magmatic CO_2 Emplacement into Sedimentary Structures I: $CO_2/^3He/\delta^{13}C(CO_2)$ Variation in CO_2 Rich Permian Basin Natural Gases

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The JM-BB field is located in the Val-Verde basin in West Texas on the foredeep margin of the late Palaeozoic Marathon Allochthon Thrust Belt (Shoemaker, 1992). The main producing formation in this section of the Permian Basin is brecciated Ellenberger Dolomite. The gas composition varies between 20-60% by volume CO_2, the remaining gas being dominated by CH_4. In addition to high precision stable isotope analysis of these gases, we have determined the He, Ne, Ar isotope and abundance composition in twelve of these gases. $^3He/^4He$ and $CO_2/^3He$ correlates directly with CO_2 content, varying between $^3He/^4He$=0.2 to 0.55Ra, $CO_2/^3He$=4.2x10^9 to 6.2x10^9 for CO_2=20 to 55% respectively. The $^3He/^4He$ ratio is a result of resolvable magmatic-crustal two component mixing. Between 3.2 to 6.8% of the ^4He is estimated to be mantle-derived. The remainder is crustal-radiogenic in origin. Measured $^{20}Ne/^{22}Ne$, $^{21}Ne/^{22}Ne$ and $^{40}Ar/^{36}Ar$ vary between 9.28-10.02, 0.037-0.073 and 1030-5660 respectively, and enable air-derived Ne and Ar to be resolved from crustal radiogenic components (e.g. Ballentine et al., 1991).

Samples free of modern air contamination have low groundwater (dissolved air)-derived Ne and Ar concentrations that are unfractionated from typical water values. This result shows that the groundwater system played no resolvable role in either the gas transport to the trapping structure or composition variation. Resolved crustal-radiogenic gases are found at their predicted $^4He/^{21}Ne/^{40}Ar$ average crustal production ratios. The crustal radiogenic gases are associated with both CO_2 and CH_4 end-members. The crustal noble gas ratios are typical of a gas phase that is derived from regions of the crust at temperatures >250°C (Ballentine et al., 1994) and has migrated to the trapping structure without any transport or phase related fractionation.

$CO_2/^3He$ are within the range found in typical mantle environments (1-10x10^9) (Marty and Jambon, 1987), compared to the range in crustal fluids of 10^5-10^{13} (Sherwood Lollar et al., 1997), and reasonably contain a significant magmatic CO_2 component. The variation in $CO_2/^3He$ can be explained by three mechanisms: i) crustal CO_2 addition; ii) precipitation of CO_2; and iii) magmatic source variation. High precision $\delta^{13}C(CO_2)$ (±0.015‰) shows <0.3‰ variation across the entire field. Exceptional coincidence notwithstanding, this is not consistent with crustal CO_2 addition or fractionation caused by CO_2 precipitation. A simple model of Rayleigh style magmatic degassing has been constructed. 10-20% partial degassing of a deep-seated magma body is consistent with both $CO_2/^3He$ and $\delta^{13}C(CO_2)$ variation.

Within the context of the magmatic degassing model, JM-BB samples with the highest $^3He/CO_2$ preserve the earliest stages of magmatic outgassing and, assuming a simple filling history, are likely to be the furthest from the CO_2 source. On the JM-BB field scale the highest $CO_2/^3He$ values are found in the samples with the highest %CO_2. On a regional scale, the highest %CO_2 natural gases are found on the Northern and Eastern margins of the Marathon Thrust Belt and Diablo Uplift respectively. These gases follow the JM-BB $^3He/CO_2$ trend and suggest that these two structures are not spatially related to the CO_2 source. The magmatic source must be to the North or East of these features. This in itself is not surprising. Magmatic fluids, traced by the presence of ^3He, are typically associated with deep melting associated with regional extension or uplift rather than compression or loading (Oxburgh et al., 1986).

Identification of the general direction of CO_2 migration also constrains the timing of the CO_2 input relative to the CH_4. Assuming simple filling, if CH_4 were already present samples nearest the source of the CO_2 might be expected to have the highest %CO_2 concentrations. These in fact have the highest %CH_4 content. The distribution of $CO_2/^3He$ and CH_4/CO_2 is consistent with an initial input of magmatic CO_2, from the North or East of the field before significant CH_4 generation. This is temporally and spatially consistent with the uplift of the Central Basin and Ozona Platforms providing the magmatic CO_2 source. The subsequent CH_4 generation in the Val-Verde and Southern Delaware basin foredeeps has resulted in the observed overprinting and dilution of the CO_2 containing the most evolved (low $CO_2/^3He$) magma-degassing signature.

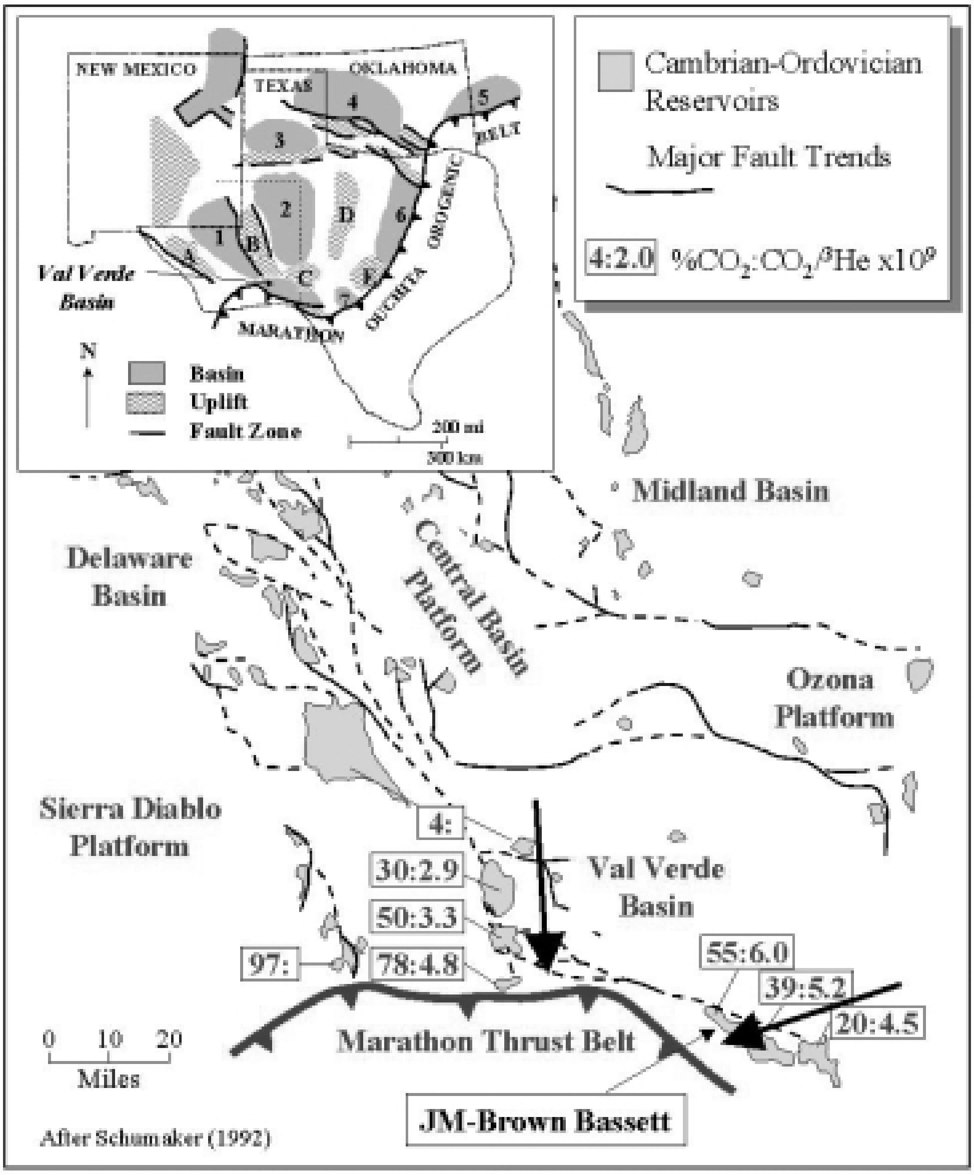

Figure 1: Tectonic location of the JM-Brown Bassett natural gas field. Arrows show direction of the regional increase in CO$_2$/^{3}He towards the Marathon Thrust Belt. The inset shows the location of the Val Verde Basin relative to the major Permian basin and uplift features. Basins: 1-Delaware, 2-Midland, 3-Palo-Duro, 4-Anadarko, 5-Arkoma, 6-Ft. Worth. Uplifts: A-Sierra Diablo, B-Central Basin, C-Ozona, D) Concho Arch, E) Llano.

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