Application of Noble Gas Isotopic Signatures at McElmo Dome-DOE Canyon Field to Investigate CO_2 Source and System Characterization*

Joshua G. Adams[1], David Gonzales[1], and Thomas Darrah[2]

Search and Discovery Article #41711 (2015)**
Posted October 26, 2015

*Adapted from oral presentation given at AAPG Annual Convention & Exhibition, Denver, Colorado, May 31-June 3, 2015

[1]Geosciences, Fort Lewis College, Durango, Colorado (jgadams@fortlewis.edu)
[2]School of Earth Sciences, The Ohio State University, Smart Gas Sciences, Columbus, Ohio

Abstract

The McElmo Dome-DOE Canyon Field in the Four Corners region is one of the largest sources of CO_2 in the Rocky Mountain region. In prior studies, hypotheses in favor of CO_2 generation by thermal in situ decomposition of carbonate-sulfate assemblages in the Leadville Limestone or magmatic-gas release were proposed. The fundamental source of the gases, however, remained poorly understood. In this investigation, noble gas isotope signatures were used in an attempt to fingerprint the source of the CO_2 gas and test competing hypotheses on its origin, migration, and evolution. Analyses of noble gas isotopes, stable isotopes, and major gas compositions across the McElmo-DOE Field reveal variable and mixed mantle-crust signatures which are dominated by the addition of radiogenic crustal signatures (4He, 21Ne, 40Ar). A comparison of CO_2/3He against CO_2 concentrations are consistent with a magmatic 3He source that mixed with crustal contributions. The crustal contributions are indicated by helium isotope ratios 3He/4He (where the ratio of RAIR=1) from 0.057 to 0.215 (R/Ra), nucleogenic (following U and Th decay) 20Ne/22Ne (<8.5), 21Ne/22Ne (>0.10), and highly elevated radiogenic Ar with 40Ar/36Ar* >15,000. Our preliminary data suggests that CO_2 gas was likely sourced from Cenozoic magmatic activity in the region that filled Leadville Formation traps at the time of magmatism. Magmatic events spanned the period from 75-5 Ma and involved melting of Proterozoic lithospheric mantle which was a key source of carbonated mantle melts in the Oligocene. Mafic rocks generated from these melts have elevated K, U, Th and F, and these magmas could have been a major source of the exceptionally high nucleogenic (21Ne, 22Ne) and radiogenic (4He,40Ar) signatures of noble gases in the McElmo Dome and Doe Canyon CO_2 fields.

Selected References

Allis, R.G., T. Chidsey, W. Gwynn, C. Morgan, S. White, M. Adams, and J. Moore, 2001, Natural CO_2 reservoirs on the Colorado Plateau and Southern Rocky Mountains: Candidates for CO_2 sequestration: Proc. of 1st National Conference on CO_2 Sequestration, DOE NETL, Washington, D.C., May 14-17.

Broadhead, R.F., M. Mansel, and J. Jones, 2009, Carbon dioxide in New Mexico: Geologic distribution of natural occurrences: New Mexico Bureau of Geology and Mineral Resources, Open File Report No. 514, 131 p.

Caffee M.W., G.B. Hudson, C. Velsko, G.R. Huss, E.C. Alexander Jr, and A.R. Chivas, 1999, Primordial noble gases from Earth's mantle: Identification of a primitive volatile component: Science, v. 285, p. 2115-2118.

Cappa, J., and D. Rice, 1995, Carbon dioxide in Mississippian rocks of the Paradox Basin and adjacent areas, Colorado, Utah, New Mexico, and Arizona: U.S. Geological Survey Bulletin, 2000-H.

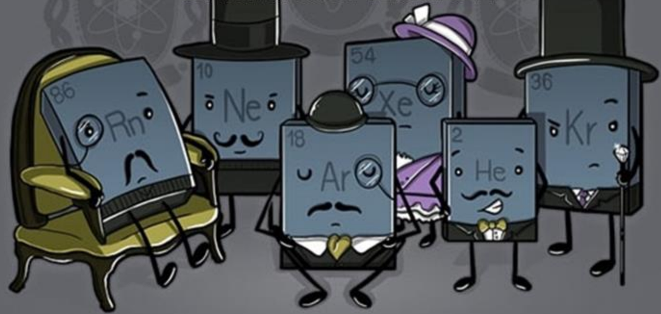
Farmer, G.L., T. Bailley, and L.T. Elkins-Tanton, 2007, Mantle source volumes and the origin of the mid-Tertiary ignimbrite flare-up in the southern Rocky Mountains, western U.S.: Lithos, v. 102, p. 279-294.

Gilfillan, S., G. Holland, D. Blagburn, S. Stevens, M. Schoell, M. Cassidy, Z. Ding, Z. Zhou, G. Lacrampe-Couloume, and C.J. Ballentine, 2009, Solubility trapping in formation water as dominant CO_2 sink in natural gas fields: Nature, v. 458, p. 614-618.

Holland, G., and S. Gilfillan, 2013, Application of noble gases to the viability of CO_2 storage: *in* P. Burnard, ed., The Noble Gases as Geochemical Tracers, Springer Berlin.

Winkler, H.G.F., 1979, Petrogenesis of Metamorphic Rocks: New York, Springer-Verlag, 348 p.

Application of Noble Gas Isotopic Signatures at McElmo Dome-Doe Canyon to Investigate CO_2 Source and System Characterization



teecraze.com

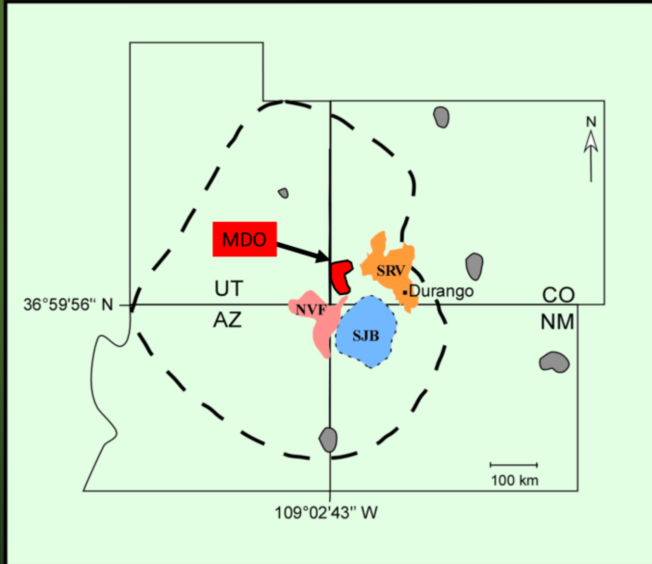
Joshua G. Adams
David Gonzales
Thomas Darrah

KINDER MORGAN CO_2 COMPANY, L.P.

FORT LEWIS COLLEGE DURANGO, COLORADO

McElmo Dome & Doe Canyon (MDO)

~8 TCF of CO_2



modified from Allis et al. (2001)

Hypotheses on Source

- Thermal decomposition of limestone (Cappa and Rice, 1995)

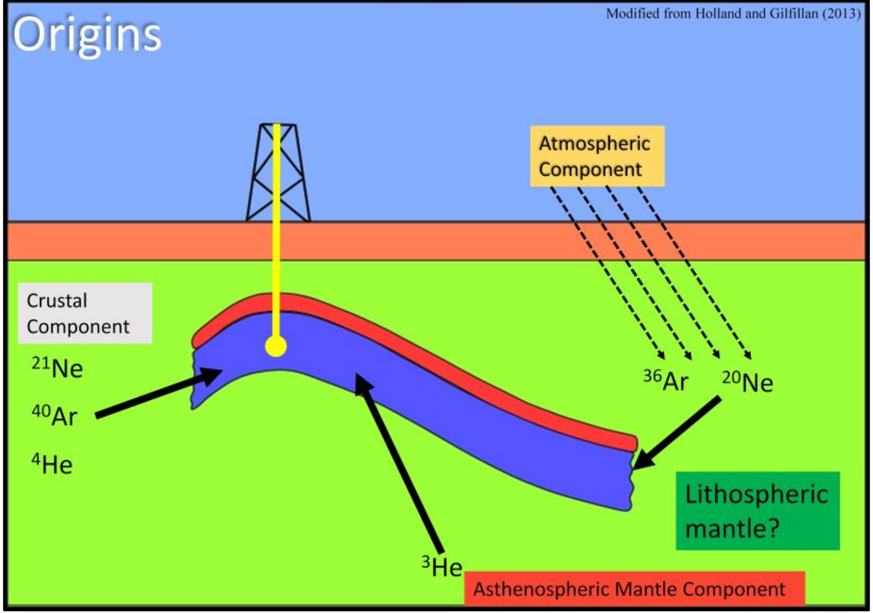
- Magmatic (Caffee et al., 1999; Gilfillan et al., 2008; Broadhead et al., 2009; Holland and Gilfillan, 2013)

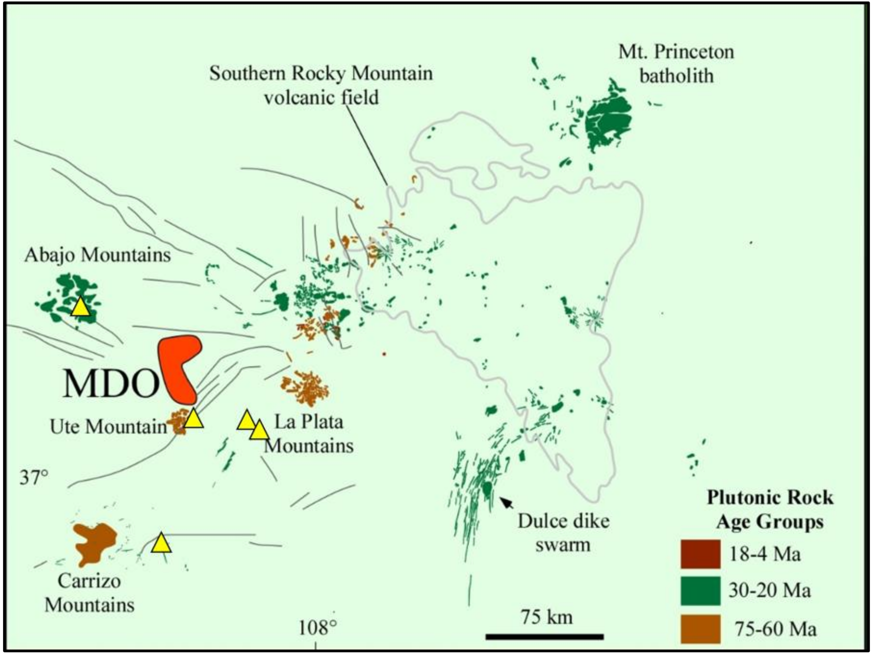
Goals

- Source and evolution of the gas using noble gas isotopes (Ar, Ne, and He)
- Spatial and temporal trends

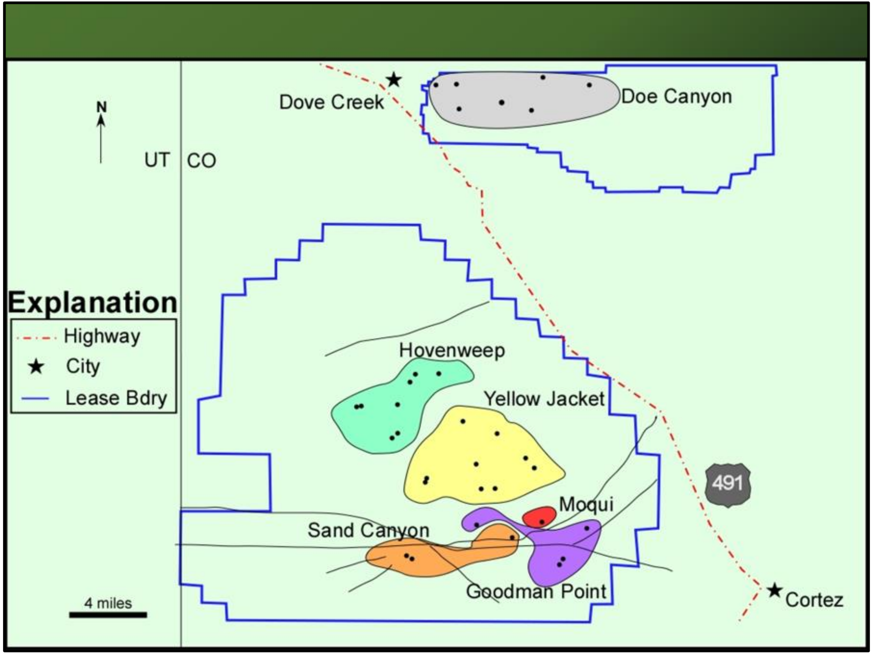
Presenter's notes: Lack of metamorphic facies in core.
Shear volume from a 300 ft thick reservoir.
Noble gases from decomposition.
We want to see if Laramide or later event are more likely to make the CO_2.

Origins


Modified from Holland and Gilfillan (2013)
Atmospheric Component
Crustal Component
^{21}Ne
^{40}Ar
^{4}He
^{36}Ar
^{20}Ne
Lithospheric mantle?
^{3}He
Asthenospheric Mantle Component



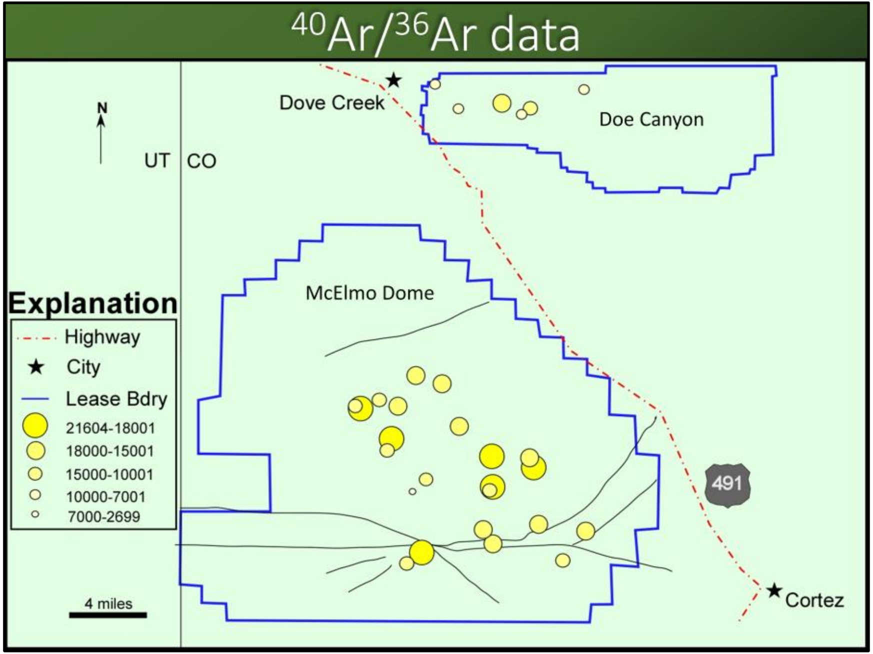
Presenter's notes: Previous research from Ballentine, Graham, Sherwood, and many others.



Presenter's notes: Lots of smoking guns.
Three greatest pulses of magmatism.

Analyses

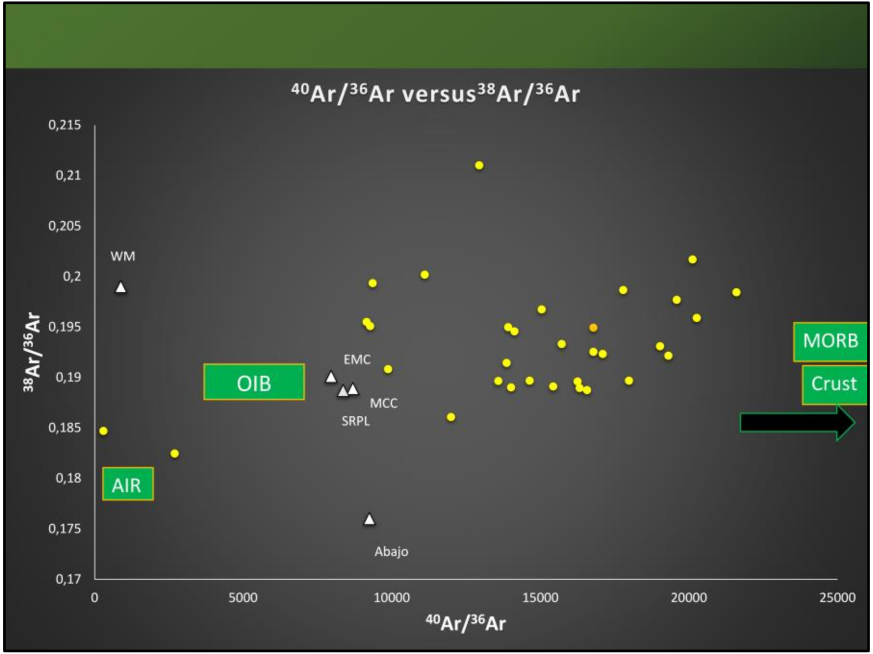
- Gas isotopes measured using the Thermo Fisher Helix SFT MS at Smart Gas Sciences
- ICP-MS on gases from crushed rock samples in a vacuum system



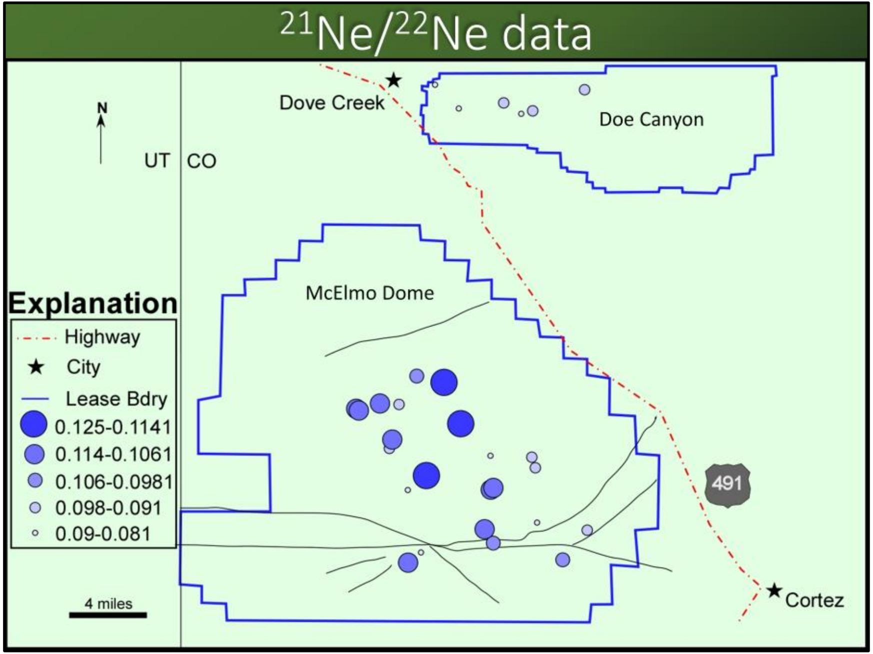
Presenter's notes: Sampling was done via a conventional 3/4-inch National Pipe Thread (NPT) sample port connected directly to the wellhead. Sulfinert stainless steel cylinders were initially filled to a pressure of 40 psi and held at a stable pressure for 2-5 minutes. The exit value on the cylinder was then closed to allow the line to pressurize. This process was repeated 5 times in order to reduce atmospheric contamination. Once the purging process was completed the container was air tight sealed and ground shipped to Smart Gas Sciences for analysis. For a more detailed description of this sampling method please refer to methods outlined by Tom Darrah.

Full distribution of the field.

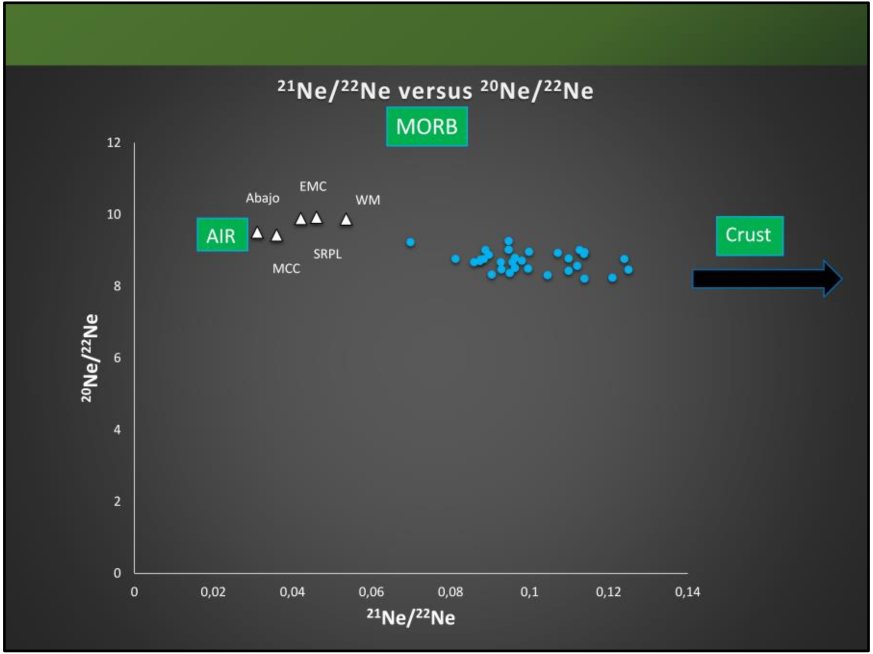
Previous studies had no constraint on sample location.



⁴⁰Ar/³⁶Ar versus³⁸Ar/³⁶Ar
³⁸Ar/³⁶Ar
0,215
0,21
0,205
0,2
0,195
0,19
0,185
0,18
0,175
0,17
0
5000
10000
15000
20000
25000
⁴⁰Ar/³⁶Ar
WM
EMC
MCC
SRPL
Abajo
OIB
AIR
MORB
Crust

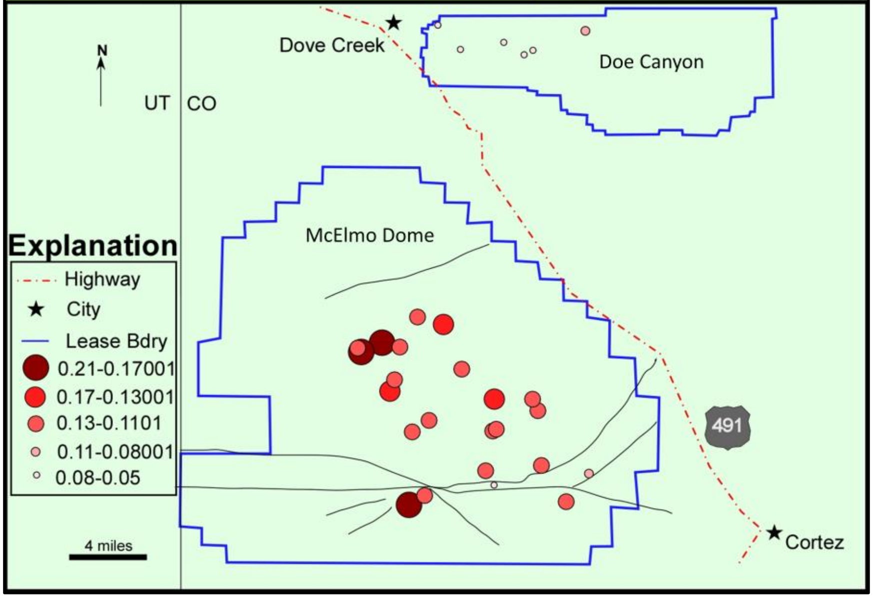


Presenter's notes: Lohoi and MORB (Vanderbracht et. al., 1997; Farley and Craig, 1994).
Archean Crust (Holland et al., 2013).

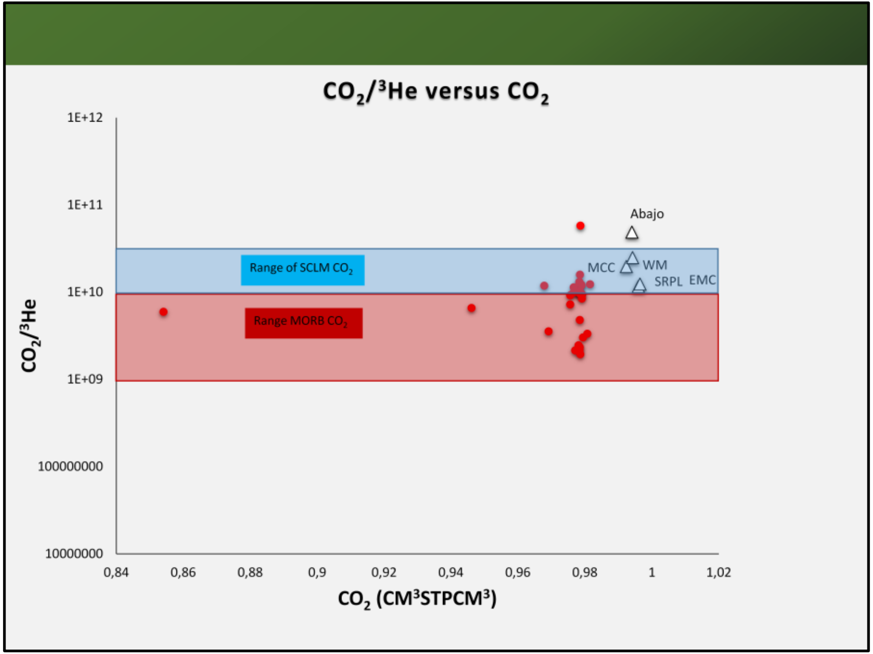


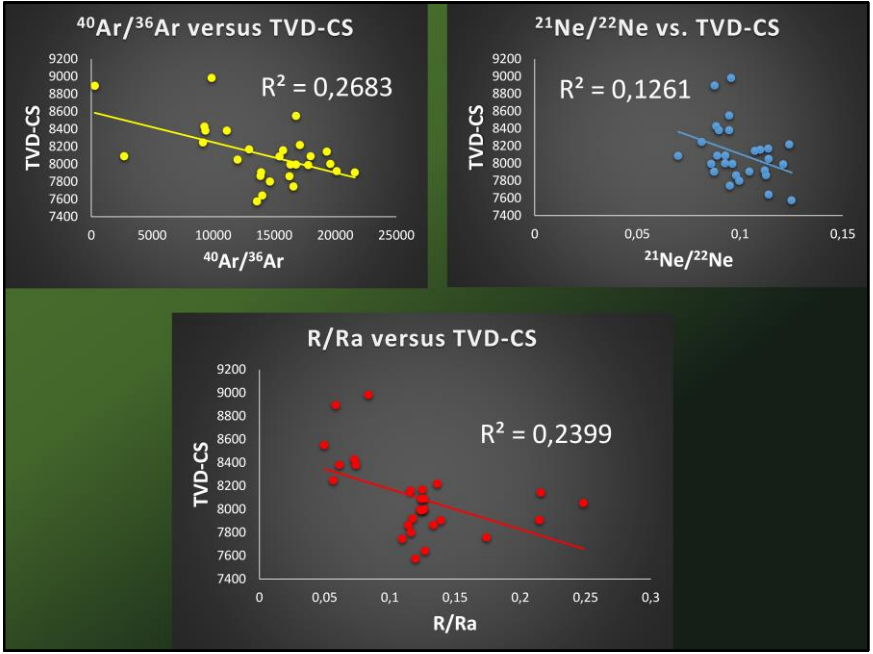
$^{21}Ne/^{22}Ne$ versus $^{20}Ne/^{22}Ne$
MORB
AIR
Crust
Abajo
EMC
WM
MCC
SRPL
$^{20}Ne/^{22}Ne$
$^{21}Ne/^{22}Ne$
0
2
4
6
8
10
12
0
0,02
0,04
0,06
0,08
0,1
0,12
0,14

$^3He/^4He$ (R/Ra) data



Presenter's notes: MORB = Ballentine, 1997.
Holland et al 2013 = Archean Crust.


CO2/3He versus CO2
1E+12
1E+11
1E+10
1E+09
100000000
10000000
CO2/3He
Range of SCLM CO2
Range MORB CO2
Abajo
MCC
WM
SRPL
EMC
0,84
0,86
0,88
0,9
0,92
0,94
0,96
0,98
1
1,02
CO2 (CM3STPCM3)



$^{40}Ar/^{36}Ar$ versus TVD-CS
R^2 = 0,2683
TVD-CS
9200
9000
8800
8600
8400
8200
8000
7800
7600
7400
0
5000
10000
15000
20000
25000
$^{40}Ar/^{36}Ar$
$^{21}Ne/^{22}Ne$ vs. TVD-CS
R^2 = 0,1261
TVD-CS
9200
9000
8800
8600
8400
8200
8000
7800
7600
7400
0
0,05
0,1
0,15
$^{21}Ne/^{22}Ne$
R/Ra versus TVD-CS
R^2 = 0,2399
TVD-CS
9200
9000
8800
8600
8400
8200
8000
7800
7600
7400
0
0,05
0,1
0,15
0,2
0,25
0,3
R/Ra

Trends

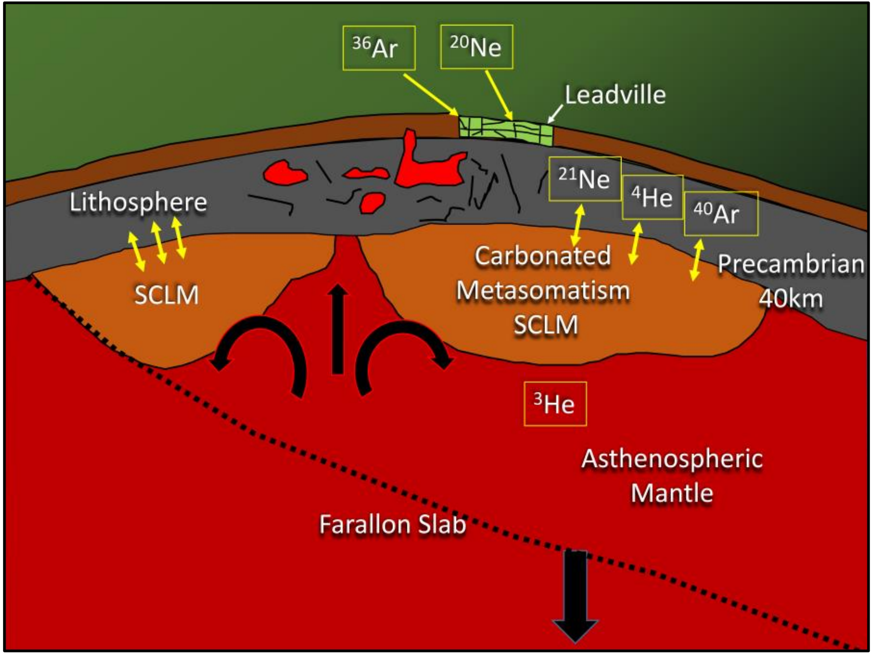
- McElmo and Doe Canyon have notable distinction
- No variation in time (Gilfillan et al., 2008)
- No depth or structural control to isotopic variation
- Not homogenized – heterogeneous
- No clear defined MORB signature

Thermal Decomposition?

- Lack of metamorphic facies or recrystallization (Gianinny personal communication, 2014)
- Extremely elevated radiogenic and nucleogenic Ar and Ne
- 1 mole of calcite + 1 mole of quartz is required to generate 1 mole of wollastonite + 1 mole of carbon dioxide (e.g., Winkler, 1979).
- Not enough Leadville

Magmatic Source

- Long term regional magmatic history (75-5Ma)
- Enormous mantle magma body during the Oligocene (Farmer et al., 2007)
- NVF rocks (SCLM) have calcite and diatremes (Gonzales and Lake, 2015 in prep)
- Isotopes are not just magmatic (crustal and atmospheric)



36Ar
20Ne
Leadville
Lithosphere
21Ne
4He
40Ar
Carbonated
Metasomatism
SCLM
SCLM
Precambrian
40km
3He
Asthenospheric
Mantle
Farallon Slab

Acknowledgments

Kinder Morgan CO_2
Dr. David Gonzales
Dr. Thomas Darrah
Dr. Brian Brister
Dr. Lanny Schoeling
Dr. Ray Kenny
Dr. Gary Gianinny
Dr. Laurie Crossey
Dr. Carl Karlstrom
Rick Gersch
Jeanie Johnson
Andrea Kirkpatrick
Fort Lewis College Geoscience Department