Loss of CO_2 Gas into Formation Water at the Natural CO_2 Deposit of Bravo Dome, New Mexico, USA*

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Abstract

Bravo Dome Field, in the NE corner of New Mexico, contains approximately 10 Trillion cubic feet of 98% pure CO_2 in the Permian age Tubb Sandstone formation on top of granite basement beneath a regional seal of the Cimmaron Anhydrite formation at the Eastern edge of the Quaternary Raton-Clayton Volcanic field. The trap for the deposit is a lateral facies change to the NW of the Tubb Sandstone draped over the SW plunging Sierra Grande uplift. The field is approximately 49 miles NW-SE and 50 miles NE-SW.

Evidence from distribution of noble gases in 14 wells spread across the field shows that within eight miles of the downdip gas water contact in the east part of the field, CO_2 has left the reservoir by dissolution in the underlying formation water. Noble gases have partitioned into the CO_2 from the water. In the west the noble gases and their isotopes are in low concentrations and distinctive of the mantle. In wells to the east the noble gases increase in concentrations because they have entered the CO_2 from the water. The gradient allowed calculation of mantle concentration of the gases (Ballentine et al., 2005).

However, the ^3He increases because it is left behind as the CO_2 dissolves in the water.

Maps of variation of each noble gas (except xenon, radon) will be presented, each showing an increase in concentration from west to east across the field. A surprise was that ^3He doubles in concentration at the gas/water contact to the east, yet it is not carried in any quantity by the water below the field. The accumulation of ^3He near the gas-water contact is therefore due to depletion of CO_2 in the gas due to dissolution in the underlying water.

From the doubling of ^3He concentration at the gas-water contact one can surmise half of the volume of the CO_2 has been lost at the gas-water contact. More detailed calculations will be shown. The continued dissolution of the CO_2 into the brine may be favored by the sinking of the

dense CO_2 saturated water away from the gas-water contact. The mass transport of CO_2 away from the gas-water contact is due to natural convection and much larger than diffusive mass transfer and may explain the observed large ^{3}He build-up.

In summary, it is highly probable that CO_2 has been lost downdip in formation water, and this may well be a general situation in nature (Gilfillan et al., 2009) and in CO_2 sequestration projects.

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Department of Earth and Atmospheric Sciences

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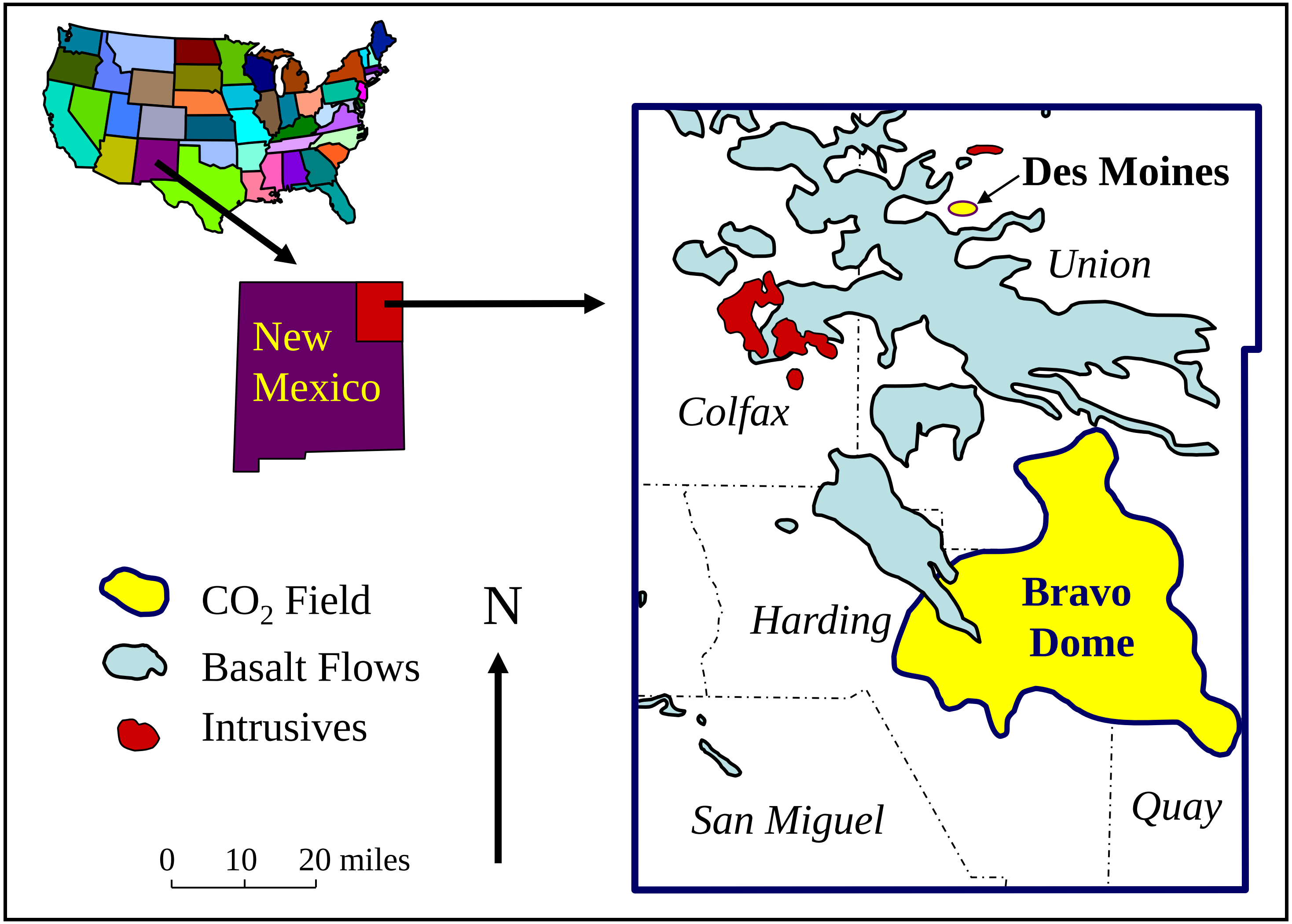
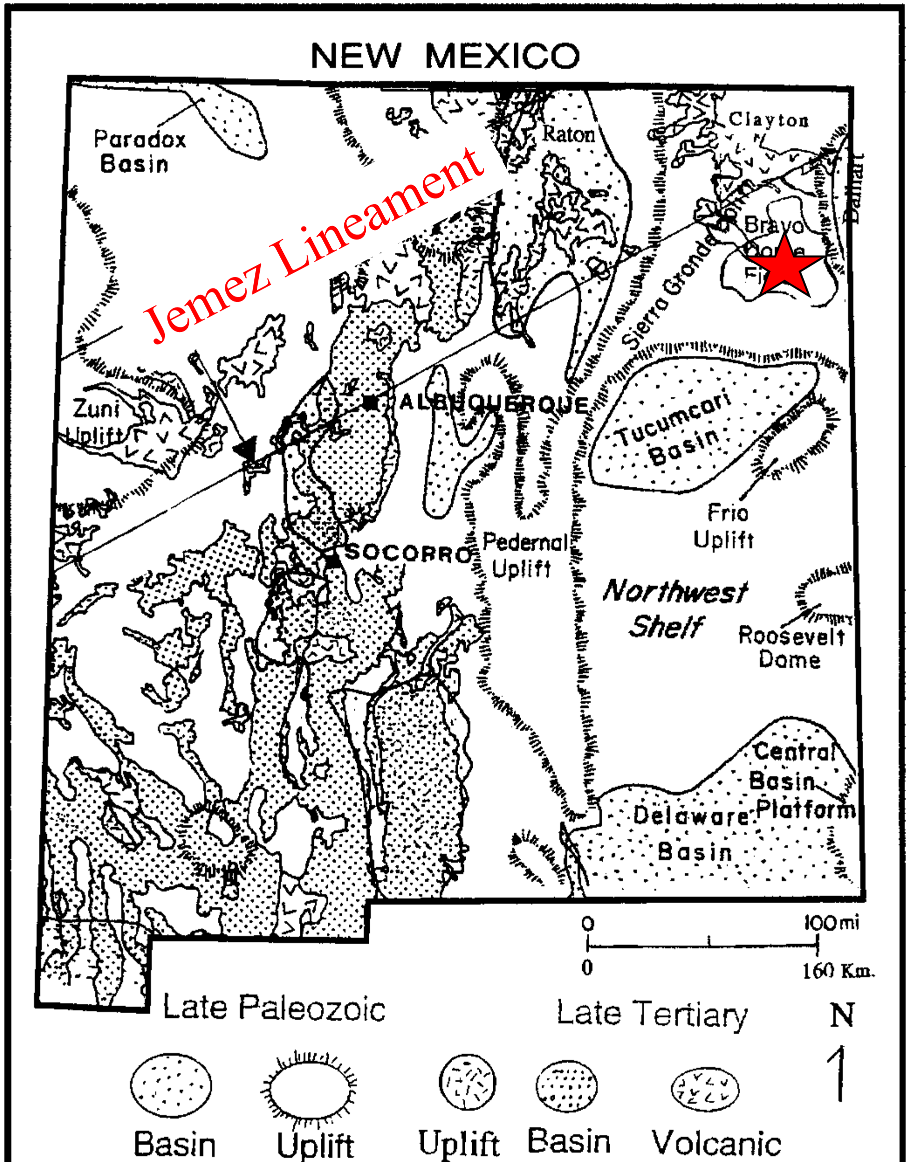
Plan of Presentation

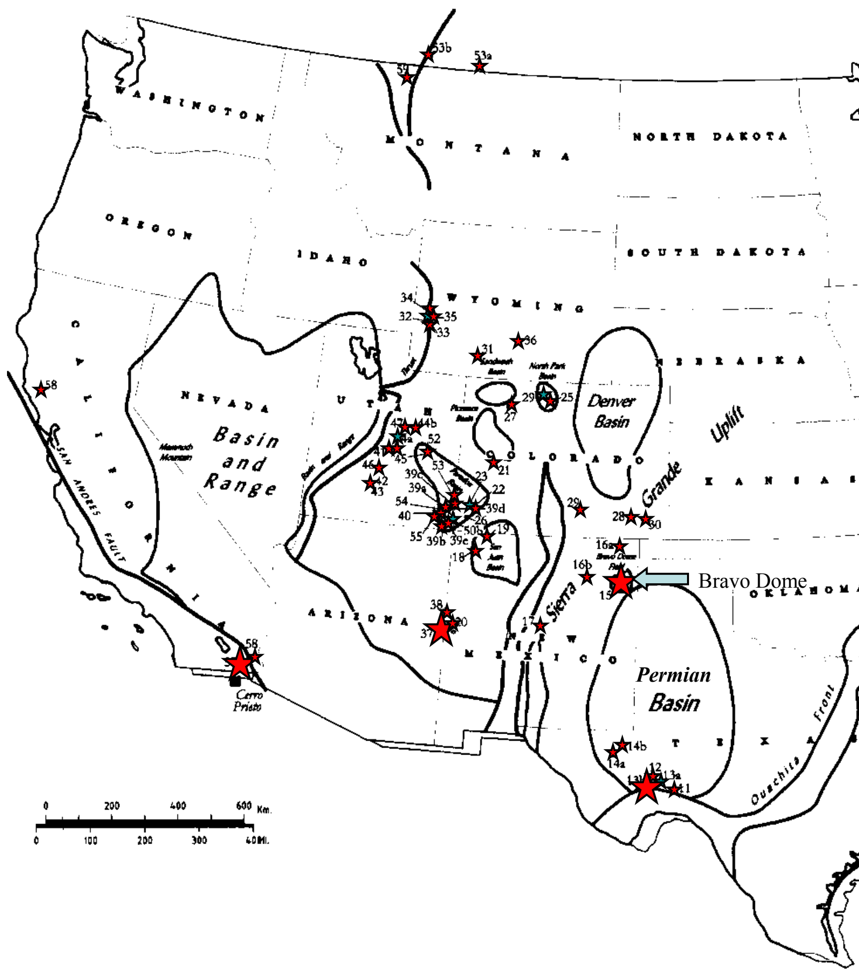
- Introduction and objective of investigation.
- Plate tectonic setting of CO_2 deposits in the Western USA and Geologic setting of Bravo Dome.
- Possible CO_2 sources and use of isotopes of carbon and noble gases to indicate the source of CO_2 at Bravo Dome.
- Examination of noble gas distribution in Bravo Dome showing it to be a dynamic CO_2 deposit changing with time.



Location Bravo Dome CO_2 natural gas field and associated basalt extrusive flows and intrusive centres of the Cenozoic Raton-Clayton volcanic field. (modified from Broadhead, 1993).



Tectonic Setting

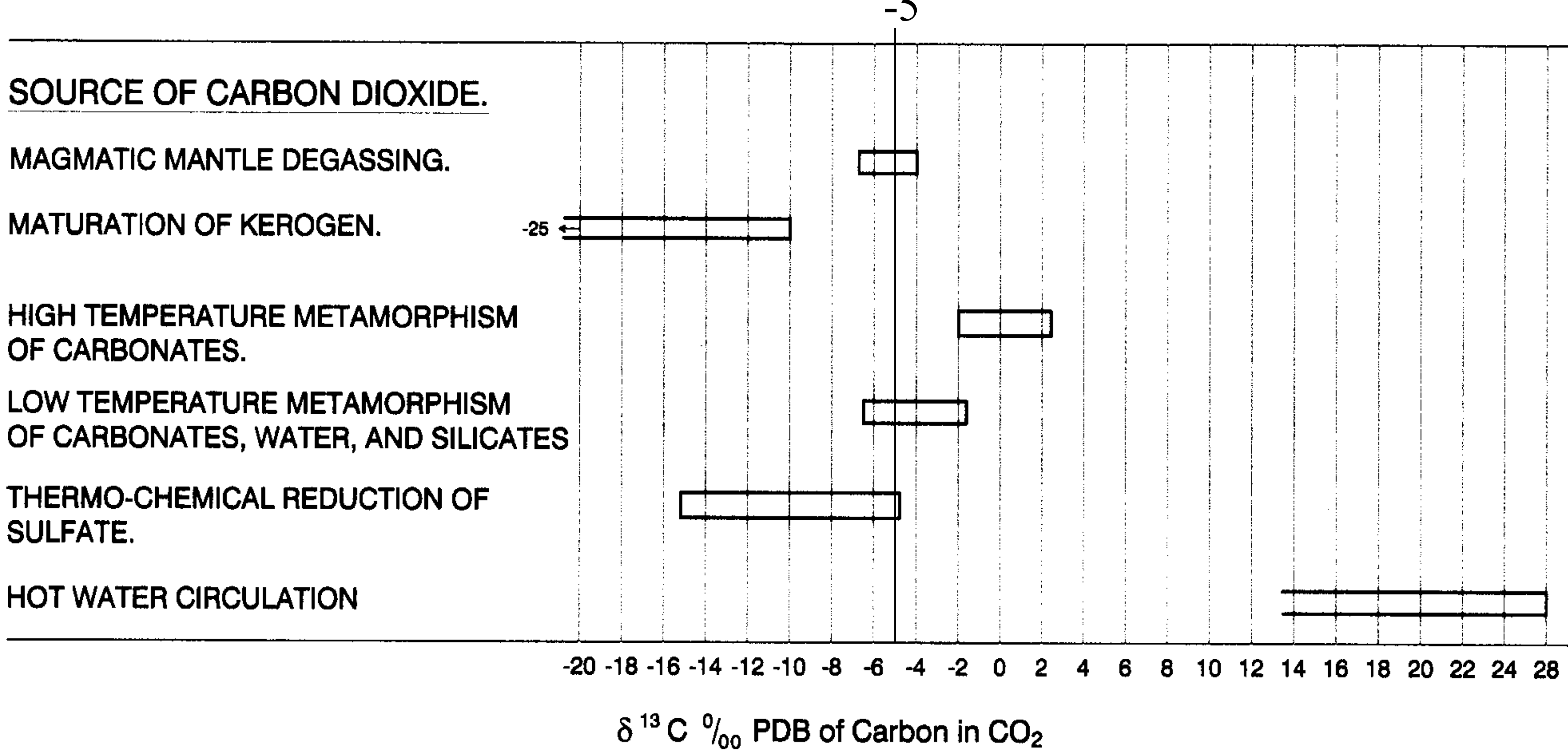


Western US > 50% CO_2

Field	CO2
St Johns	14.8 TCF
Bravo Dome	10 TCF
Sheep Mtn.	2 TCF
McElmo D.	10 TCF
La Barge Platform	100+ TCF

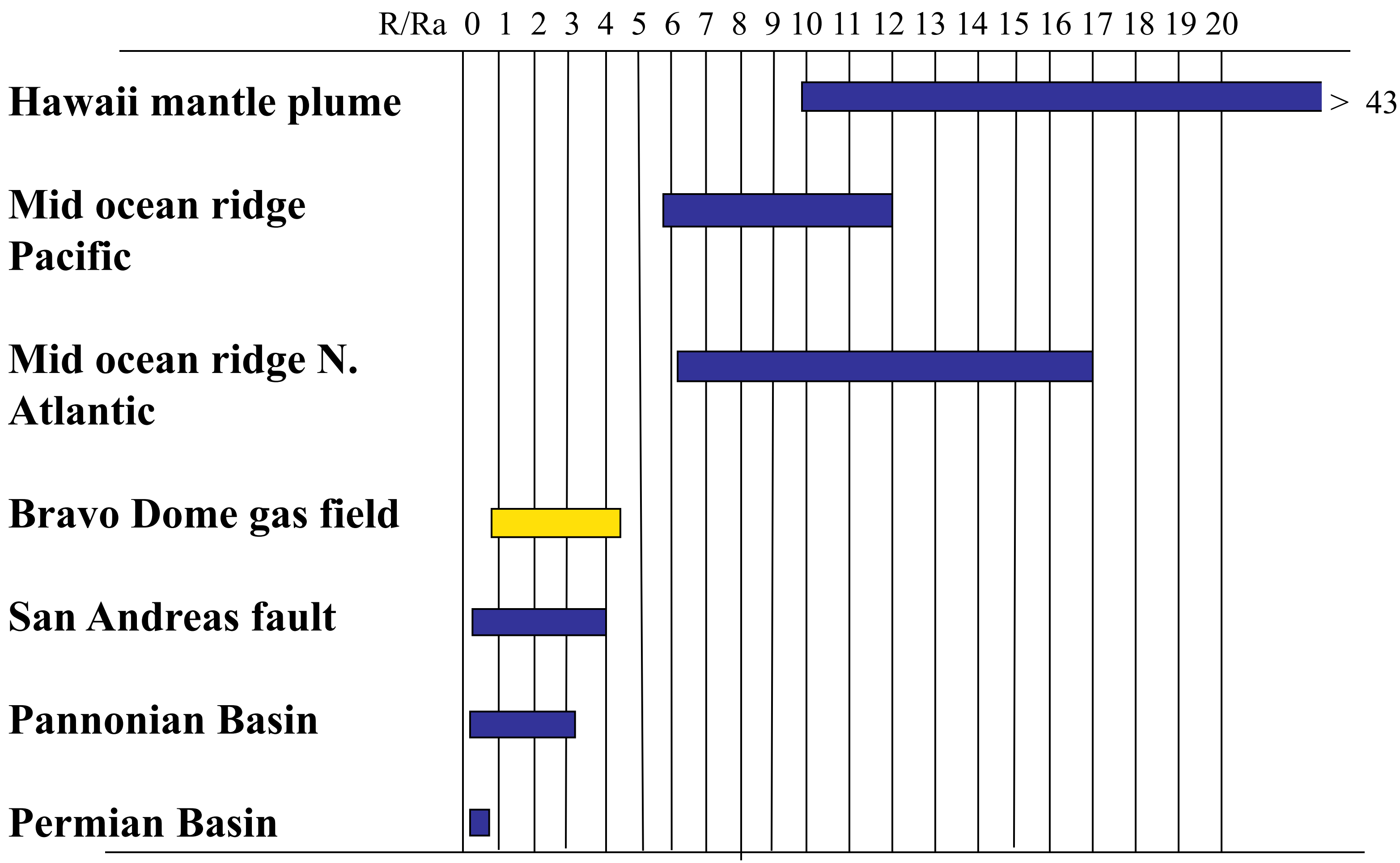
★ 55 Significant deposits of gas, CO_2 over 50%

Typical carbon isotope values of major sources of CO_2 in the subsurface



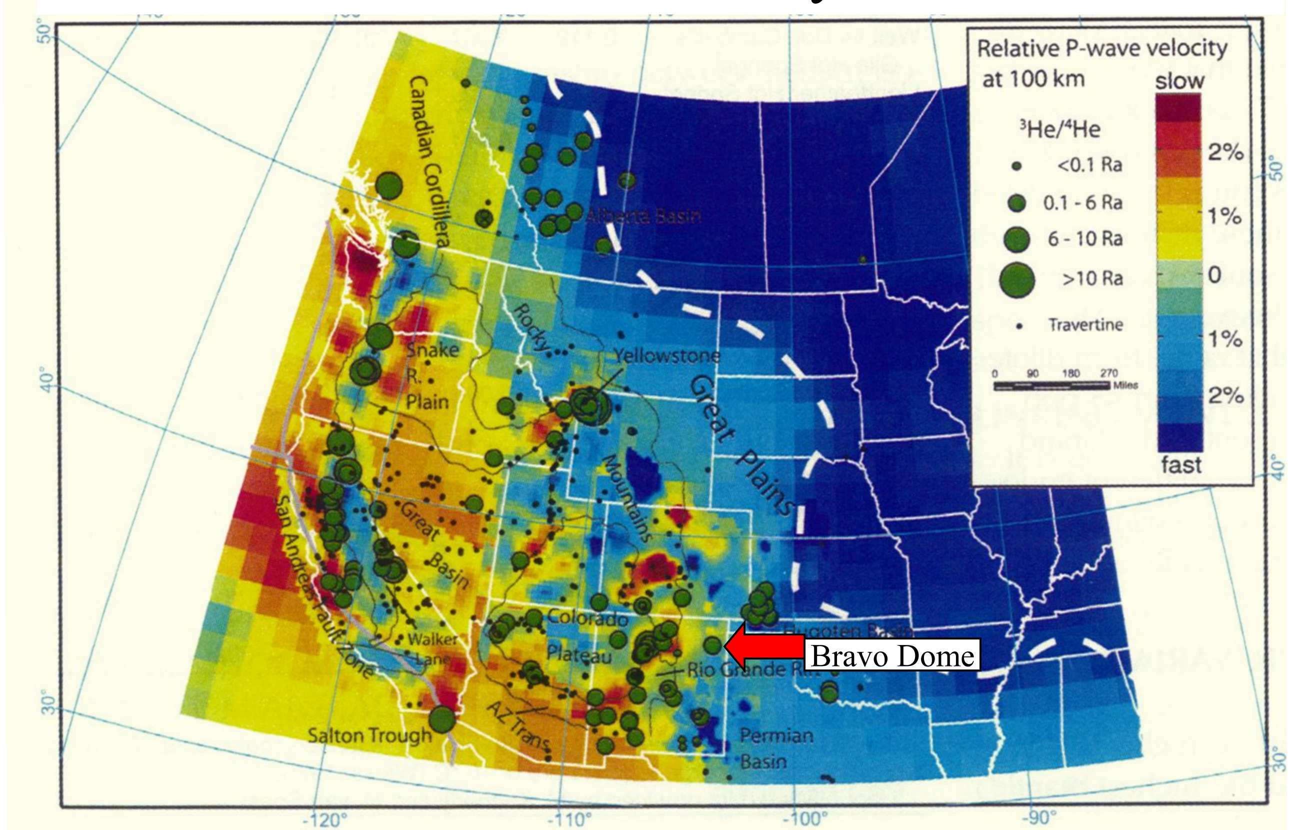
After Thrasher & Fleet, 1995; Wycherley, 1999.

^3He /^4He R/Ra various geologic settings



From Cassidy, 2005: Newell et al,, 2005; Graham, 2002; Ballentine et al., 2001; Sherwood Lollar et al., 1997.

Relative P-Wave Velocity at 100 KM



Slow P wave velocity indicates mantle that is tectonically active and partly molten, High $^3He/^4He/Ra$ in spring waters and gas deposits shows mantle access.
Modified from Newell *et al., 2005*.

Helium 3 (^3He)
Marker of the Mantle

- Stable isotopes of Helium are ^3He and ^4He.

- Helium 3 (^3He) is created in stars, including our sun, but it is not created on earth by any common process.

- ^4He is also created in stars but that in the earth is primarily from radioactive decay of uranium and thorium.

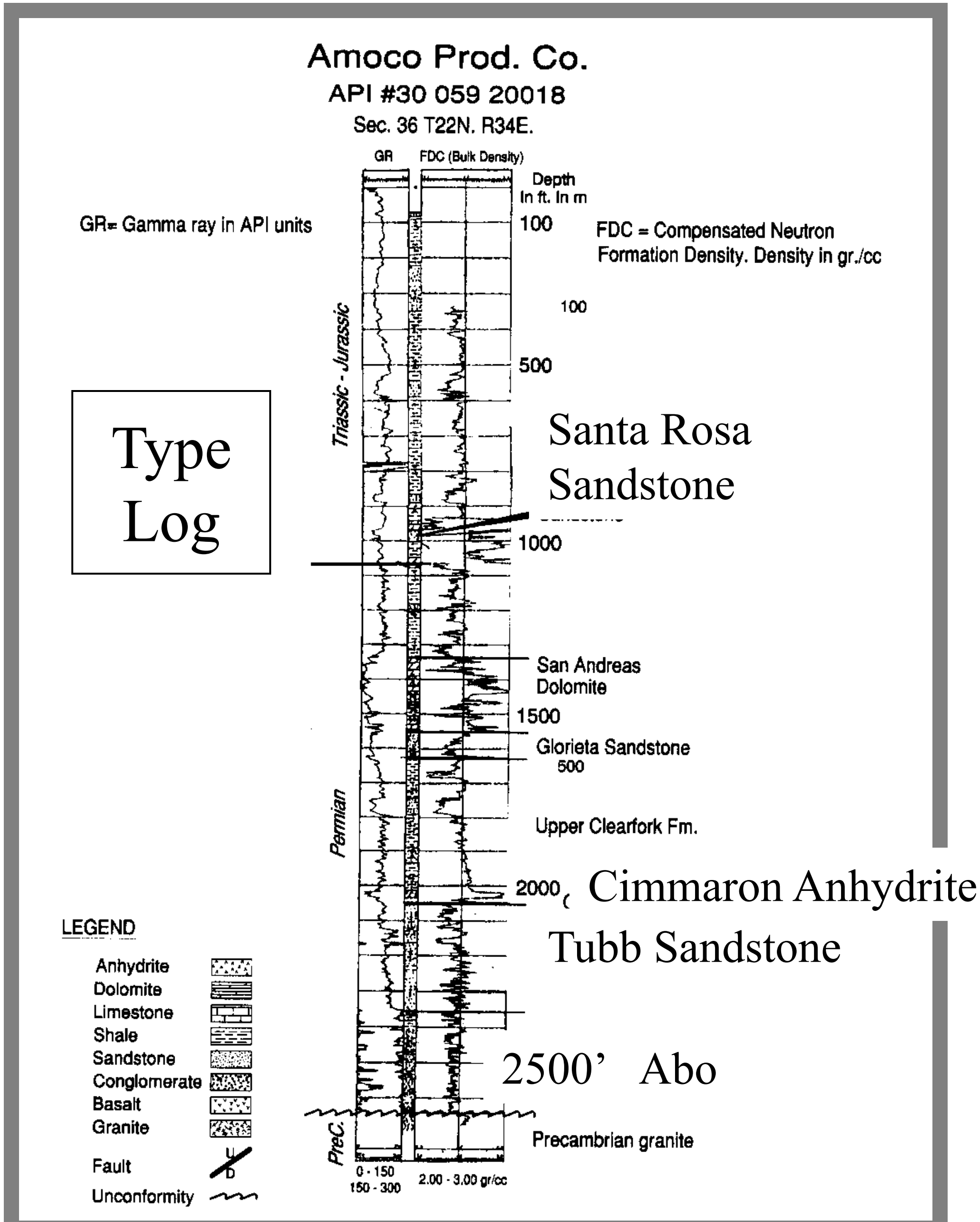
- ^3He now in the earth is from the original accretion. It is still leaking to the surface.
- From the atmosphere helium gradually escapes into space, unlike other noble gases that accumulate in the atmosphere. Helium content is 5.24 X 10^{-6} cc/cc.
- The ratio in air of $^3He/^4He$ is 1.4 X 10^{-6}.
- That ratio in air (Ra) is the standard to which is compared the ratio of $^3He/^4He$ in subsurface gases.
- Helium from the upper mantle has an Ra of about 6 to 12 Ra, helium from the crust has .02 to .04 Ra.

Average Gas Composition

Bravo Dome
Tubb Sandstone
Reservoir

Compound	Average % (6 different wells)
CO_2	99.6266
N_2	0.1991
He	0.0168
H_2	0.0132
A_r	0.0033
CH_4	0.0005
O	ND
H_2S	ND
CO	ND

Producing Reservoir Depth	2500' - 3000'
Original Reservoir Pressure	336 to 1082 psi
Reservoir Temperature	92ºF at 2400ft


Amoco Prod. Co.
API #30 059 20018
Sec. 36 T22N. R34E.
GR
FDC (Bulk Density)
Depth
In ft. In m
GR= Gamma ray in API units
FDC = Compensated Neutron
Formation Density. Density in gr./cc
100
100
500
Triassic - Jurassic
Type
Log
Santa Rosa
Sandstone
1000
San Andreas
Dolomite
1500
Glorieta Sandstone
500
Permian
Upper Clearfork Fm.
2000
Cimmaron Anhydrite
Tubb Sandstone
2500'   Abo
Precambrian granite
PreC.
0 - 150
150 - 300
2.00 - 3.00 gr/cc
LEGEND
Anhydrite
Dolomite
Limestone
Shale
Sandstone
Conglomerate
Basalt
Granite
Fault
U
D
Unconformity

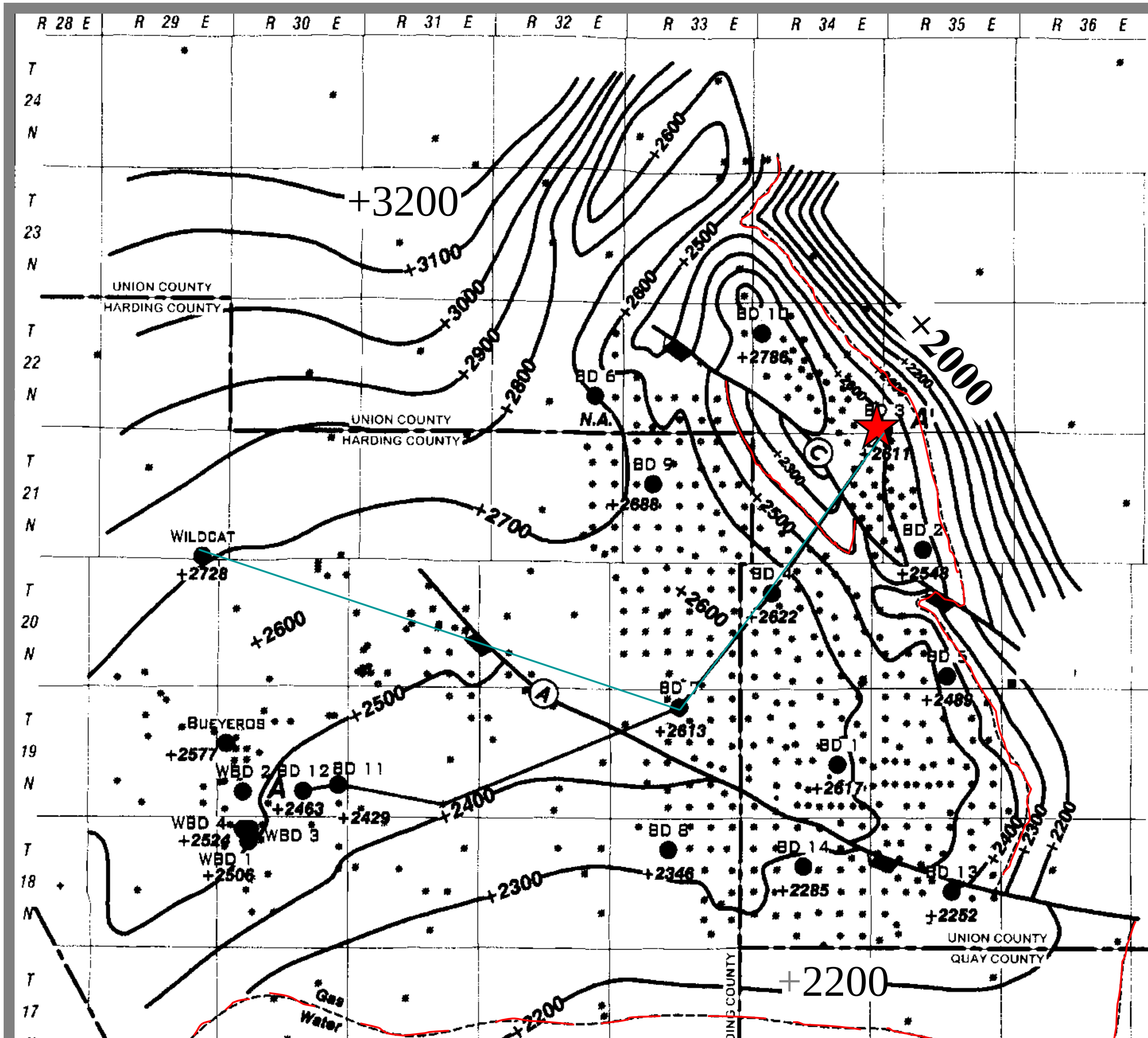


Figure 3.2-**4A**. Bravo Dome Field structure map at top of Tubb Sandstone. The gas-water contact is shown at top Tubb Sandstone and is poorly defined to the southwest.

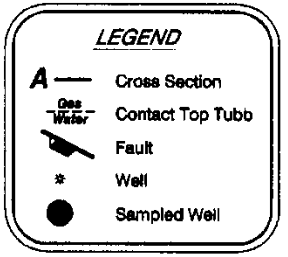
Bravo Dome Field

Top Tubb Sandstone

C.I. 100'

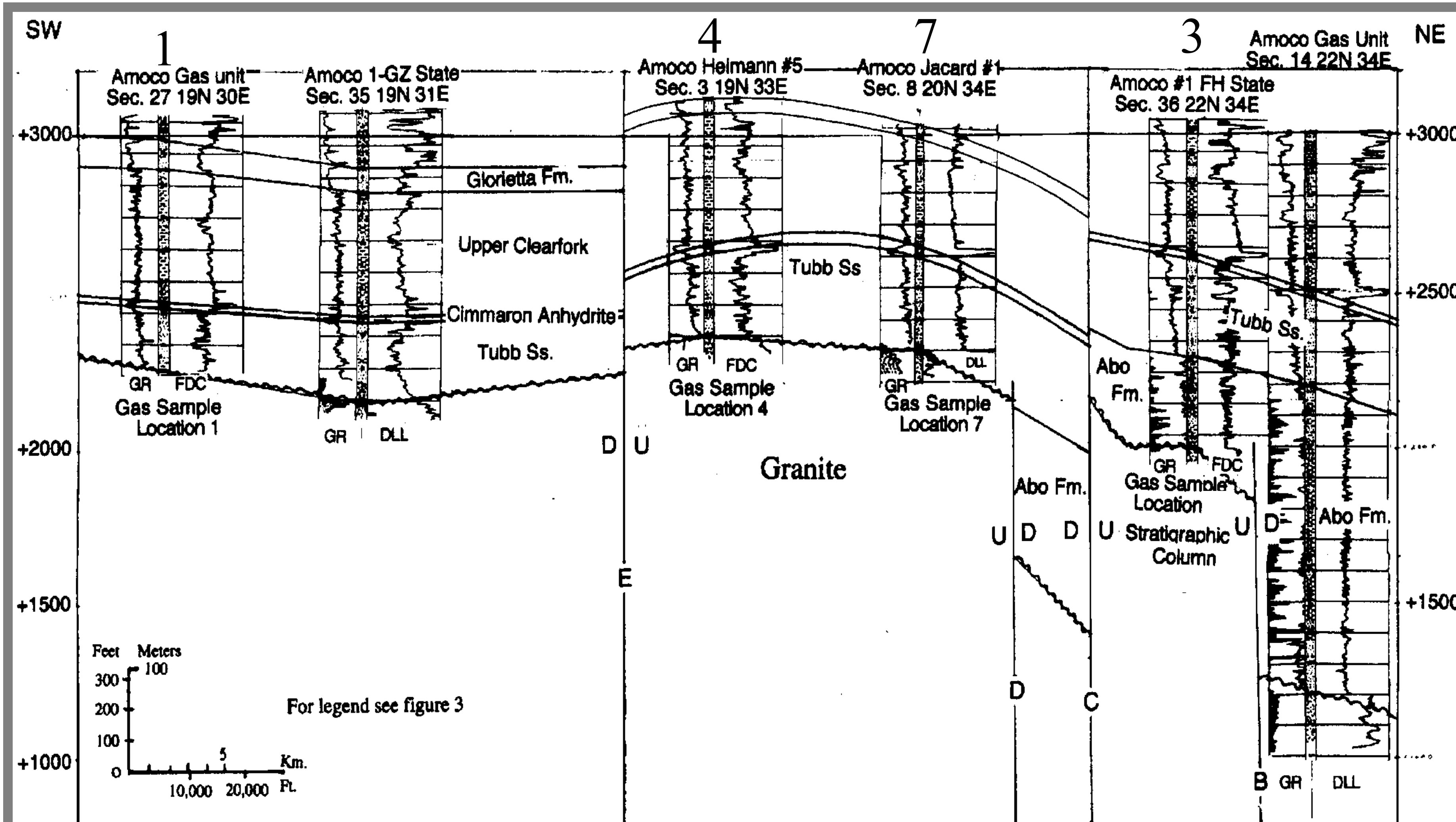
● **Sampled well**

Gas/ Water Con.



0 10km

NE – SW Structural Stratigraphic Cross Section



Noble Gases Concentration Air and Bravo Dome, cc/cc

Noble Gas	In Air	BD West	BD East
^{3}He	7.36×10^{-12}	1.87×10^{-10}	4.00×10^{-10}
^{4}He	5.24×10^{-6}	3.1×10^{-5}	41.46×10^{-5}
^{20}Ne	1.07×10^{-5}	1.03×10^{-9}	7.00×10^{-9}
^{36}Ar	3.08×10^{-5}	1.10×10^{-9}	14.0×10^{-9}
^{40}Ar	9.30×10^{-3}	2.40×10^{-5}	6.52×10^{-5}
^{84}Kr	1.14×10^{-6}	0.473×10^{-10}	5.04×10^{-10}

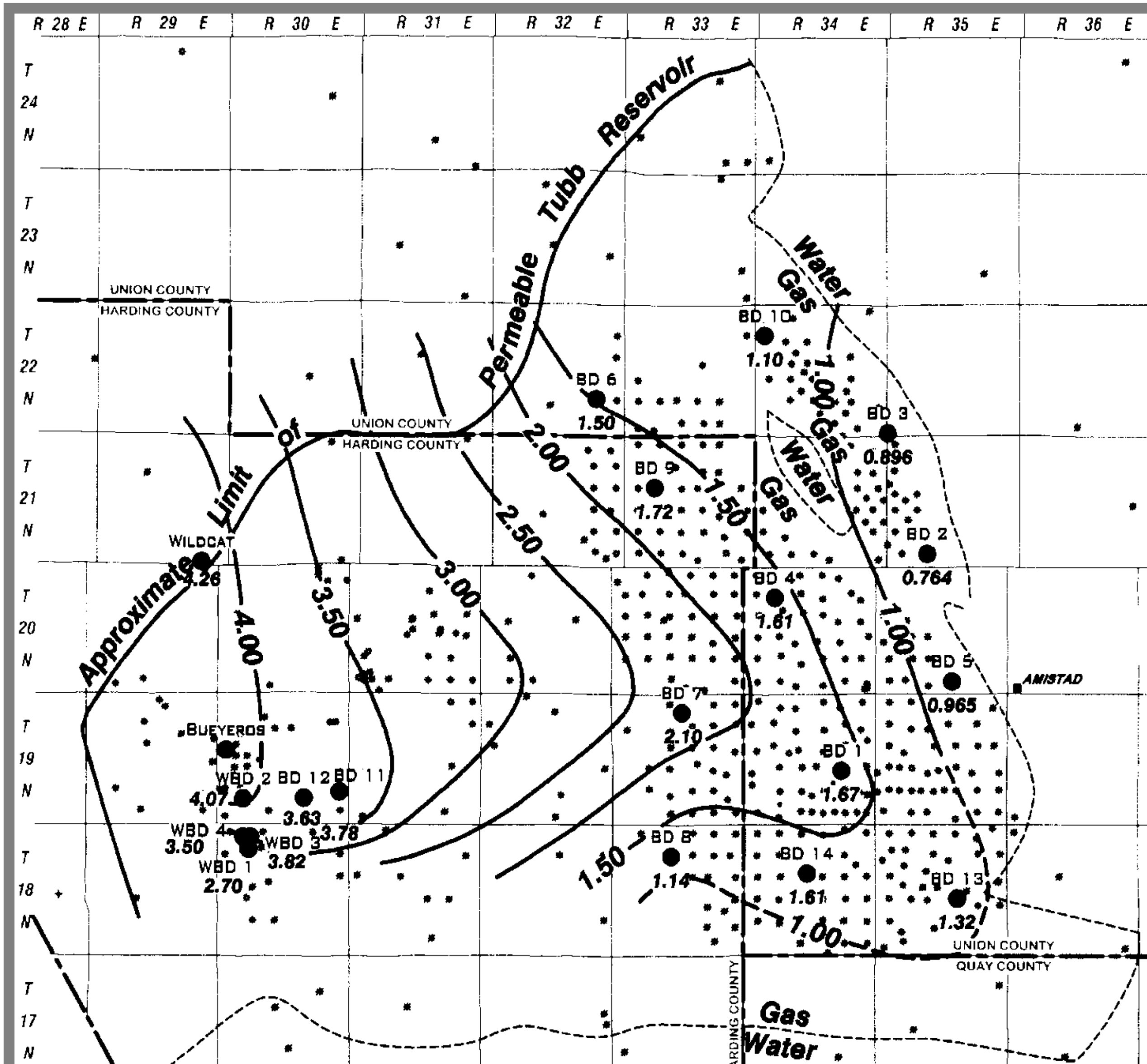


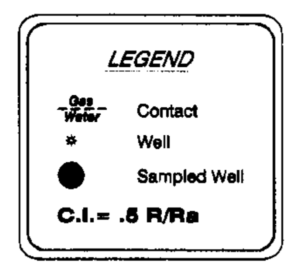
Figure 3.2- **11**. Distribution of ^{3}He/R/Ra in sampled wells at Bravo Dome Field.

Bravo Dome field

^{3}He/R/Ra

CALCULATED FROM ^{3}He / ^{4}He RATIO

C.I.= .5 R/Ra



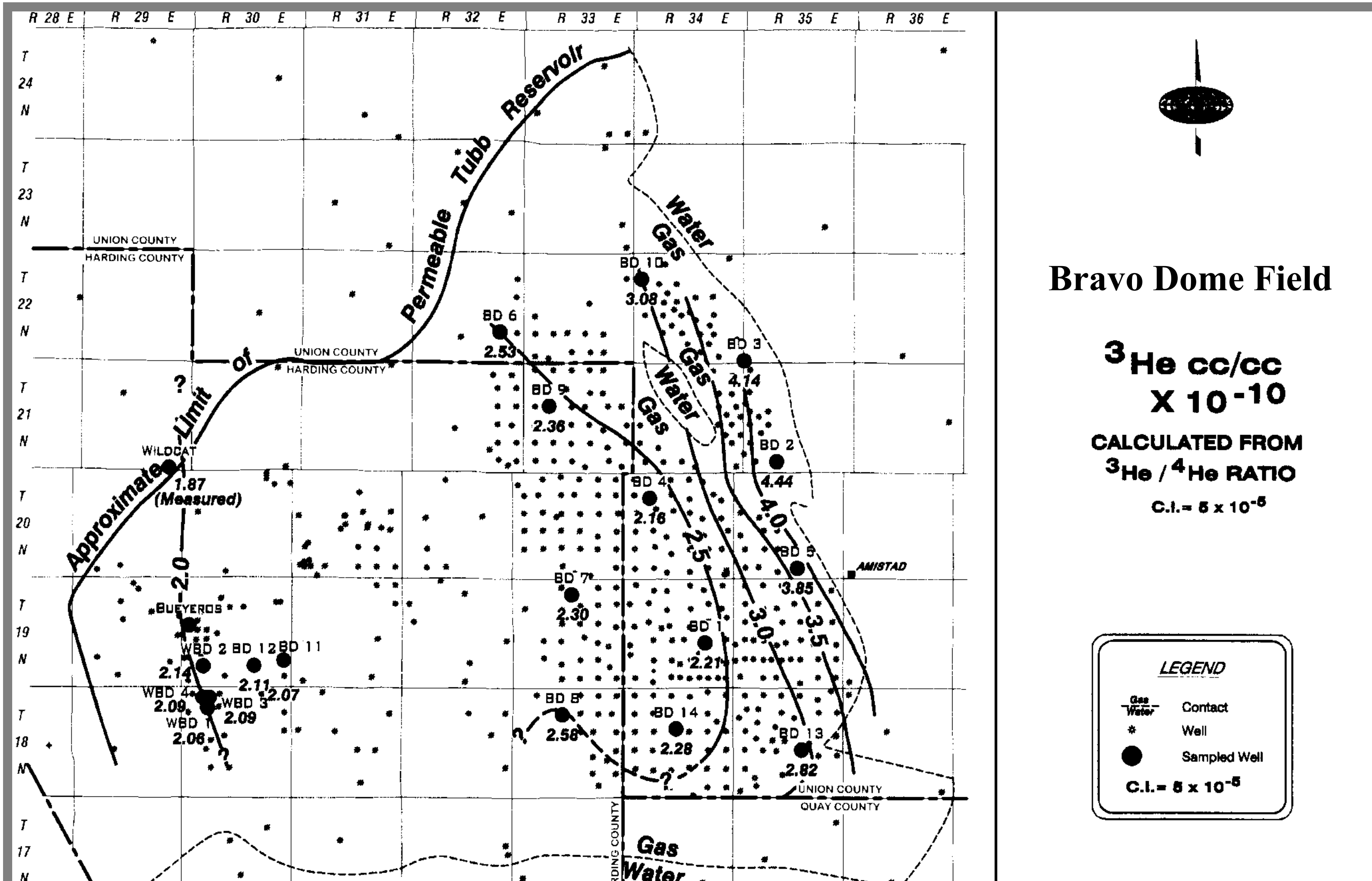


Figure 3.2-**8B**. Distribution of ^{3}He in sampled wells at Bravo Dome Field.

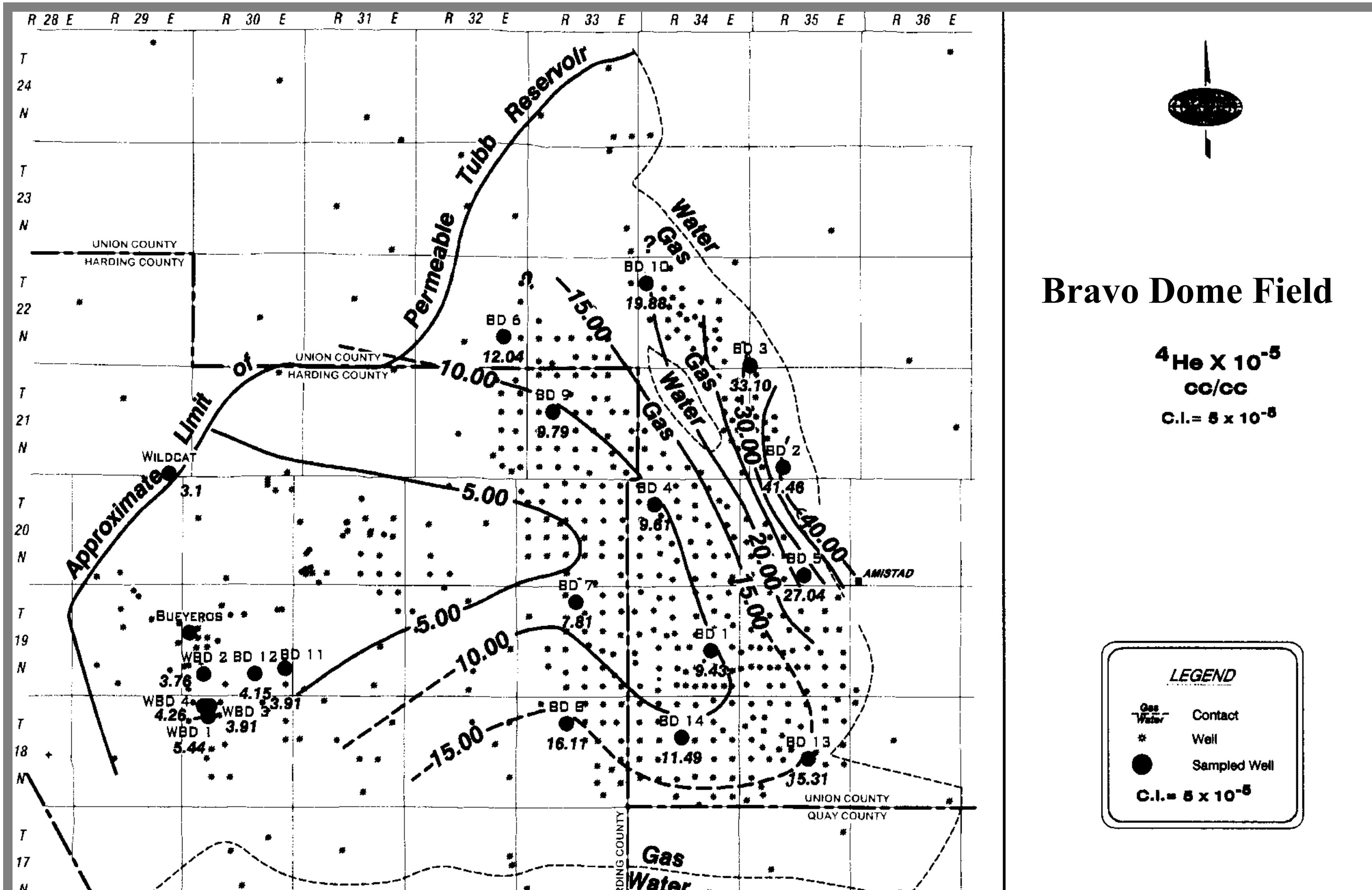


Figure 3.2-**8A**. Distribution of ^{4}He in sampled wells at Bravo Dome Field.

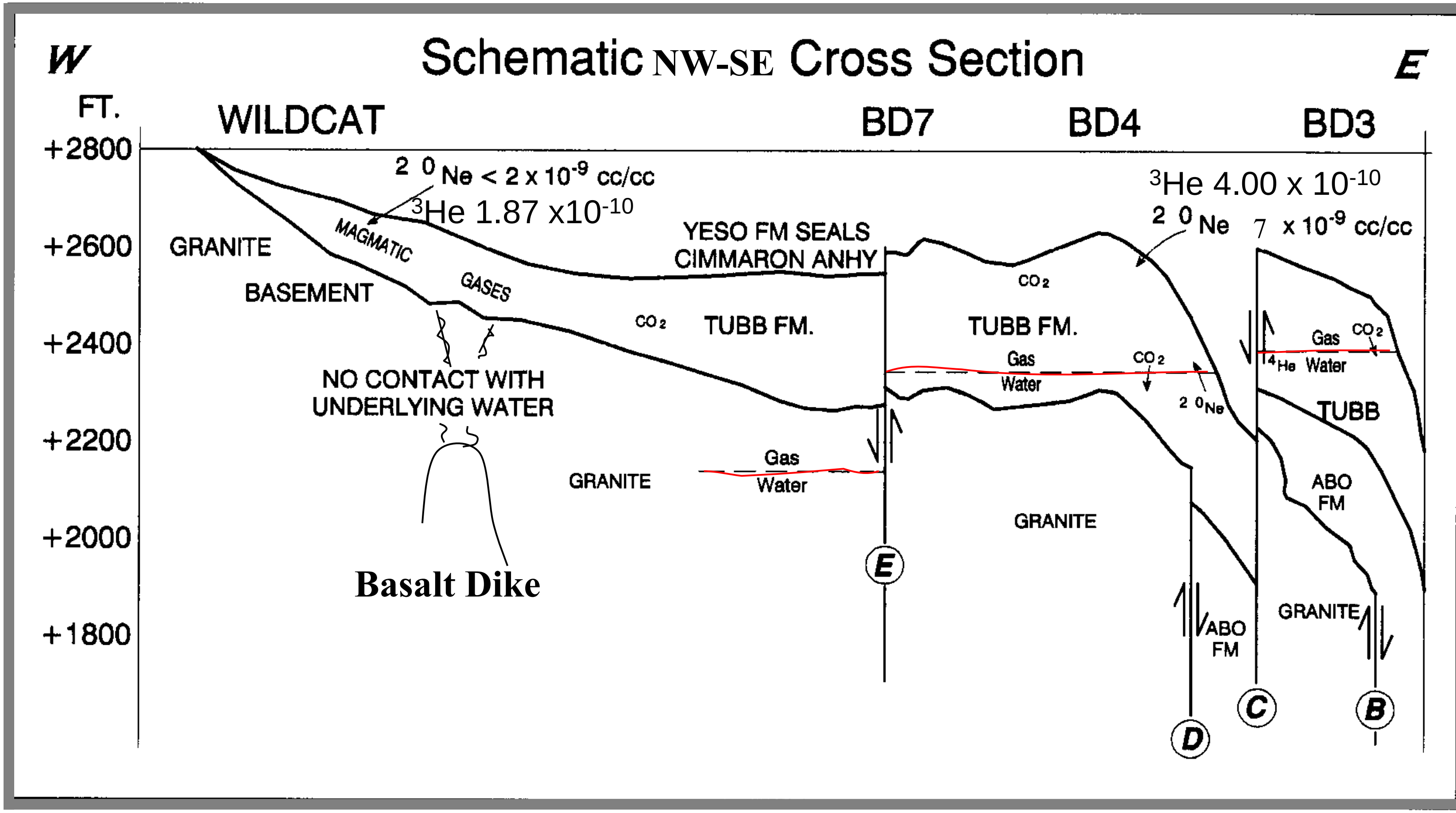


Figure 3.2-6.

1. Original magmatic gases fill Tubb Sandstone.above dike sweeping water and noble gases down dip . .
2. CO_2 dissolves in water laterally down dip.
3. Noble gases enter CO_2 laterally from water down dip.

History of Bravo Dome Gas Deposit.

1. CO_2 degassed from basalt magma of dike below field.
2. Rising through cracks in granite basement it entered and collected in the first reservoir with effective seal.

3 It swept down-dip connate water with noble gases.

4. CO_2 dissolves in the water leg, noble gases remain in reservoir and more noble gases enter from the water leg. Noble gases accumulate in the CO_2 with time.

Conclusions

1. Bravo Dome field is sourced from the mantle.

2. It is likely western US CO_2 deposits are sourced from the mantle.

3. CO_2 deposits are found in association with basic igneous rocks where they pierce sedimentary section with reservoirs and seals.

4. CO_2 gases carry noble gases distinctive of their source.

5. CO_2 deposits change with time as the gas dissolves in down dip water and noble gasses enter the CO_2.

6. CO_2 escapes from the trap in moving formation water.

Acknowledgements

Thanks to the operators of Bravo Dome, Amoco, then BP, and now Occidental and also Hess for allowing sampling, providing data, consultations, and support of the project over the last several years.

Thanks are due to many individuals but especially to Herb Wacker, Steve McCants, Danny Holcomb, and David DeFelice, who are or were with of Oxy and Profs. Lawrence, Chafetz, Casey, and Burke of the University of Houston.

General funding for study of CO_2 in the subsurface has been provided by the University of Houston, by Amoco, and through a grant from Unocal. A new study by Prof. Marc Hesse and Ph. D. graduate student Kiran Sataye is funded by the NSF.

Dr. Chris Ballentine made all the analysis of the Noble gas content and isotopes in Bravo Dome gases.

Hypothesis

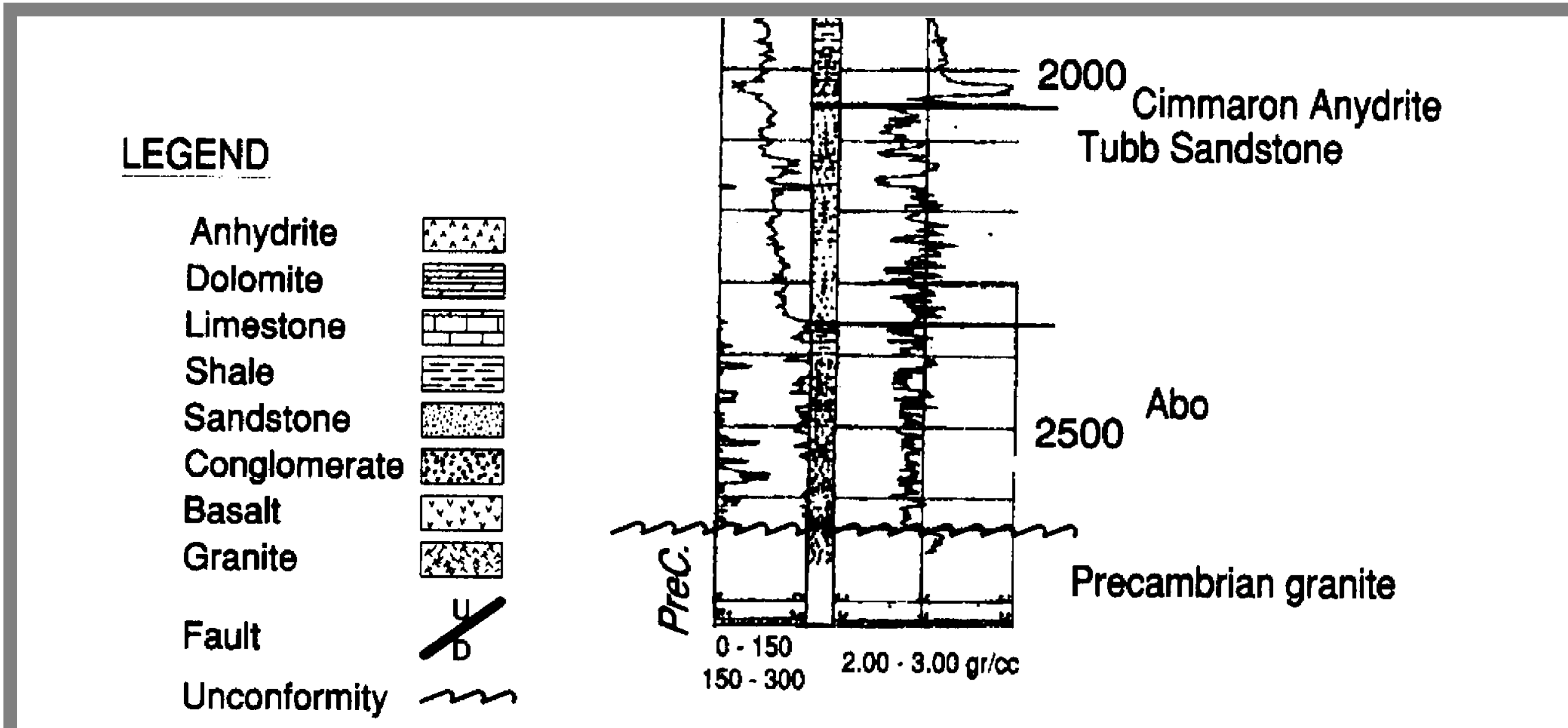
CO_2 rises in ultramafic basalt mantle magma.

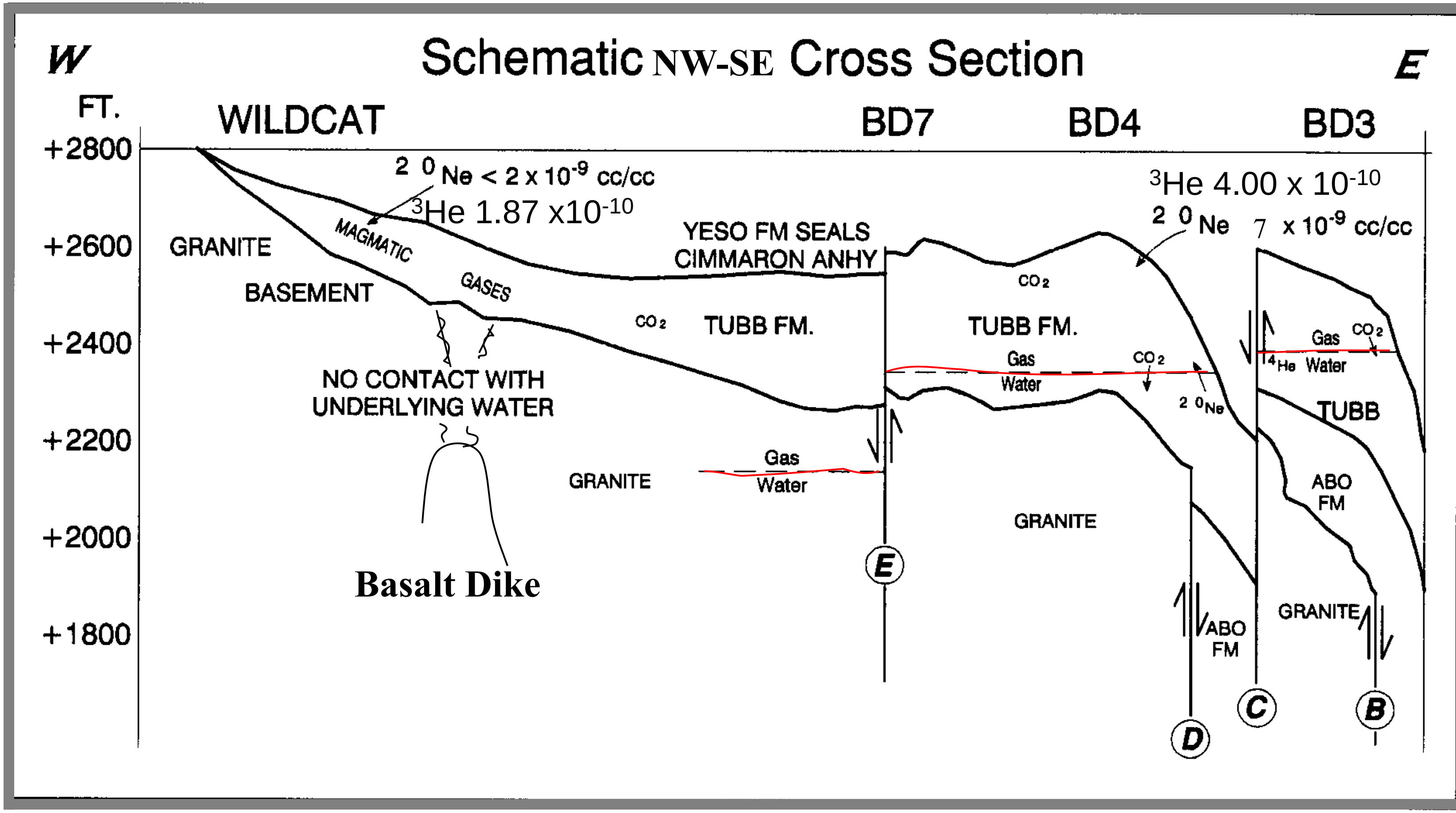
It brings with it noble gases distincite of the mantle.

It exsolves and enters the first porosity above basement. If seals are present it is trapped.

CO_2 dissolves in underlying and down dip water columns. The deposit is ephemeral in geologic time!

Productive Section
Bravo Dome field





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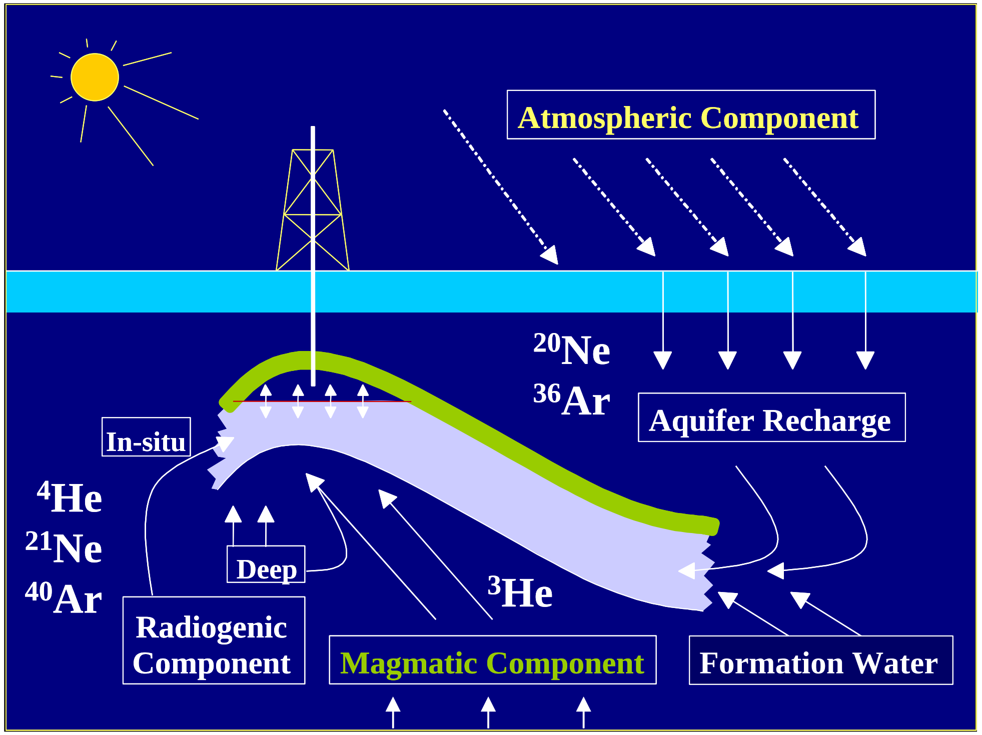
Noble Gases in a Nutshell

- He, Ne, Ar, Kr, Xe
- Three Sources
  - Groundwater (air)
  - Crust (Radiogenic)
  - Mantle
- Isotopically Distinct
  - Resolvable
- Quantify interaction/origin of fluids sourced from these different regions



Comparison of Noble Gas Fingerprints