Hydrogeologic Risks
in the
Groundwater Supply of Harris County, Texas: Radioactive Constituents, Natural Gas, & Growth Faults

by

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I2M Associates, LLC
Houston and Seattle

and

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SWS Environmental Services
LA Porte, Texas

An Invited Lecture Presented to the Houston Geological Society
Environmental and Engineering Group's Dinner Meeting

May 8, 2013
Version 1.9

Geologic and Hydrogeologic Risks in the Ground-Water Supply Harris County, Texas:

Here is what we'll cover:

- Groundwater Sampling and Analysis in Harris County, TX
  1970s, 1980s, and 2000s
- Radiometric Constituents: Uranium, ^{222}Radon and ^{226}Radium
- Likely Source of Radiogenic Material: ^{238}Uranium Radioactive Decay Series
- Relationship to Growth Faulting in Harris County
- Natural Gas in the drinking water of Harris County and in a project that discovered explosive levels in MUD Storage Tanks. Mitigation issues.
- Natural Gas in private water wells located next to company gas well.
- Use of Isotopes to determine source of natural gas in project in East Texas and source of brine in project in Ohio.
- Character of Deep Growth Faults and Potential Hazard at the surface.

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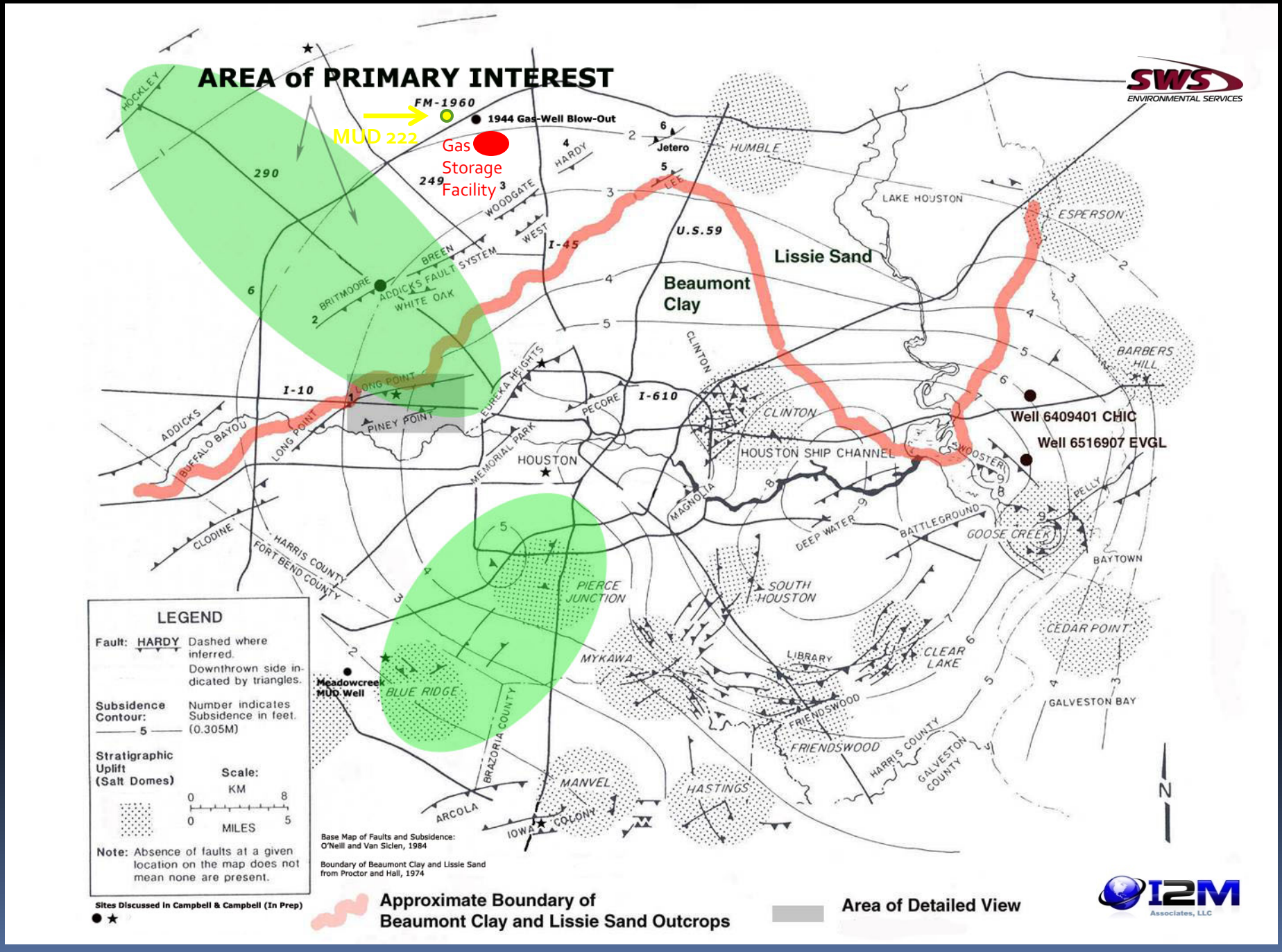
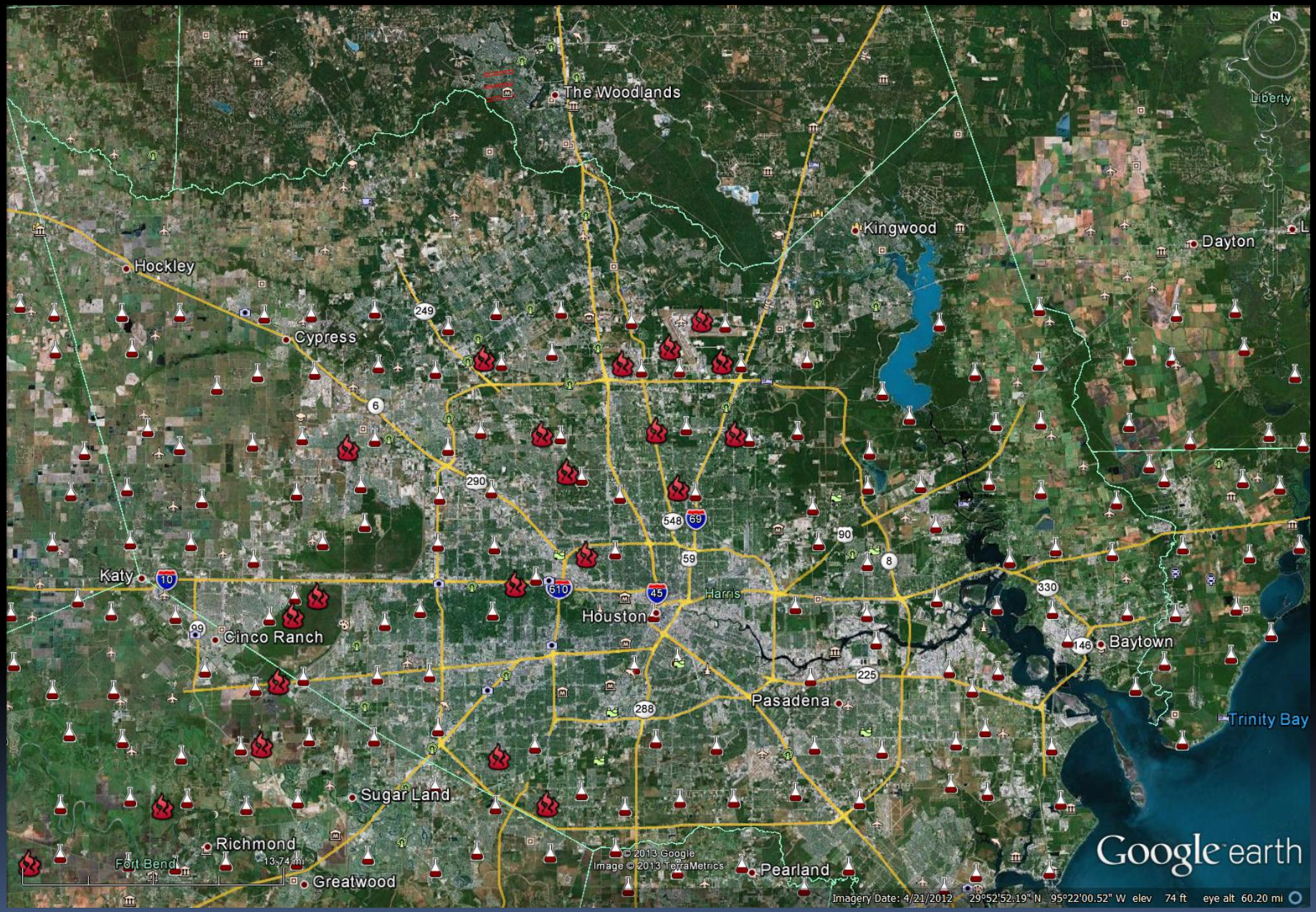
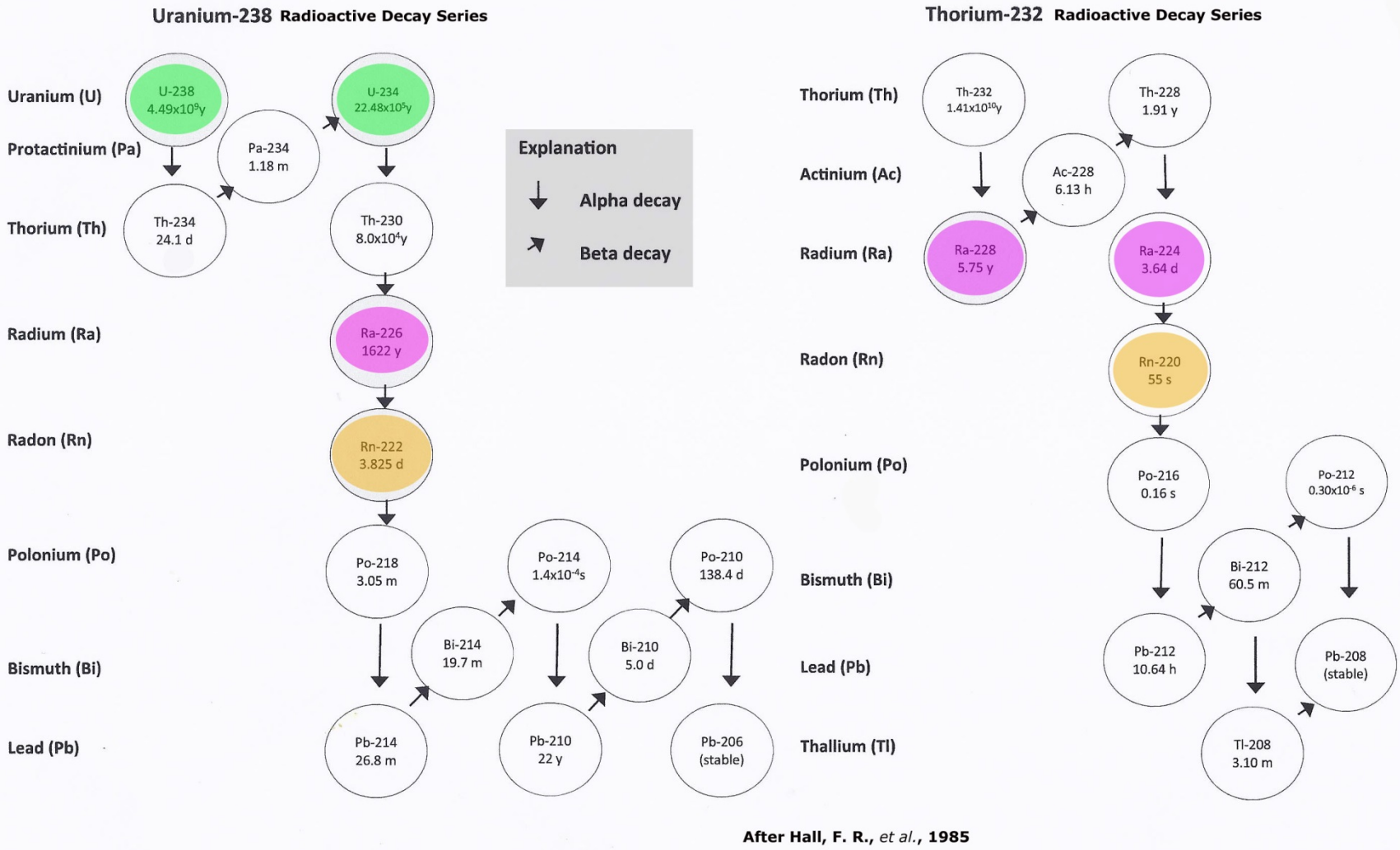

AREA of PRIMARY INTEREST
SWS ENVIRONMENTAL SERVICES
FM-1960
1944 Gas-Well Blow-Out
MUD 222
Gas Storage Facility
Jetero
HUMBLE
LAKE HOUSTON
ESPERSON
HOCKLEY
290
249
HARDY
WOODGATE
WEST
LEE
I-45
U.S.59
Lissie Sand
Beaumont Clay
BRITMOORE
BREEN
ADDICKS FAULT SYSTEM
WHITE OAK
I-10
LONG POINT
EUREKA HEIGHTS
PINEY POINT
PECORE
I-610
CLINTON
BARBERS HILL
Well 6409401 CHIC
Well 6516907 EVGL
ADDICKS
BUFFALO BAYOU
MEMORIAL PARK
HOUSTON
HOUSTON SHIP CHANNEL
WOOSTER
PELLY
MAGNOLIA
DEEP WATER
BATTLEGROUND
GOOSE CREEK
BAYTOWN
CLODINE
HARRIS COUNTY
FORT BEND COUNTY
PIERCE JUNCTION
SOUTH HOUSTON
CEDAR POINT
MYKAWA
LIBRARY
CLEAR LAKE
Meadowcreek MUD Well
BLUE RIDGE
BRAZORIA COUNTY
FRIENDSWOOD
GALVESTON BAY
HARRIS COUNTY
GALVESTON COUNTY
MANVEL
HASTINGS
ARCOLA
IOWA COLONY
N
LEGEND
Fault: HARDY Dashed where inferred. Downthrown side indicated by triangles.
Subsidence Contour: 5 Number indicates Subsidence in feet. (0.305M)
Stratigraphic Uplift (Salt Domes)
Scale:
KM 0 8
MILES 0 5
Note: Absence of faults at a given location on the map does not mean none are present.
Sites Discussed in Campbell & Campbell (In Prep)
Base Map of Faults and Subsidence: O'Neill and Van Siclen, 1984
Boundary of Beaumont Clay and Lissie Sand from Proctor and Hall, 1974
Approximate Boundary of Beaumont Clay and Lissie Sand Outcrops
Area of Detailed View
I2M Associates, LLC



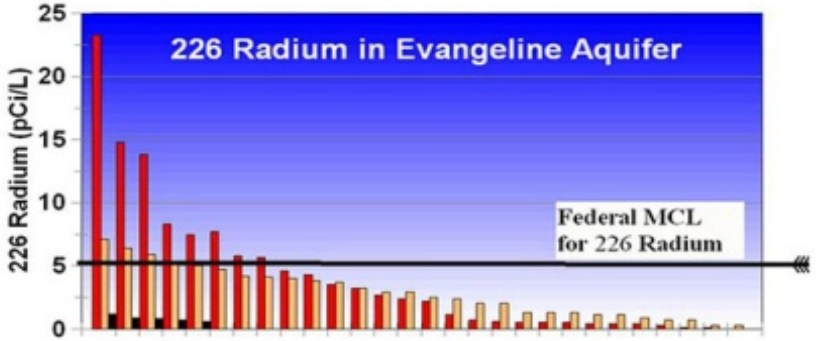
Red Flame Symbol = > 5 µg/L Uranium as Anomalous



After Hall, F. R., *et al.*, 1985

End Result: NORM Scale from High-Volume, Long-Duration Produced Water: The two radium isotopes present in produced water and barite scale are ^{226}Ra (half-life =1,600 years) and ^{228}Ra (half-life =5.8 years).

Radium^{226} Distribution in Areas Sampled



MUD Ground-Water Analyses

- South of Hockley / Tomball Salt Domes
- Pierce Junction / Blue Ridge Salt Dome

Sample Code (pCi/L):

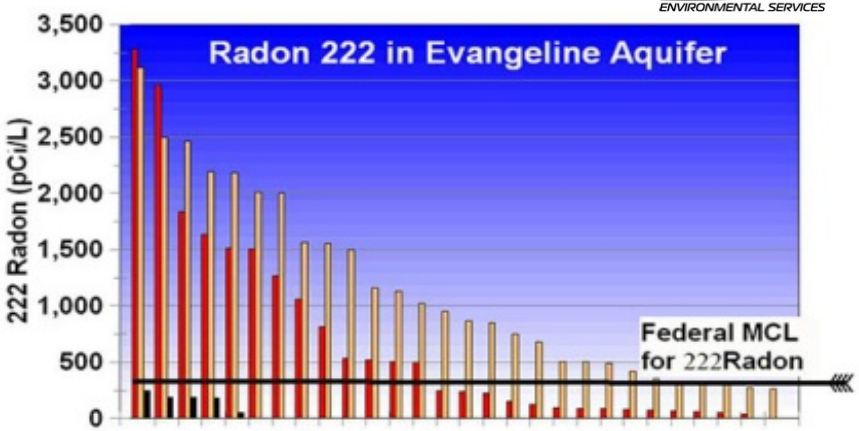
- **Very High Radium Values** > 7.0 Radium^{226}
- **High Radium Values** < 7.0 >3.0 Radium^{226}
- **Intermediate Radium Values** < 3.0 >1.0 Radium^{226}
- **Low Radium Values** < 1.0 Radium^{226}

Tomball Salt Dome
Hockley Salt Dome
Clinton Salt Dome
Pierce Junction Salt Dome
South Houston Salt Dome
Mykawa Salt Dome
Blue Ridge Salt Dome
Sugarland Salt Dome
US 290
FM 1960
I-10
I-45
US 59
610
Hy 6
8
US 288

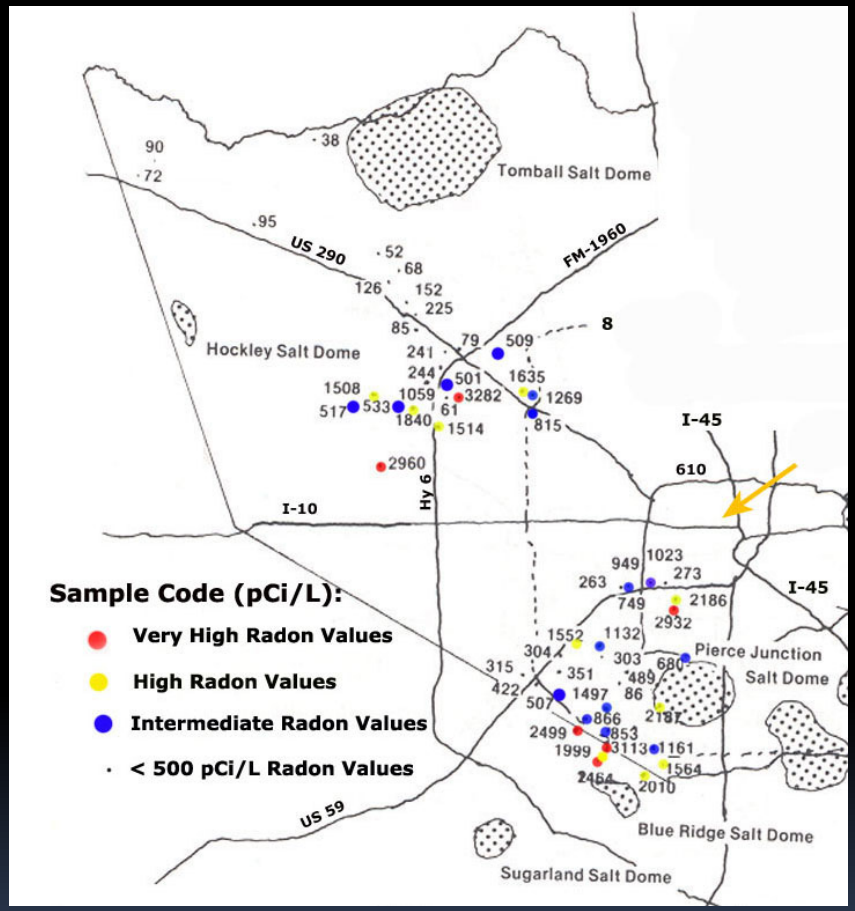
Scale
5 Mi.

Base Map w/Point-Source Data after Cech, *et al.*, 1987

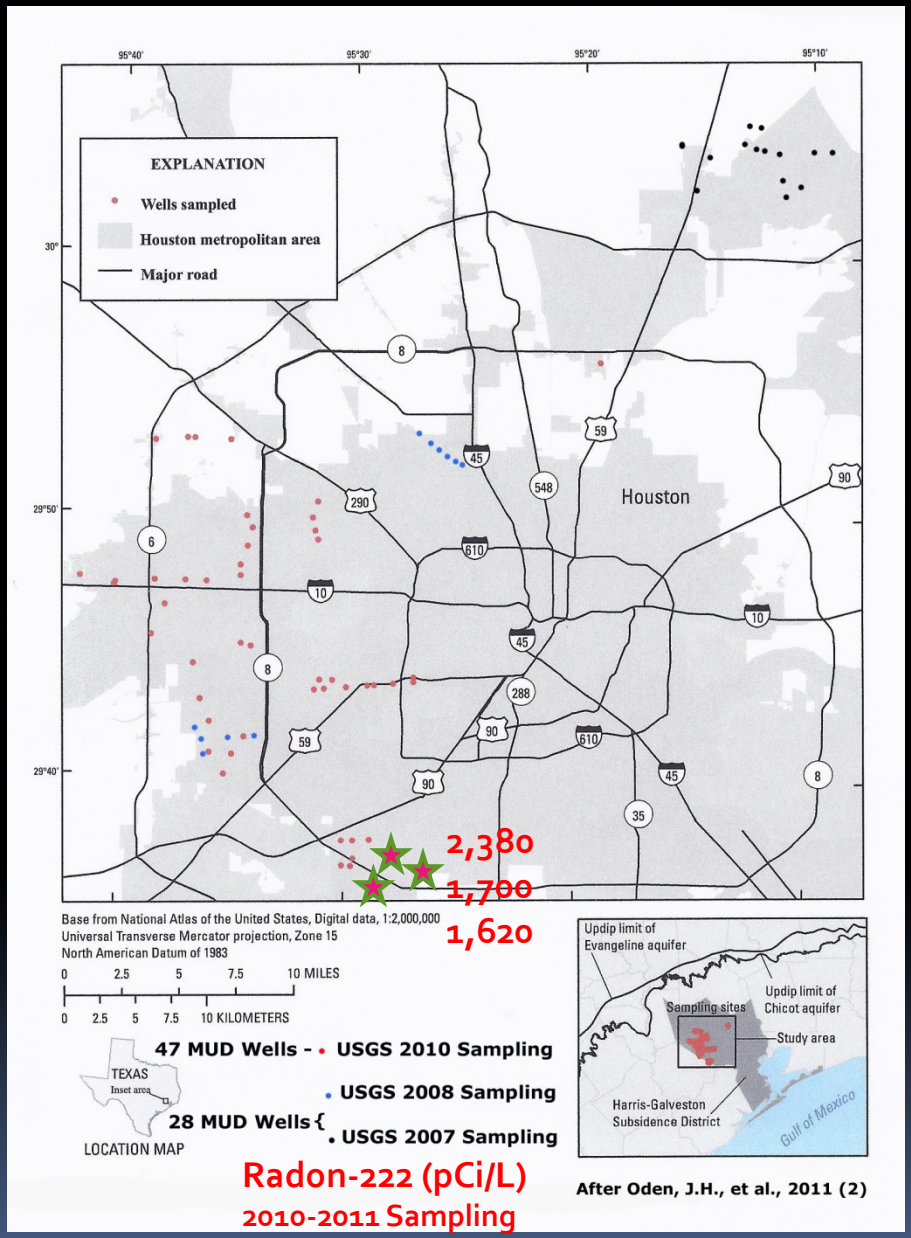
Radon^{222} Distribution in Areas Sampled



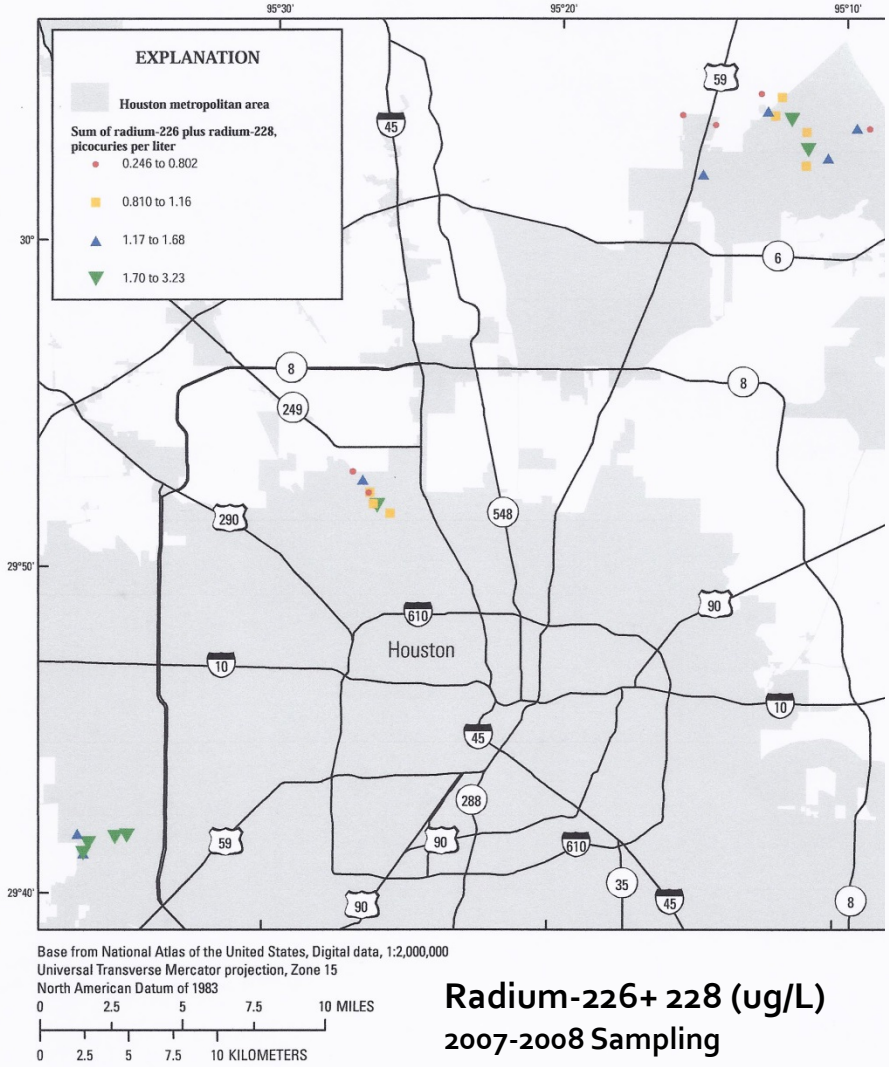
What Wells were Sampled?



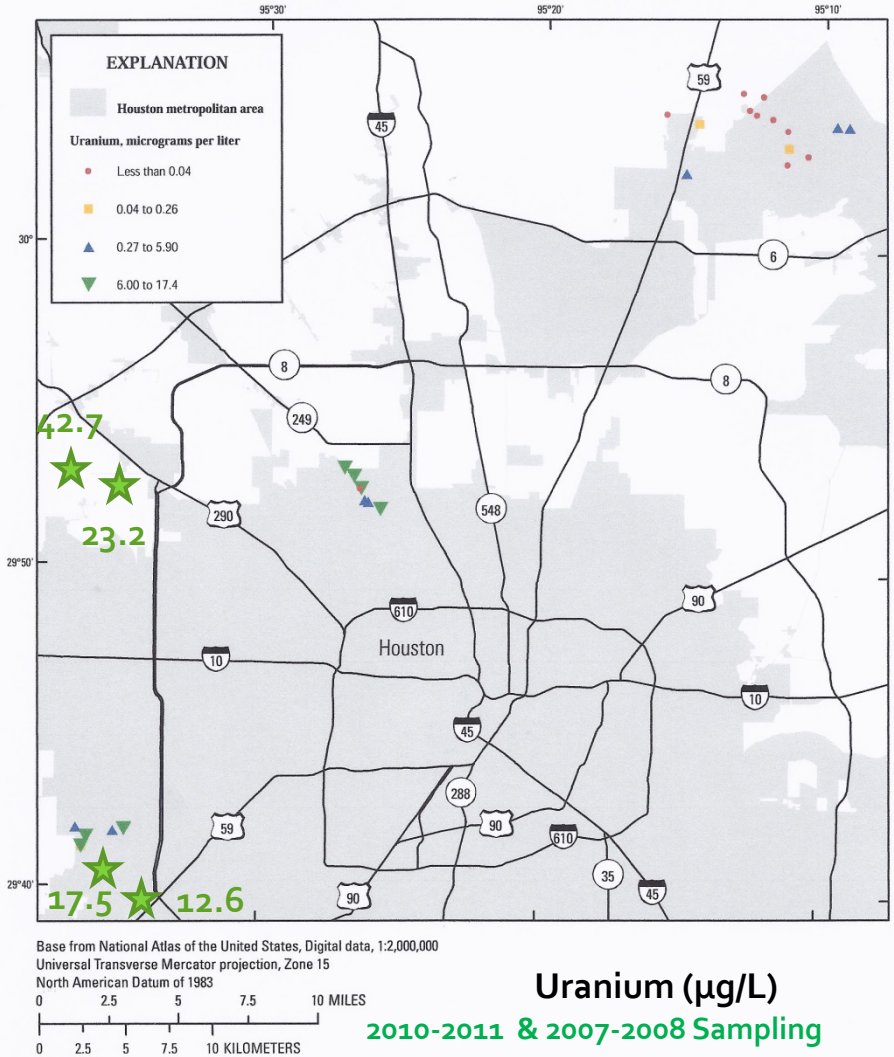
Early 1980s Sampling by Cech



USGS Sampling 2007-2008 w/High U Values from 2010-2011 Data

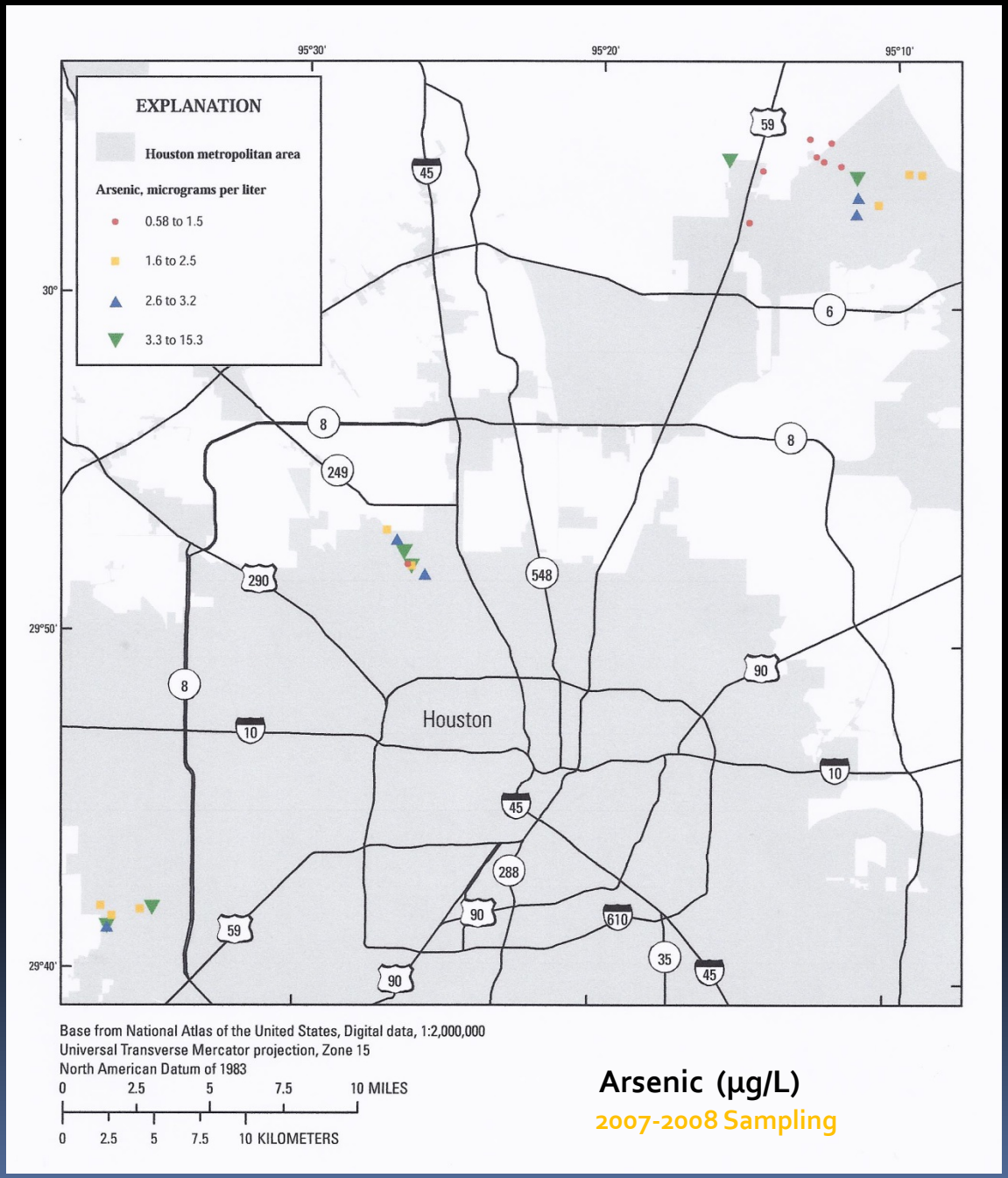


Radium-226+ 228 (ug/L)
2007-2008 Sampling



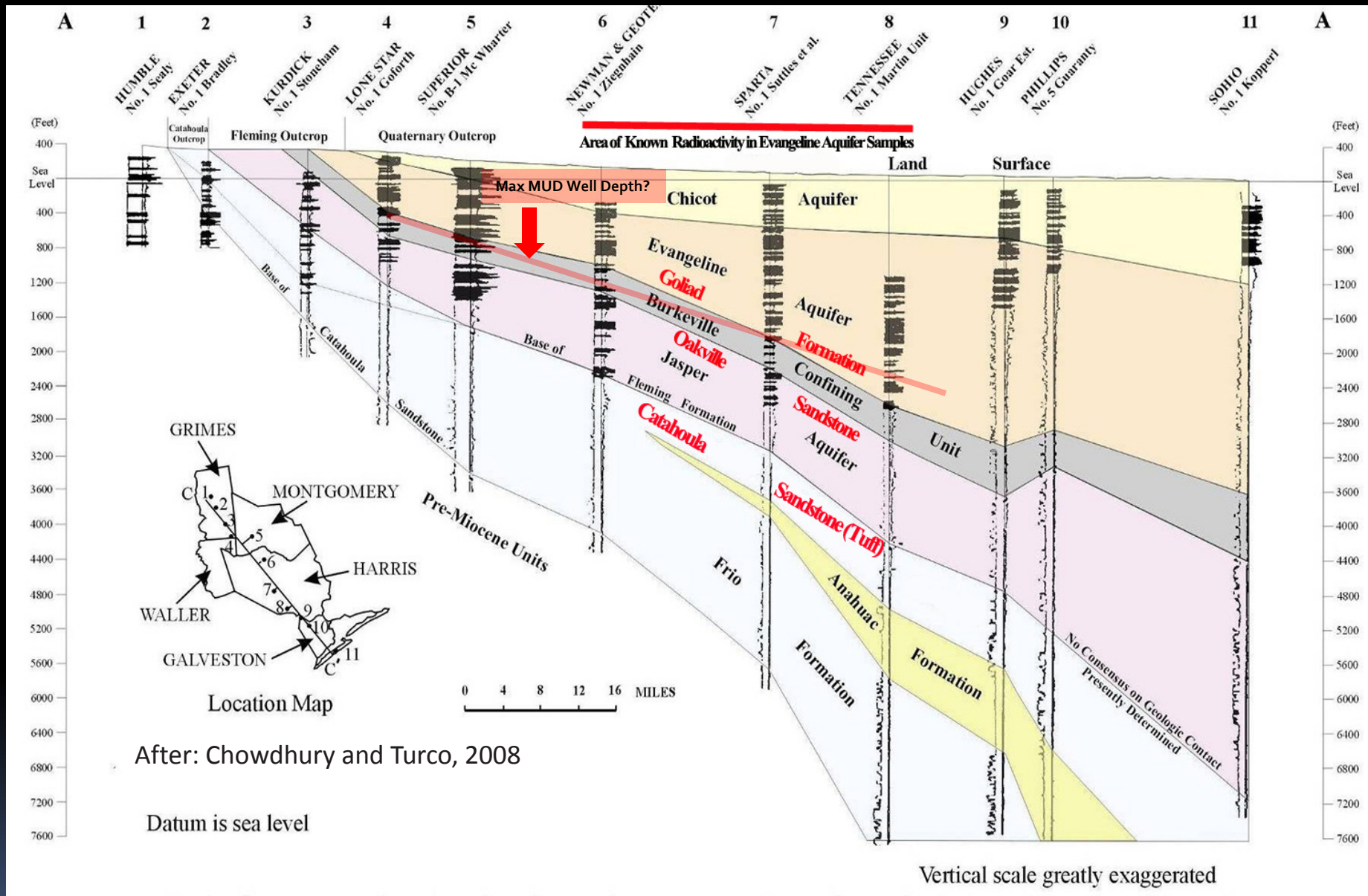
Uranium (µg/L)
2010-2011 & 2007-2008 Sampling

USGS Sampling 2007-2008 w/High U Values from 2010-2011 Data



Arsenic (µg/L)
2007-2008 Sampling

USGS Sampling 2007-2008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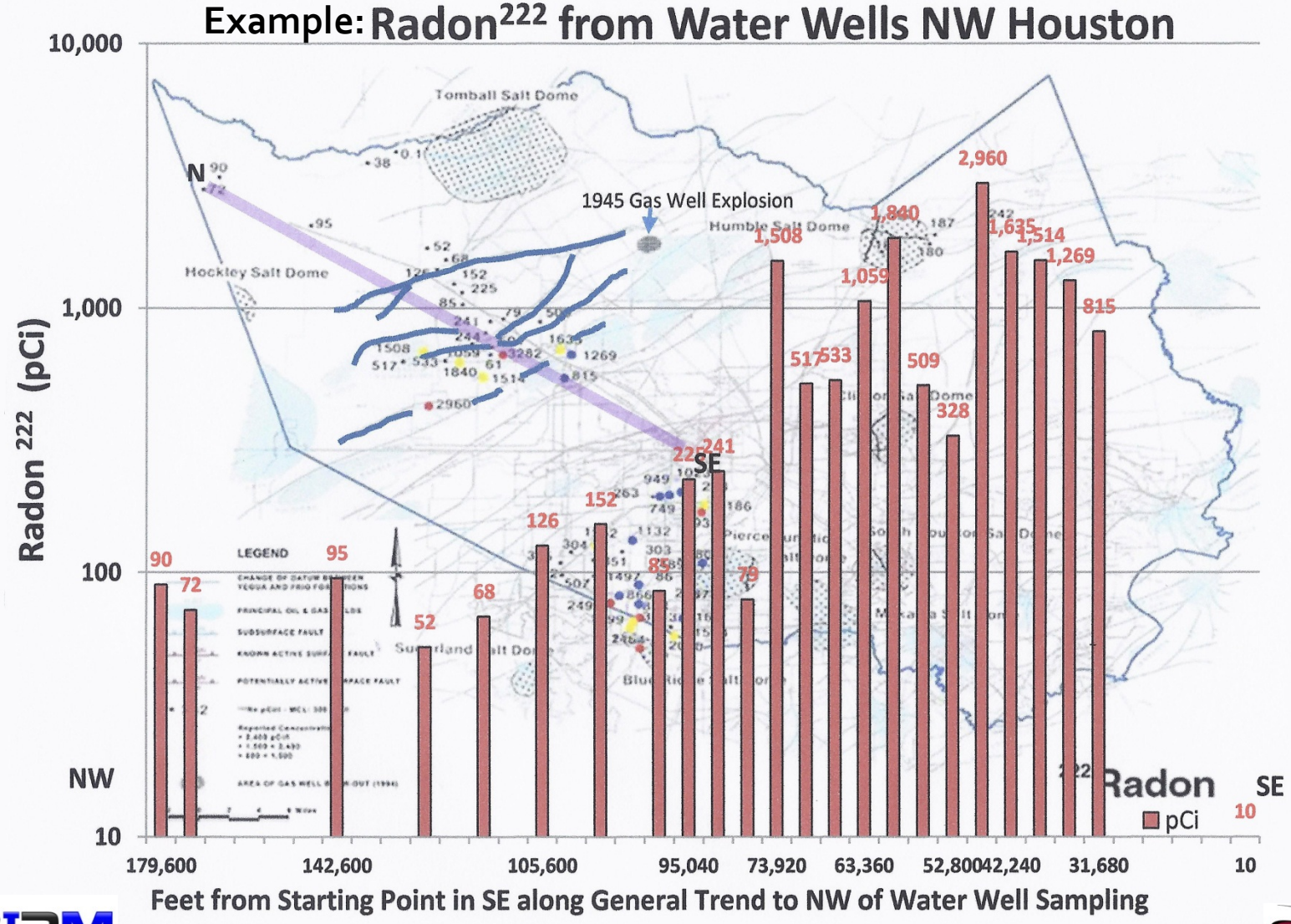
HUMBLE No. 1 Sealy
EXETER No. 1 Bradley
KURDICK No. 1 Stoneham
LONE STAR No. 1 Goforth
SUPERIOR No. B-1 Mc Wharter
NEWMAN & GEOTE No. 1 Ziegnhain
SPARTA No. 1 Suttles et al.
TENNESSEE No. 1 Martin Unit
HUGHES No. 1 Goar Est.
PHILLIPS No. 5 Guaranty
SOHIO No. 1 Kopperl
(Feet)
Sea Level
Catahoula Outcrop
Fleming Outcrop
Quaternary Outcrop
Area of Known Radioactivity in Evangeline Aquifer Samples
Max MUD Well Depth?
Land Surface
Chicot Aquifer
Evangeline Aquifer
Goliad Formation
Burkeville Confining Unit
Oakville Sandstone Aquifer
Jasper Aquifer
Fleming Formation
Catahoula Sandstone
Catahoula Sandstone (Tuff)
Frio Formation
Anahuac Formation
Base of Catahoula Sandstone
Base of Pre-Miocene Units
No Consensus on Geologic Contact Presently Determined
GRIMES
MONTGOMERY
HARRIS
WALLER
GALVESTON
Location Map
0 4 8 12 16 MILES
After: Chowdhury and Turco, 2008
Datum is sea level
Vertical scale greatly exaggerated

Migration Avenues for Uranium, Radium, and Radon



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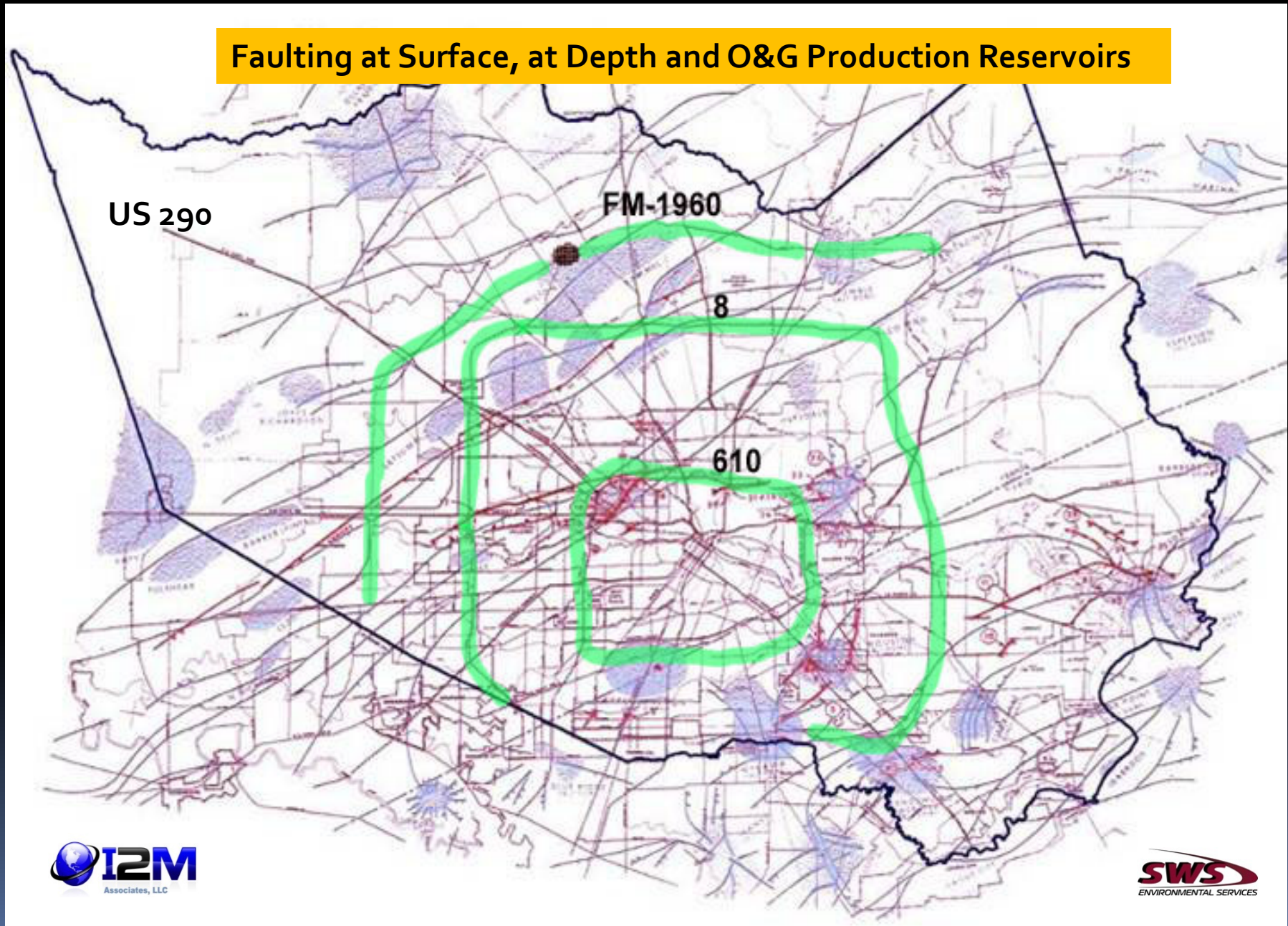
Faulting at Surface, at Depth and O&G Production Reservoirs



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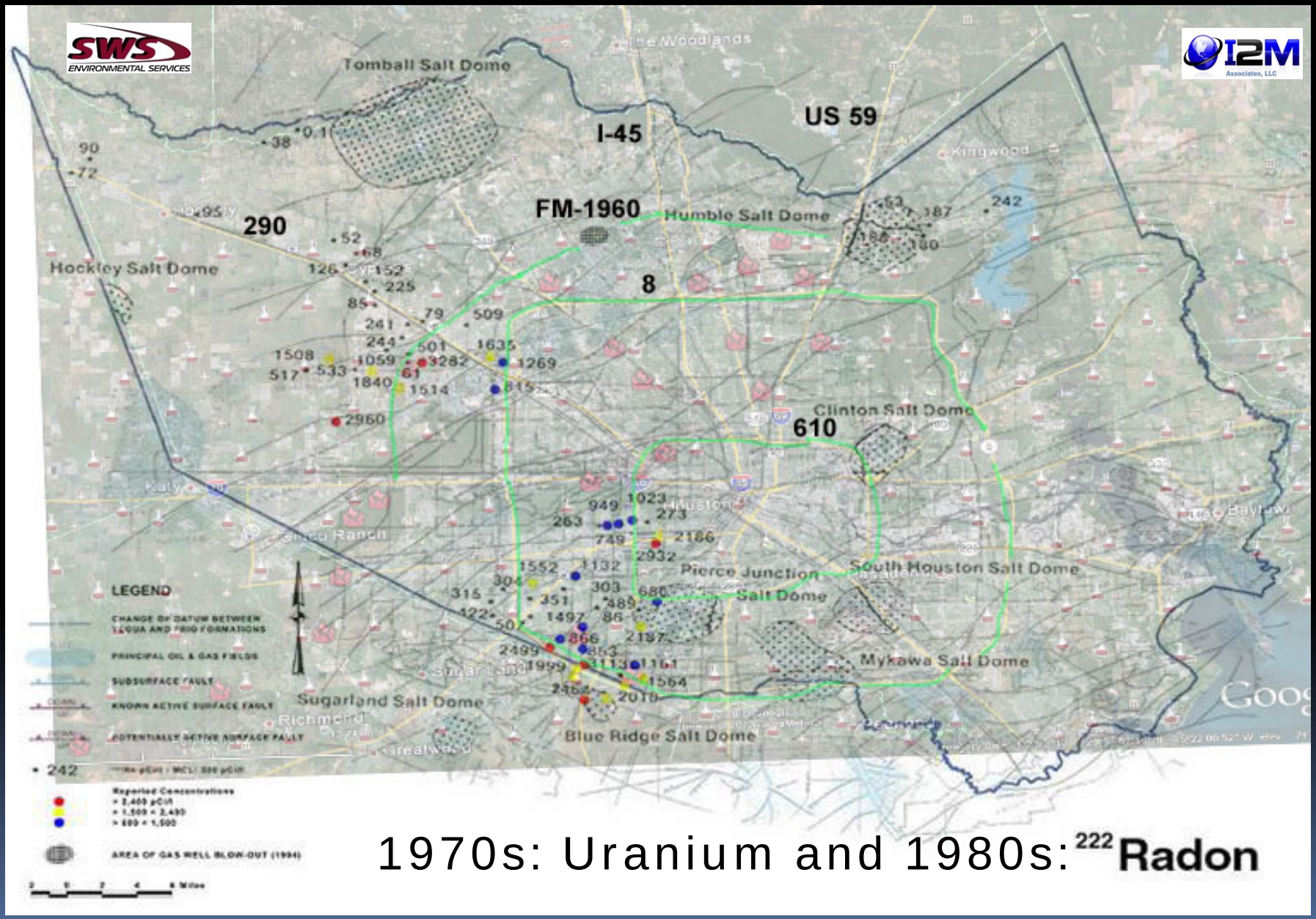
SWS ENVIRONMENTAL SERVICES

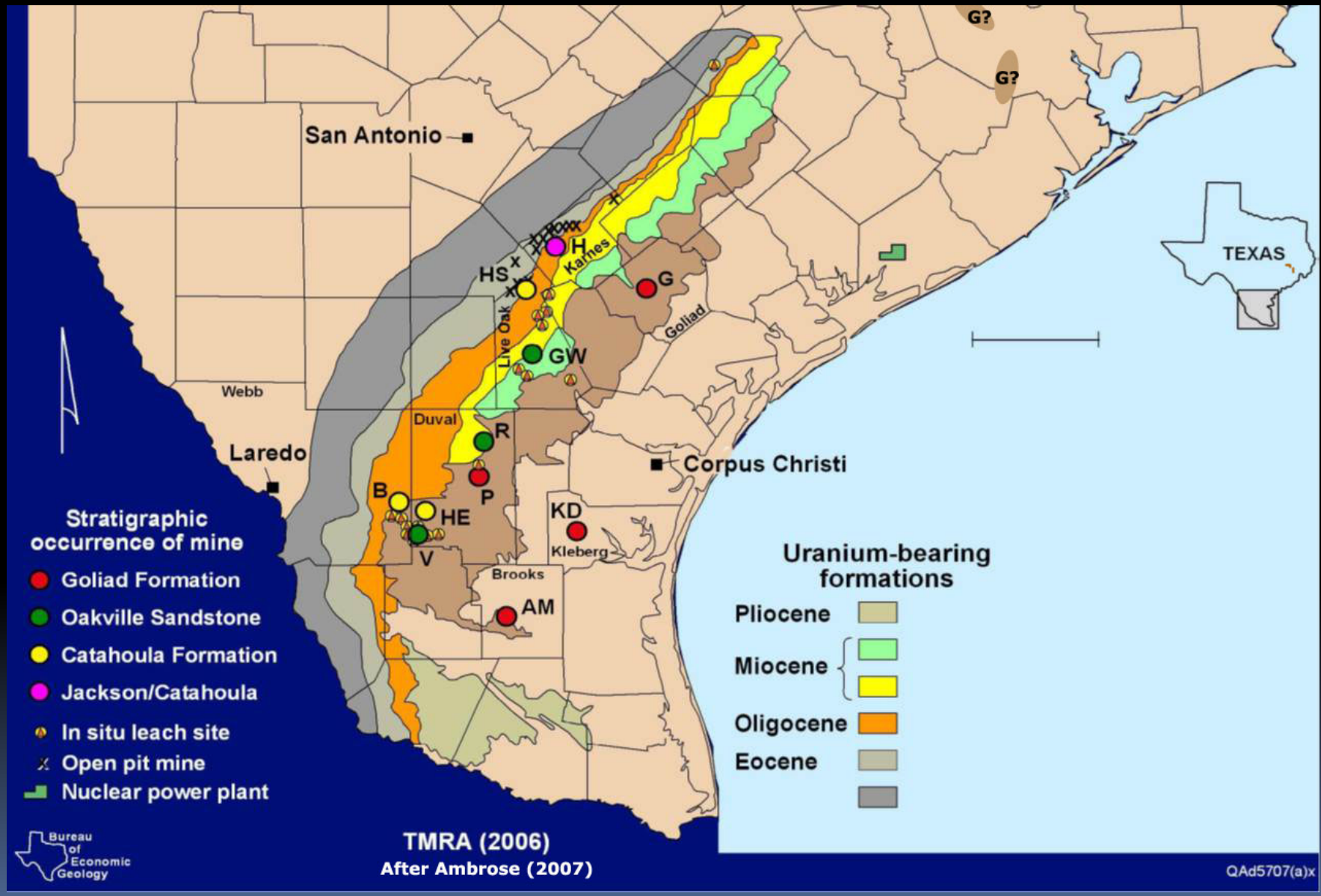


1970s: Uranium and 1980s: ^{222}Radon

* in HGS Text

Typical Uranium Deposit in Selected Formations of U.S. Gulf Coast

Favorable Formations Along Trend



Impact and Remediation

1) Although Radon-222 MCLs are high, Radon-222 gas may concentrate in houses to dangerous levels, and is especially harmful if person also smokes tobacco.
2) Can fix any problems by installing a ventilation system in the home.
3) Removal of natural gases at MUD Well by venting.

- GAC (Granulated Activated Carbon) technology is the most cost-effective; however, over very long periods, it does become a source of low-level radioactivity and requires special disposal.
- Aeration technology initial costs ($2,500 to $4,000) are estimated to be twice those of GAC. An air diffuser makes air bubbles rise through the water to strip radon and carry it to above the roof line. This is known as diffused-bubble aeration. Most units are about 99% effective.

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Natural Gas in Harris County Water Supply

Background:

During project to investigate why pumping rate has decreased in MUD Well.

- Reviewed MUD Maintenance Records and Downhole Video.
- Pulled Pump Assembly to Inspect condition.
- Sampled Water and Headspace.
- Confirmed natural gas and advanced scaling on down pipe.
- Research confirmed major gas blow-out in 1940s nearby.

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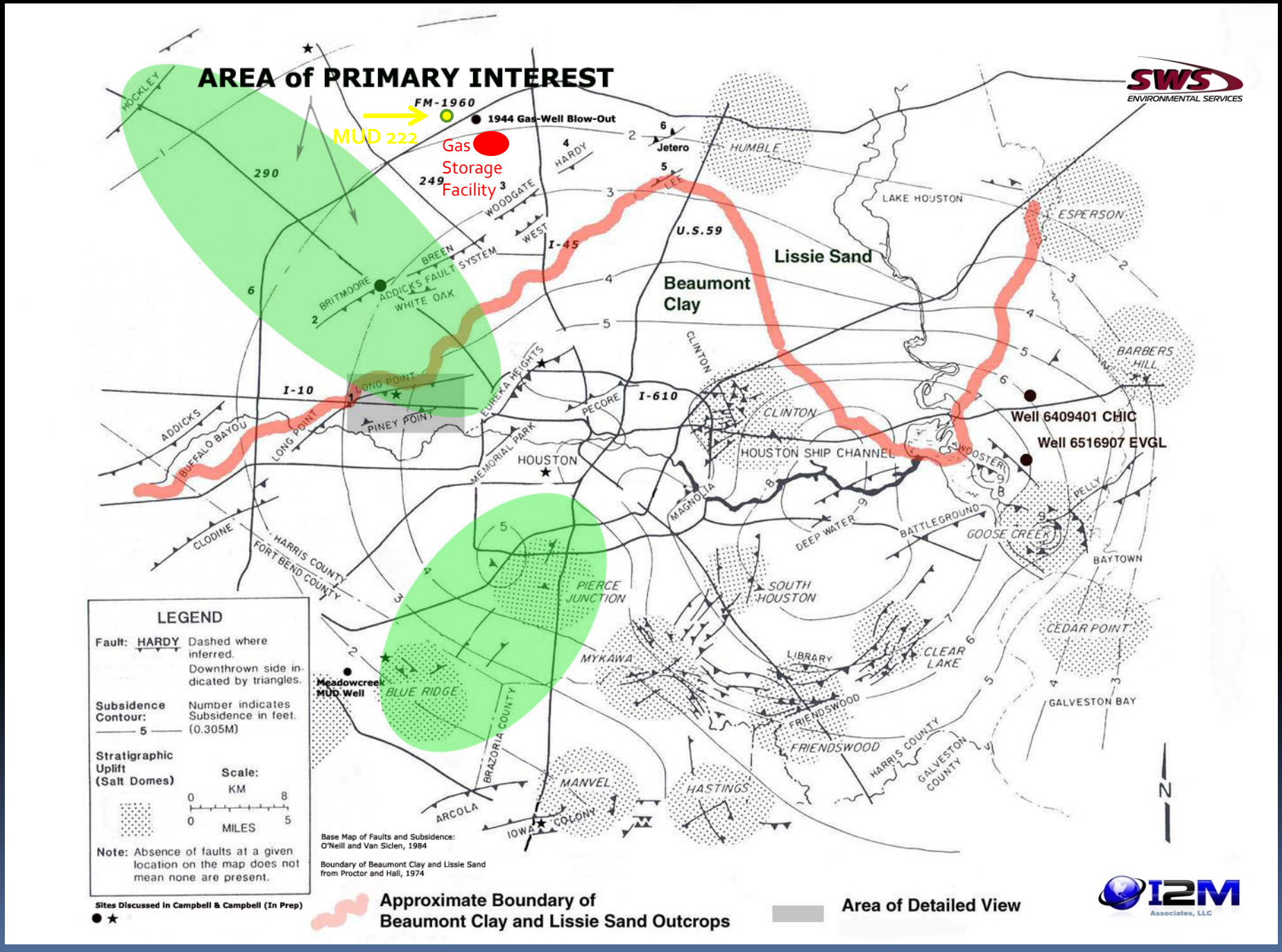
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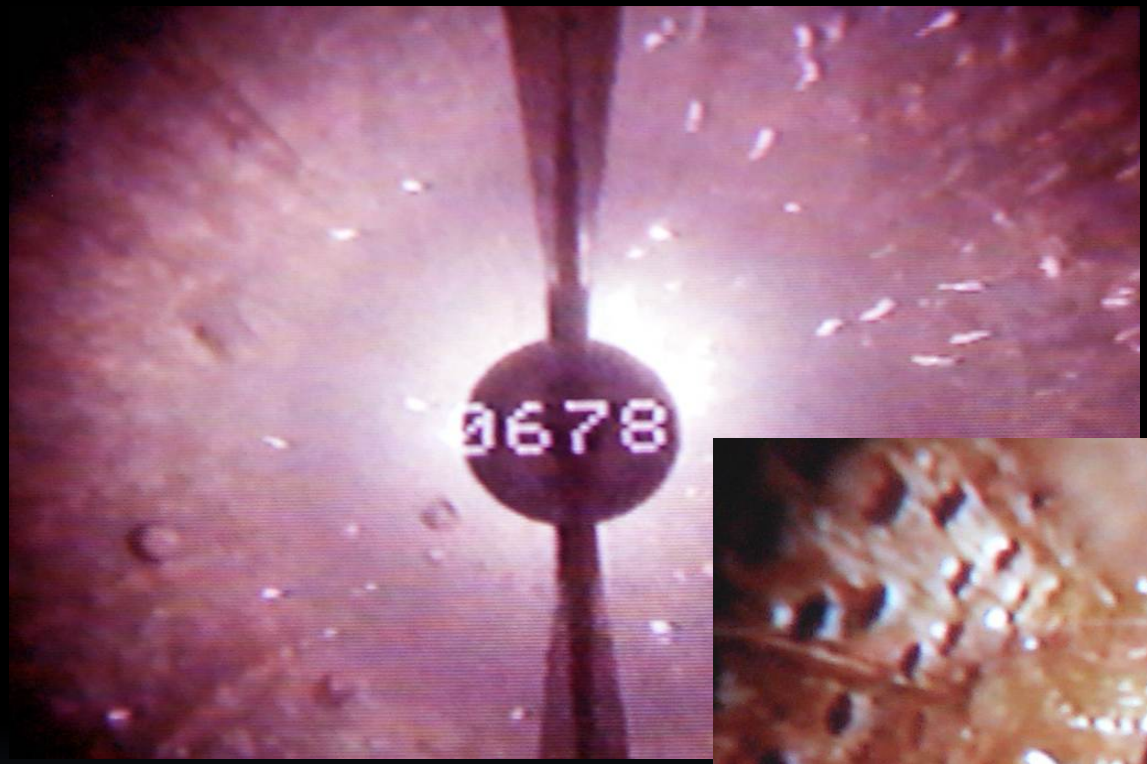
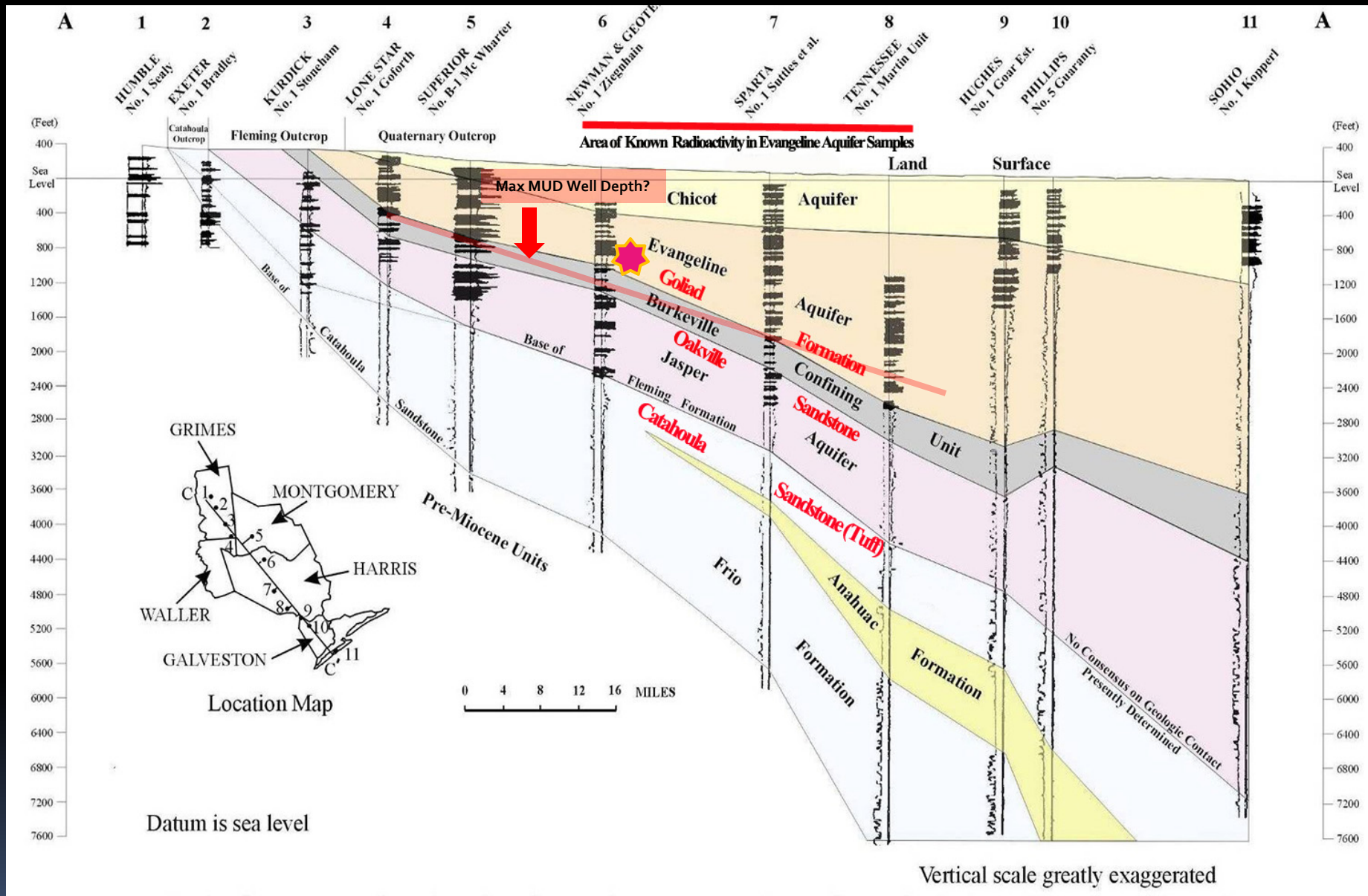
Boundary of Beaumont Clay and Lissie Sand from Proctor and Hall, 1974
Approximate Boundary of Beaumont Clay and Lissie Sand Outcrops
Area of Detailed View
I2M Associates, LLC

Downhole Video Logging of MUD Well



Minor Gas Bubbles at 678 Feet

Major Gas Bubbles at 710 Feet at Top of First-Screened Zone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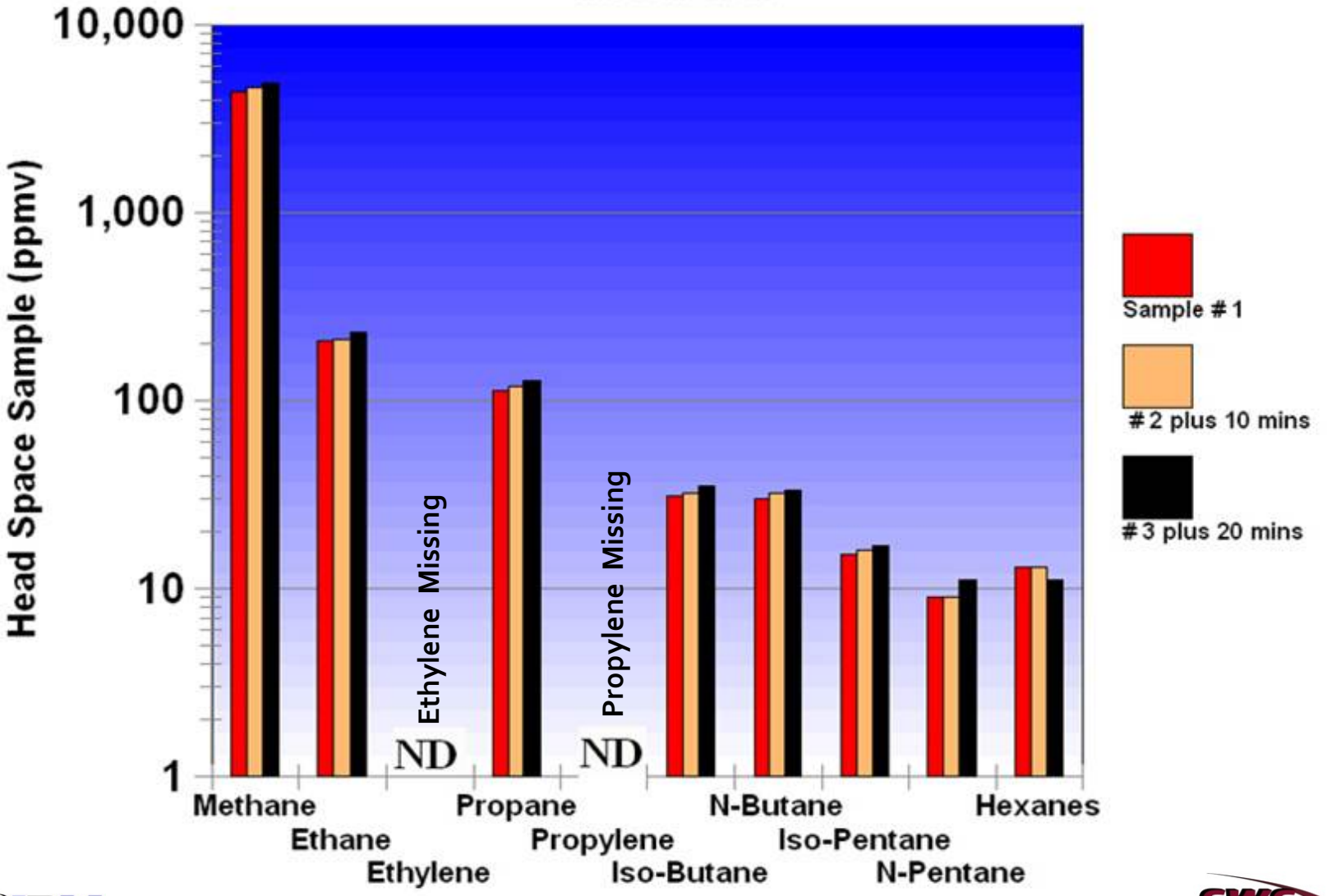
SOHIO No. 1 Kopperl
(Feet)
Sea Level
Catahoula Outcrop
Fleming Outcrop
Quaternary Outcrop
Area of Known Radioactivity in Evangeline Aquifer Samples
Max MUD Well Depth?
Land Surface
Chicot Aquifer
Evangeline
Goliad
Burkeville
Oakville
Jasper
Fleming Formation
Catahoula
Aquifer
Formation
Confining Unit
Sandstone Aquifer
Sandstone (Tuff)
Anahuac Formation
Frio Formation
Base of Catahoula Sandstone
Base of Pre-Miocene Units
No Consensus on Geologic Contact Presently Determined
GRIMES
MONTGOMERY
HARRIS
WALLER
GALVESTON
Location Map
0 4 8 12 16 MILES
Datum is sea level
Vertical scale greatly exaggerated

Purging MUD Well in Northern Houston

Sampling MUD Well-Casing Headspace and Ground Water

MUD Well Sampling for Natural Gas

FM-1960 Area



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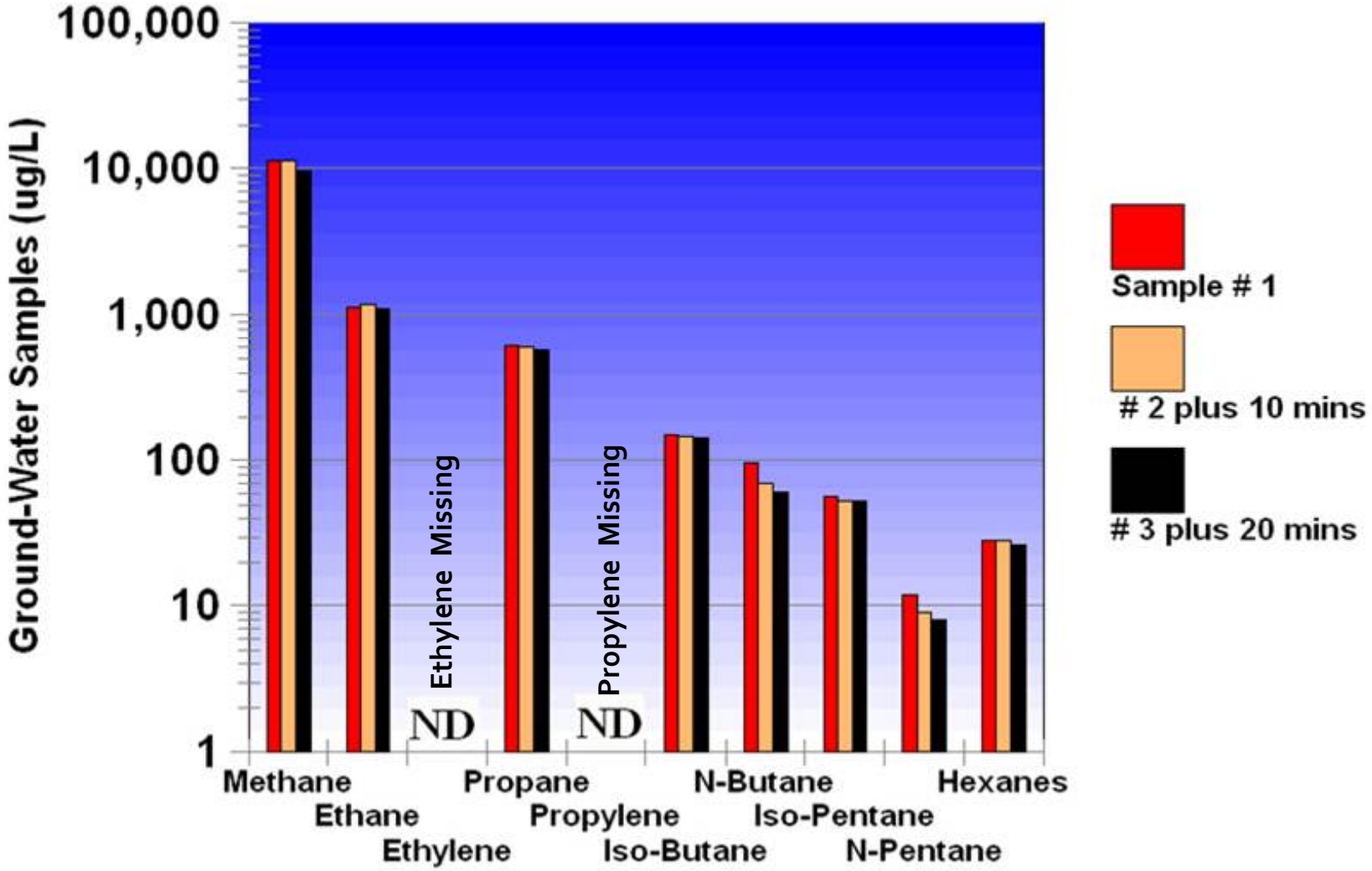
MUD Well Sampling for Natural Gas

FM-1960 Area



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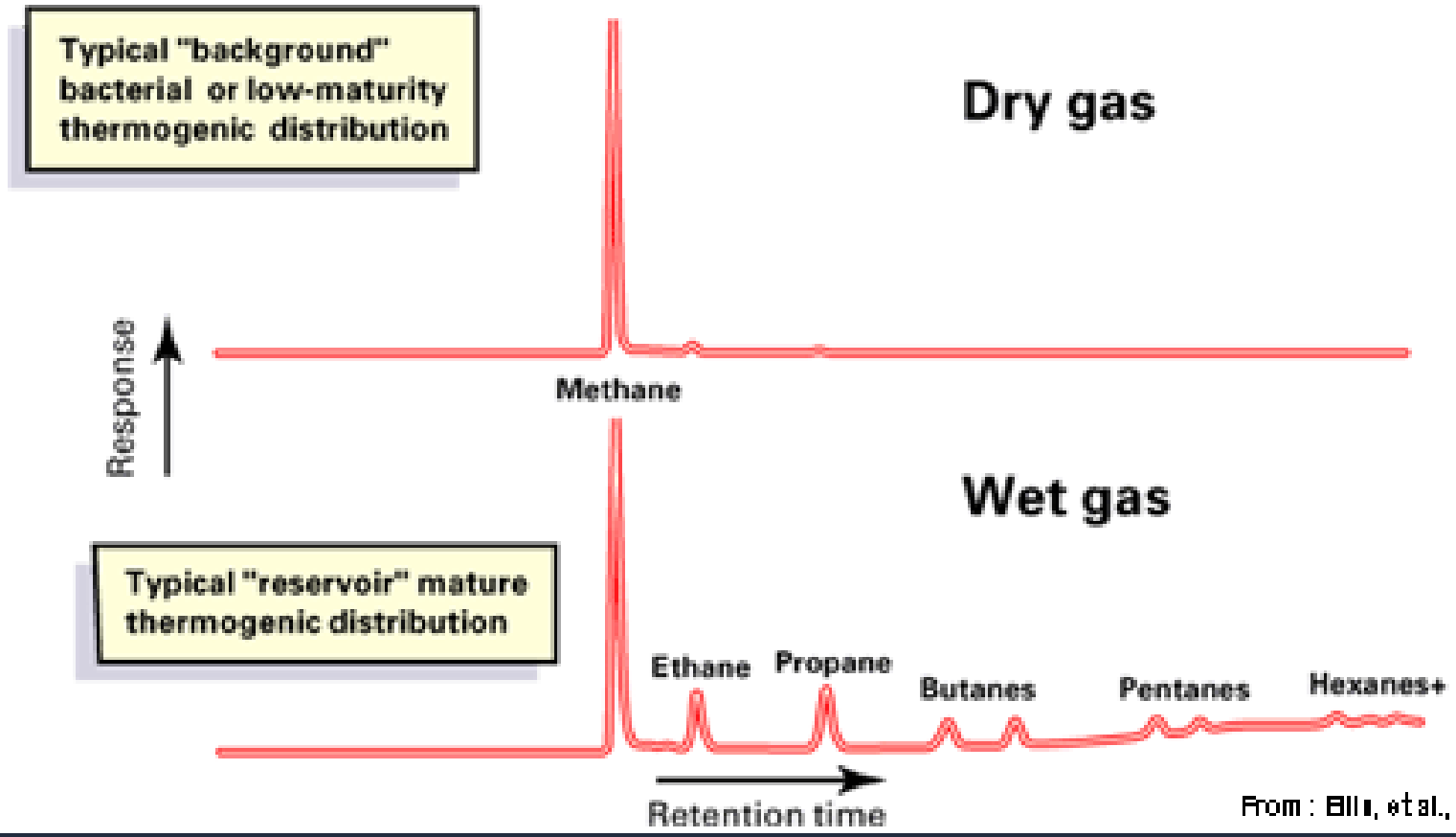
HYDROCARBON GASES IN THE SUBSURFACE



From : Bills, et al., 2003

MUD Well and Storage Facility North of FM 1960 w/ De-Gassing & De-Sanding Equipment

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Impact and Remediation:

1) Explosive Levels Indicated within Water Storage Tanks, requiring Immediate Shut-Down of MUD Well.

2) Explosion-proof electrical fittings installed, or

3) Degassing at MUD Well.

Natural Gas in Rancher's Domestic Well

Background:

During project to investigate why groundwater from Ranch house water wells just began to exhibit bad taste and to be cloudy in appearance.

- Observed both wells and treatment filters.
- Pulled Pump Assemblies to Inspect conditions.
- Sampled Water & Headspace over 2-week period for natural gases.
- Investigation hampered by loss of seal on one WW.
- North well indicated by D isotope natural gas was thermogenic in origin but C isotope indicated biogenic.

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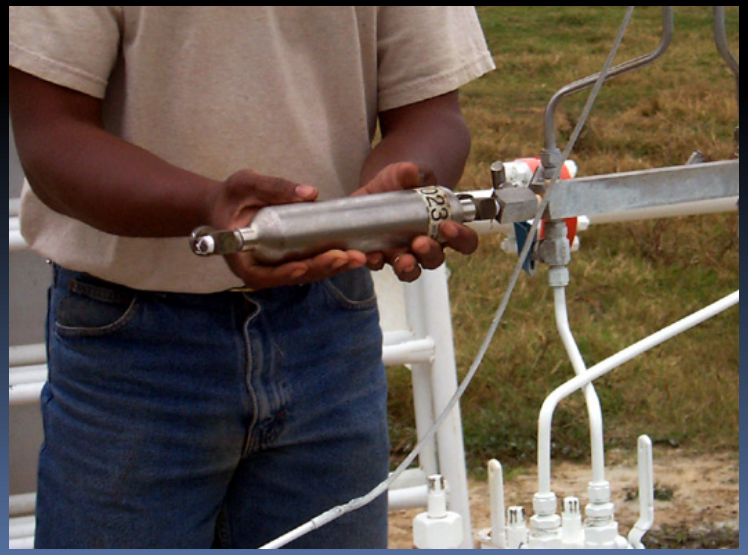
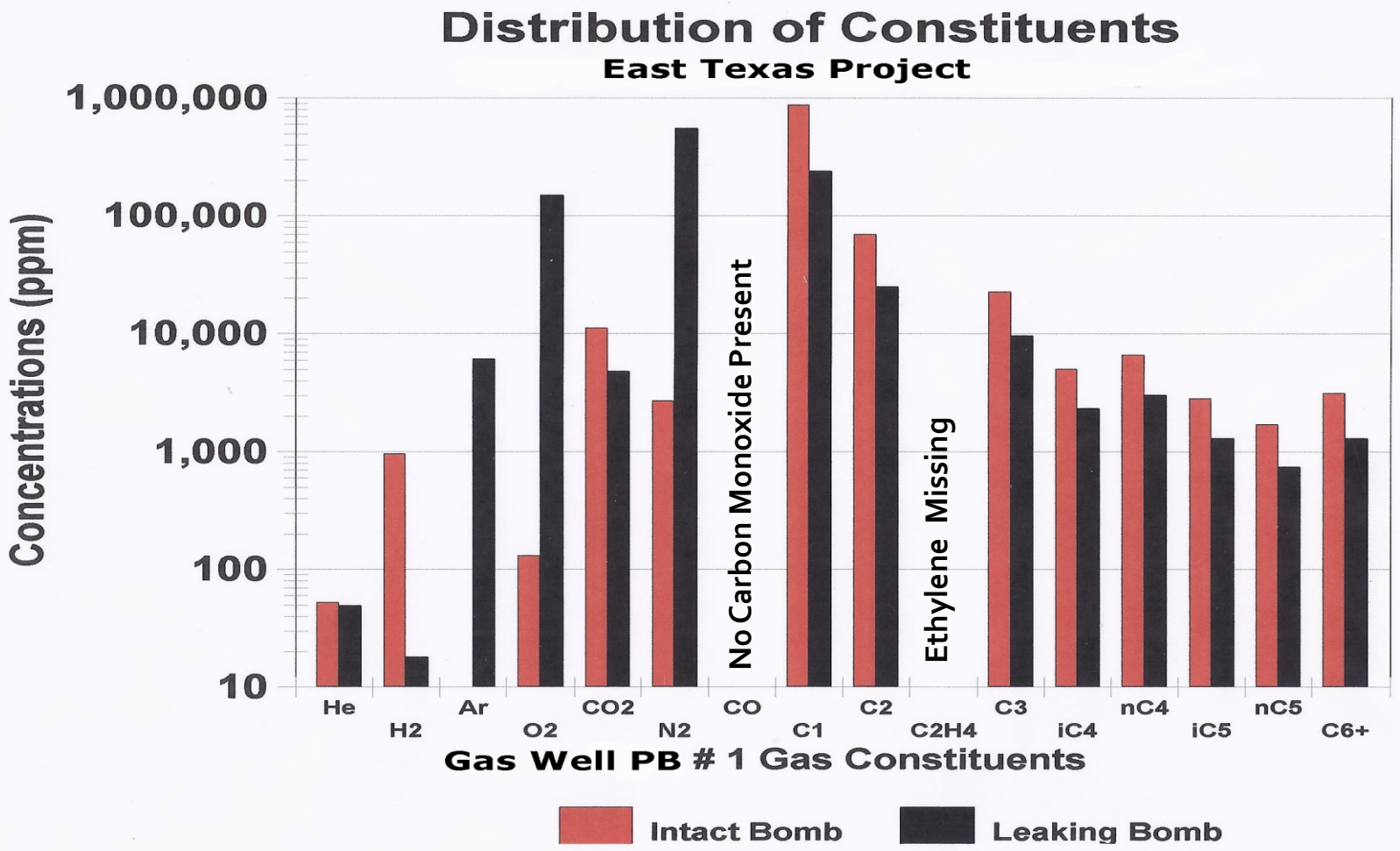
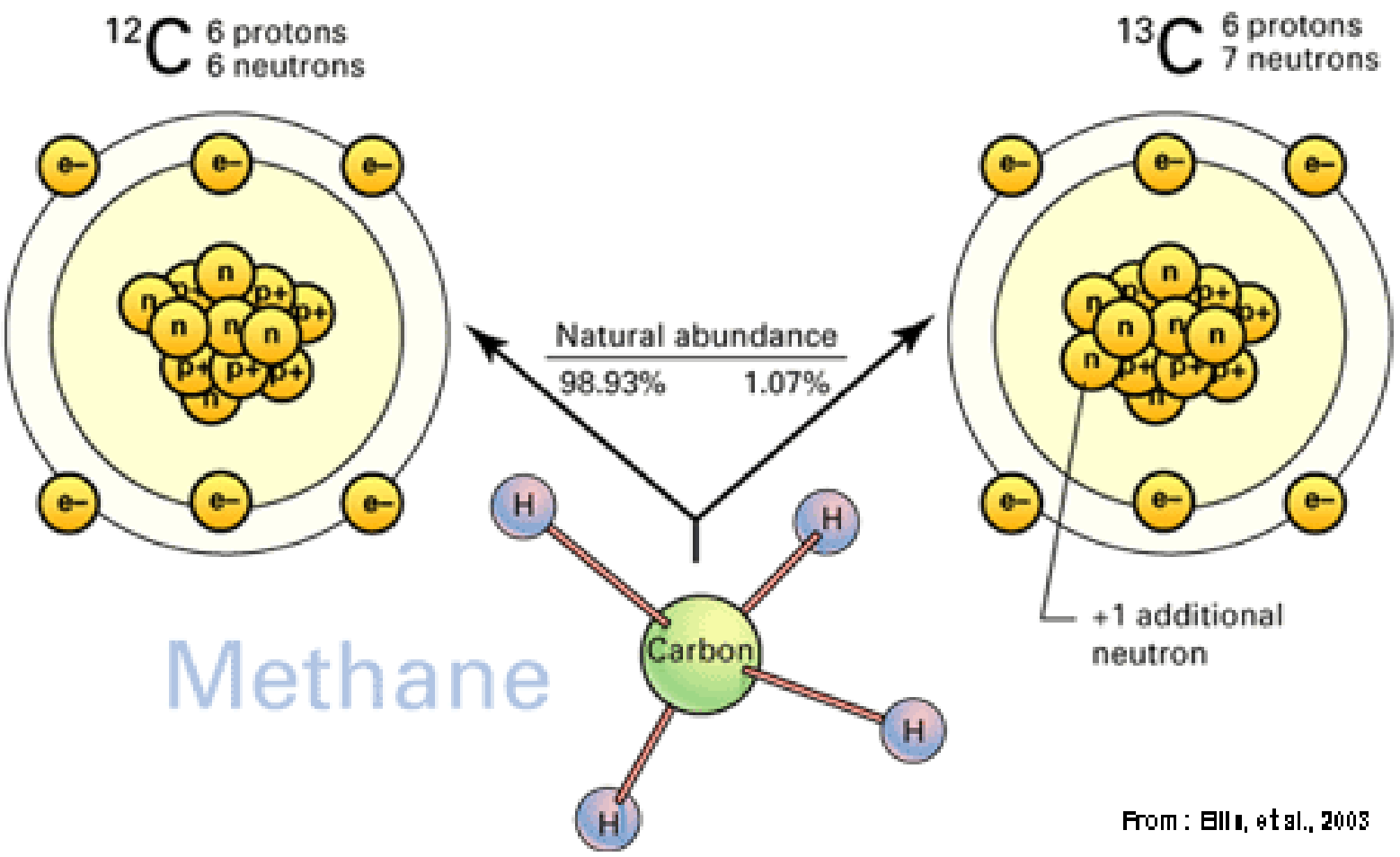
Sampling Headspace of North Water Well



Sampling Natural Gas from Nearby Well


Distribution of Constituents
East Texas Project
Concentrations (ppm)
1,000,000
100,000
10,000
1,000
100
10
No Carbon Monoxide Present
Ethylene Missing
He
H2
Ar
O2
CO2
N2
CO
C1
C2
C2H4
C3
iC4
nC4
iC5
nC5
C6+
Gas Well PB # 1 Gas Constituents
Intact Bomb
Leaking Bomb

Two Stable Isotopes of Carbon



Deuterium Isotope in Methane

δDC_1 per mil

Biogenic Methane -197 [----------] -353

-150 [----------] -303 Thermogenic Methane

-170 -180

PD#1 North Water Well

Gas Well Sample Headspace

Carbon 13 Isotope in Methane

$\delta^{13}C_1$ per mil

North Water Well Headspace

Biogenic Methane -33 [----------] -57 ..... -67

-27 [----------] -55 Thermogenic Methane

-42

PD#1

Gas Well Sample

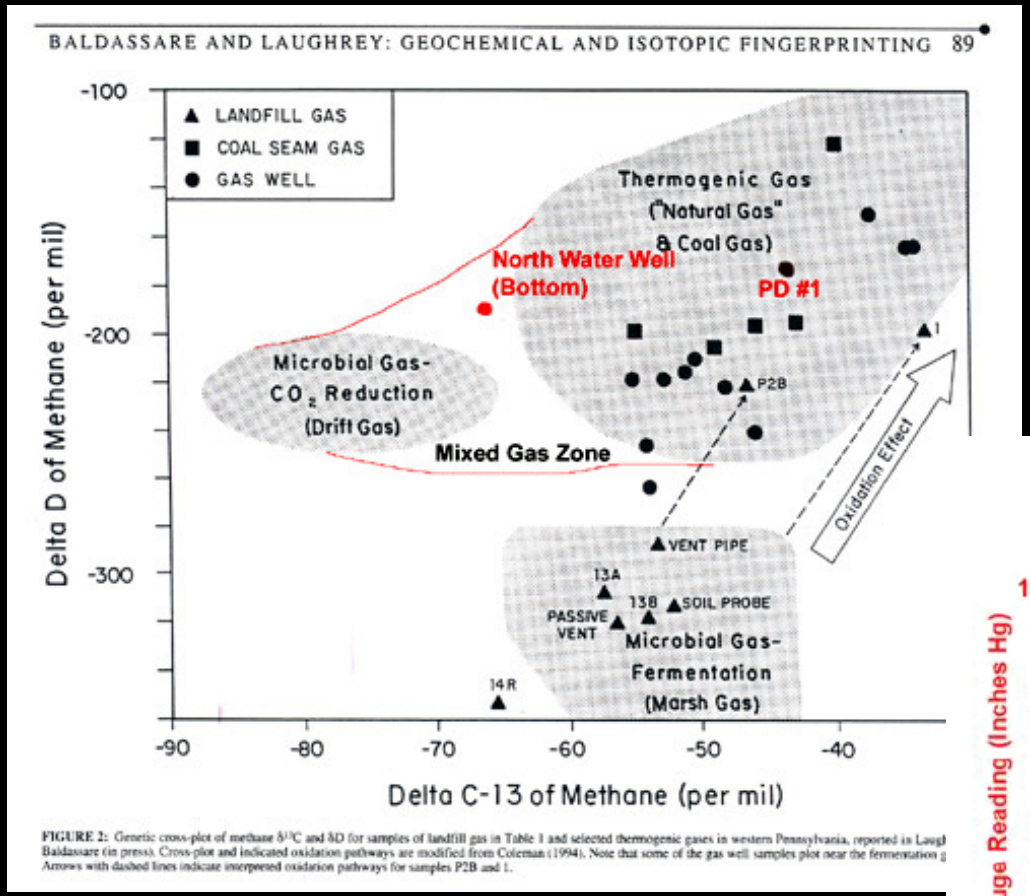
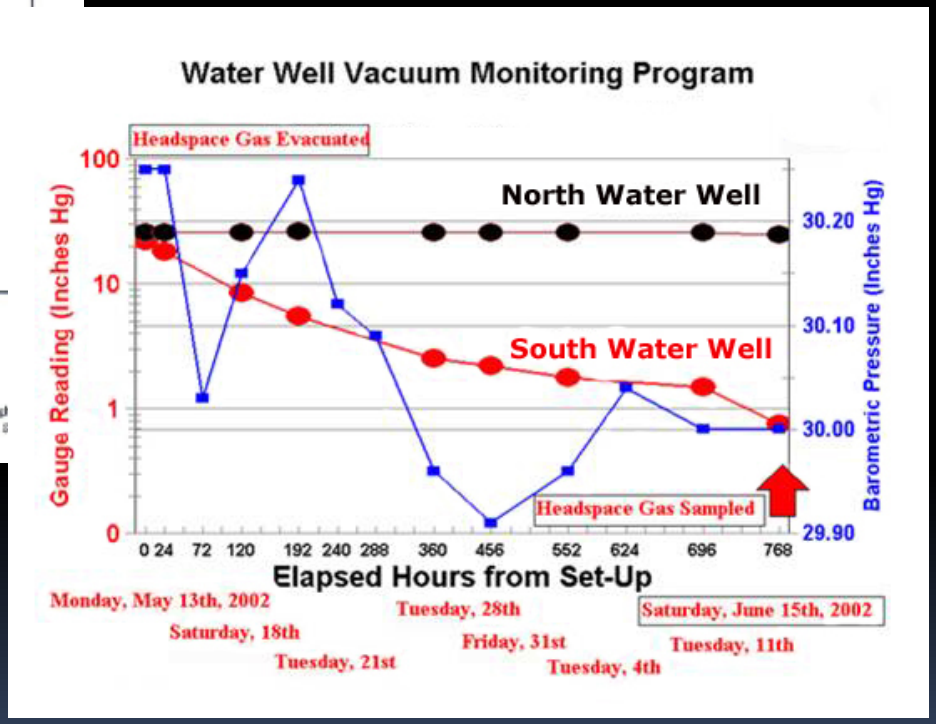


FIGURE 2: Genetic cross-plot of methane $\delta^{13}C$ and δD for samples of landfill gas in Table 1 and selected thermogenic gases in western Pennsylvania, reported in Laugh Baldassare (in press). Cross-plot and indicated oxidation pathways are modified from Coleman (1994). Note that some of the gas well samples plot near the fermentation g Arrows with dashed lines indicate interpreted oxidation pathways for samples P2B and 1.

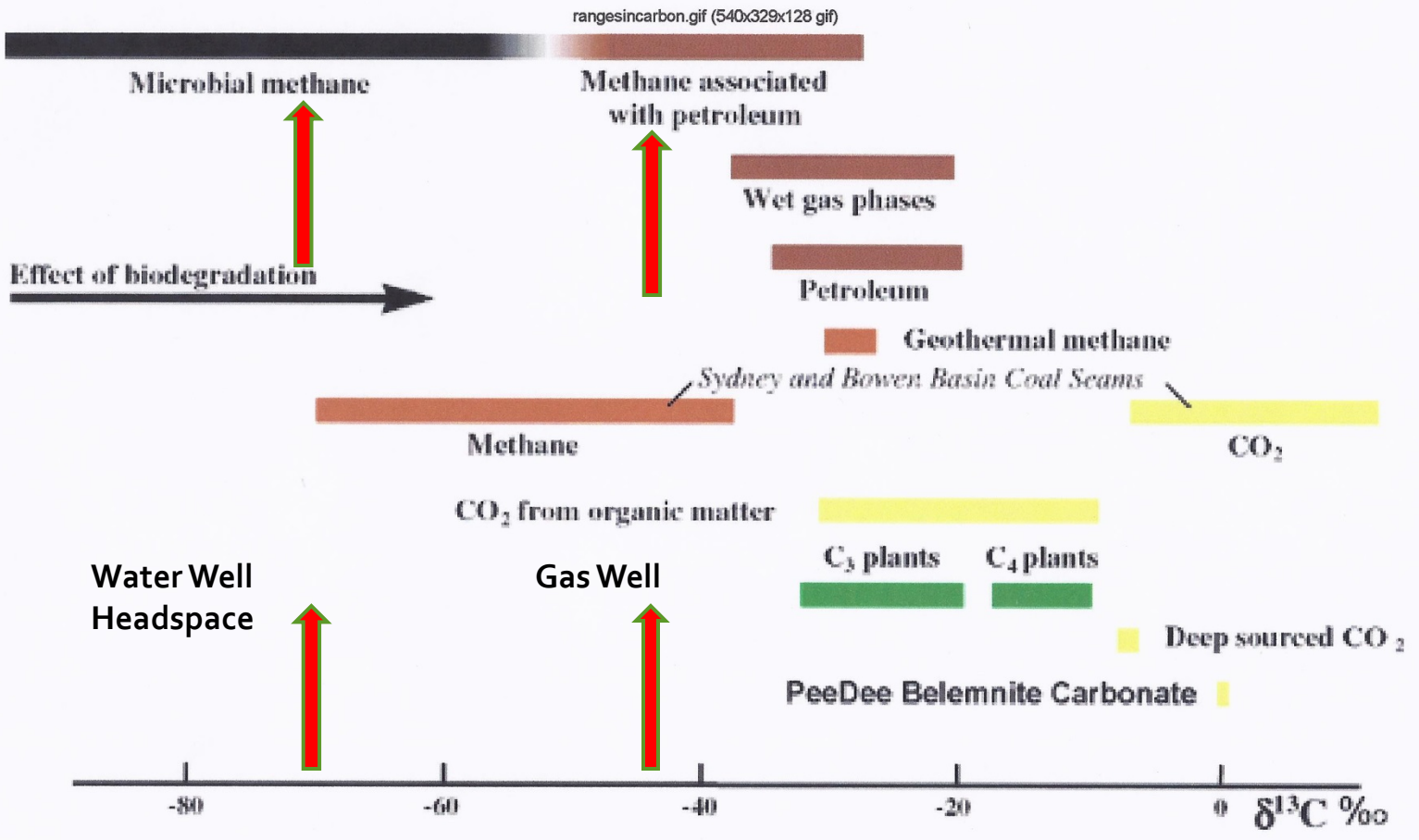
Fingerprint Reference



Field Data

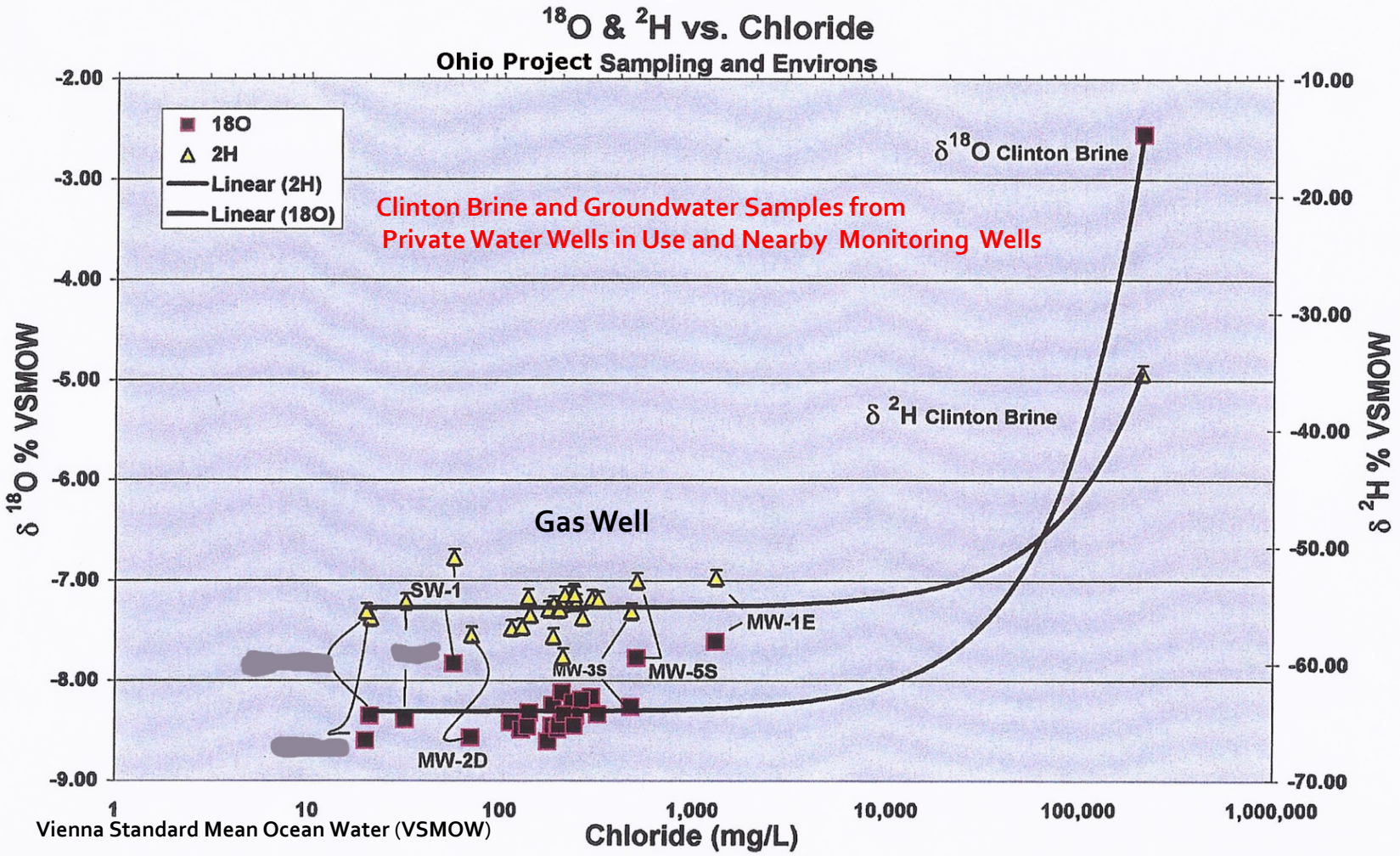
Issues Related to Sampling Existing Water Wells:

1) Age, Condition, & Materials of WW, PVC, Steel, etc., presence of Fe-Mn bacteria
2) Age, Condition, & Materials of Pump w/in WW, presence of S-Reducing bacteria
3) Maintenance History of WW & Pump & Drop-Pipe
4) Type of Sampling Equipment, bailer, pump, etc.
5) Type & Handling of Sample Containers, liquid of gas
6) Rate of Water Discharge
7) Changes of water table / potentiometric surface levels
8) Location of Well Screens or screened zones



Ranges in carbon isotope signatures from different sources

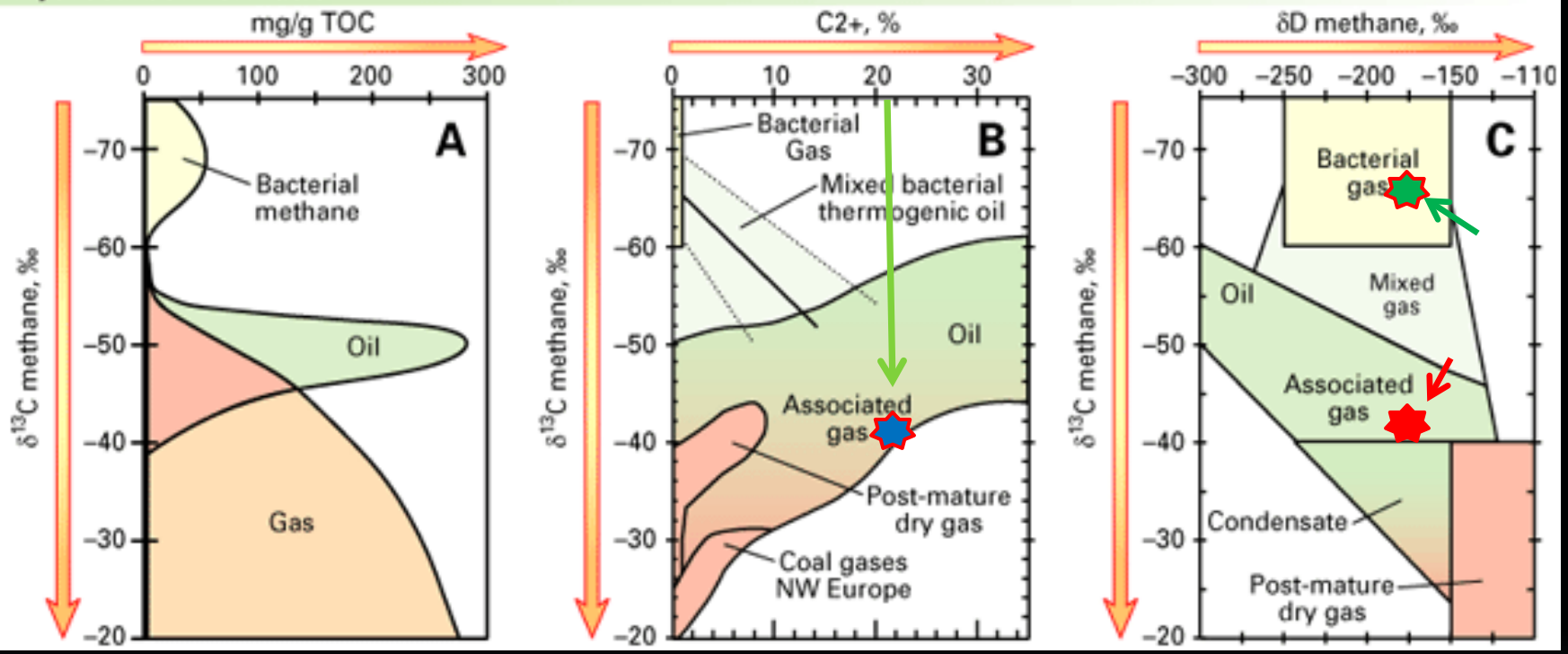
After: Johnson, 2001


18O & 2H vs. Chloride
Ohio Project Sampling and Environs
18O
2H
Linear (2H)
Linear (18O)
Clinton Brine and Groundwater Samples from
Private Water Wells in Use and Nearby Monitoring Wells
δ18O Clinton Brine
δ 2H Clinton Brine
Gas Well
SW-1
MW-1E
MW-3S
MW-5S
MW-2D
-2.00
-3.00
-4.00
-5.00
-6.00
-7.00
-8.00
-9.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
δ 18O % VSMOW
δ 2H % VSMOW
1
10
100
1,000
10,000
100,000
1,000,000
Chloride (mg/L)
Vienna Standard Mean Ocean Water (VSMOW)

GENETIC CHARACTERIZATION OF GASES

From: Ellis, et al., 2003

Hydrocarbon formation



FM-1960 Area MUD Well

East-Texas Gas Well

N WW Headspace

East Texas Project Outcome:

Additional Isotope work was recommended but Defendant Gas Company offered to drill and equip two deep water wells for Rancher.

Case Closed !

Regional Impact of Growth Faults

Growth Faults, aside from just contributing to surface subsidence, also allow:

1) Migration of deep groundwater into MUD wells and shallow drinking-water supplies

2) Migration of natural gas, uranium, & other radionuclides into MUD and Private water wells.

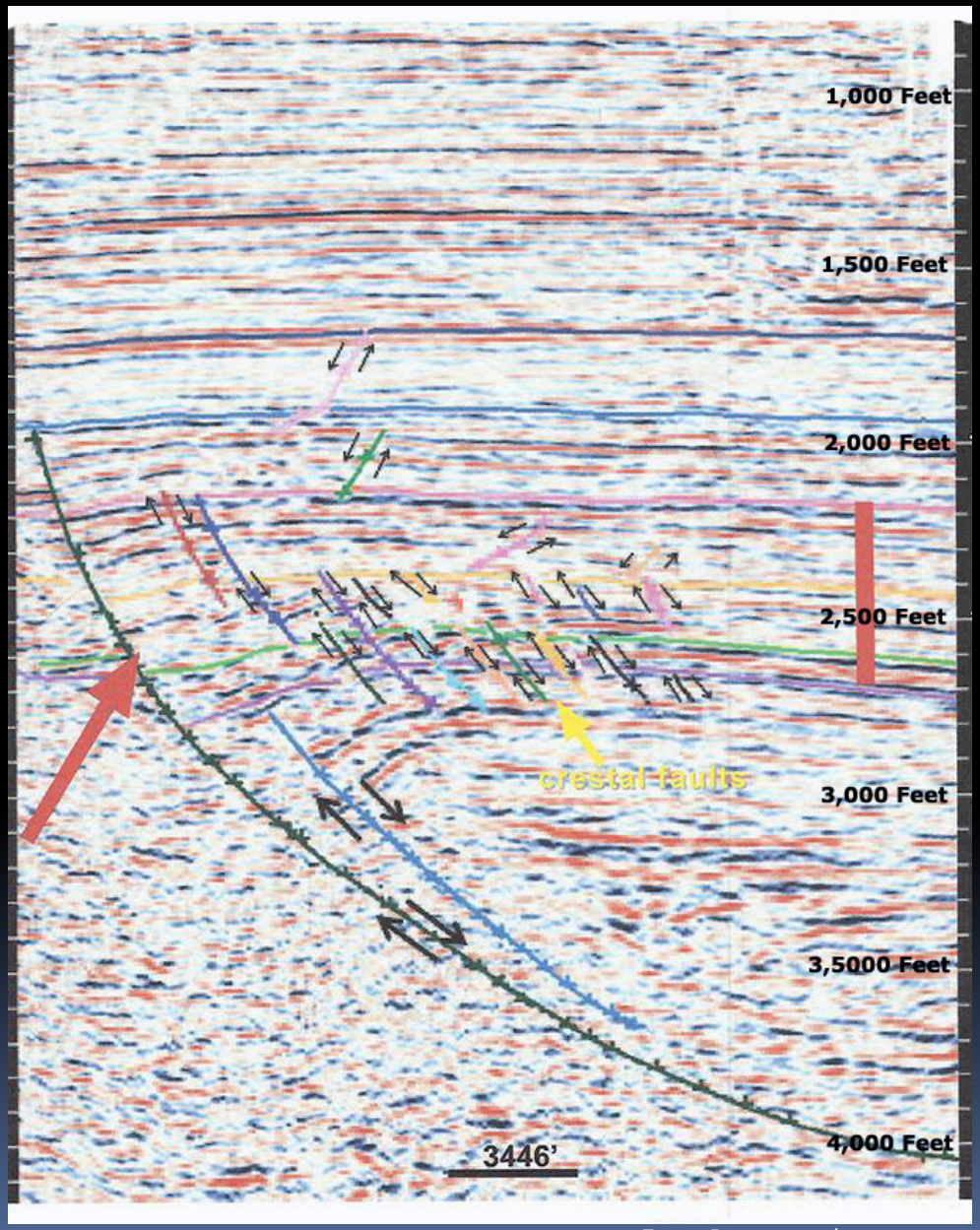
3) Nothing abnormal, nothing unusual: natural gas, uranium and radionuclides occur in the groundwater throughout the U.S. Mitigations are readily available. Only some exceptions.

I2M Associates, LLC

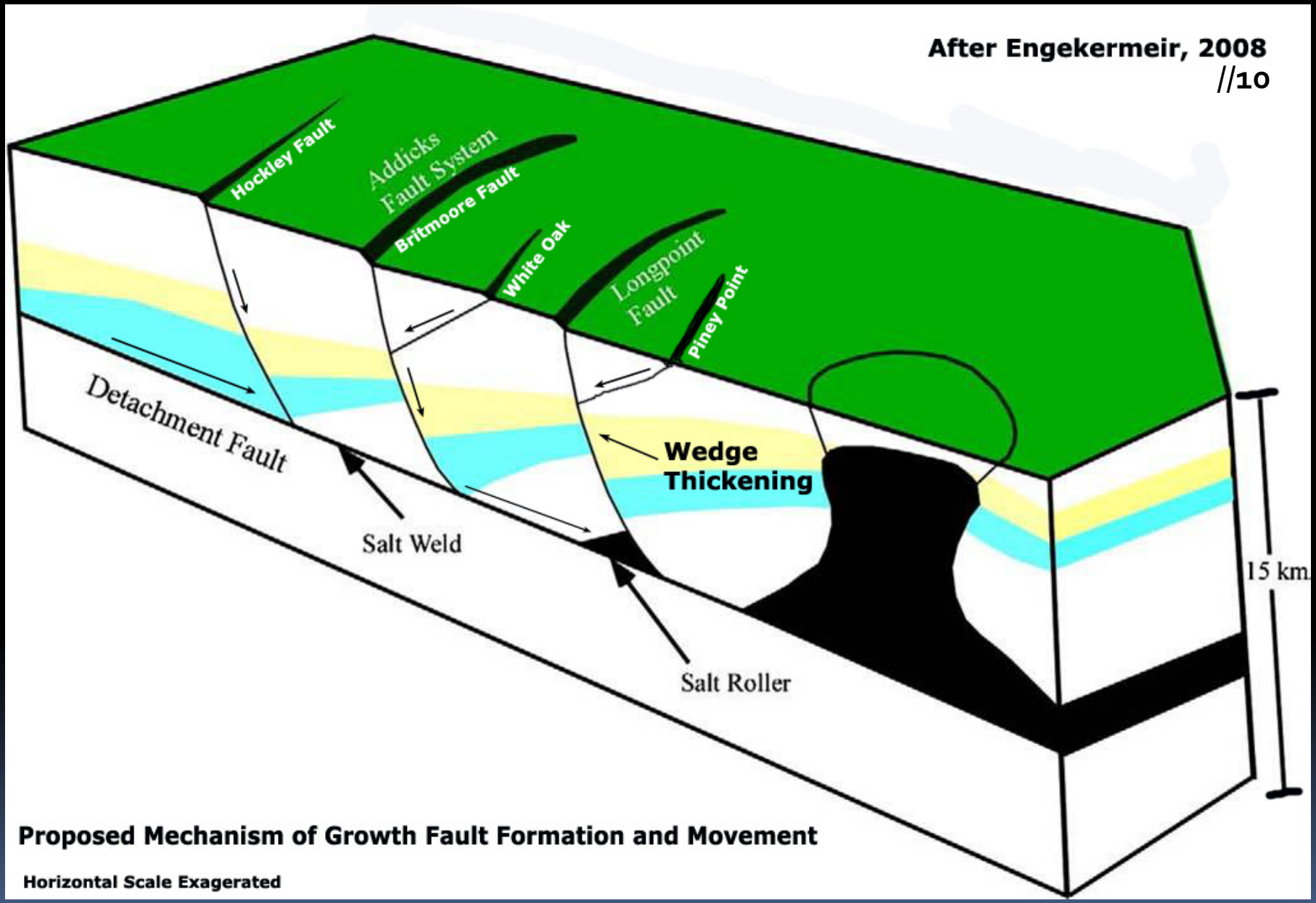
SWS ENVIRONMENTAL SERVICES

Seismic Dip Line Exhibiting Growth Faults (Blue and Black)

- Setting Up Subbasin
- Antithetic and Synthetic Crestal Faults
- Compartmentalizing Prograding Wedge Reservoir
- Expansion of Wedge into Growth Fault
- Increasing Permeability along Growth Fault?
- Allowing Gases (and Fluids) to Migrate up Growth Fault



From Brown, et al., 2004
and Hammes, et al., 2006



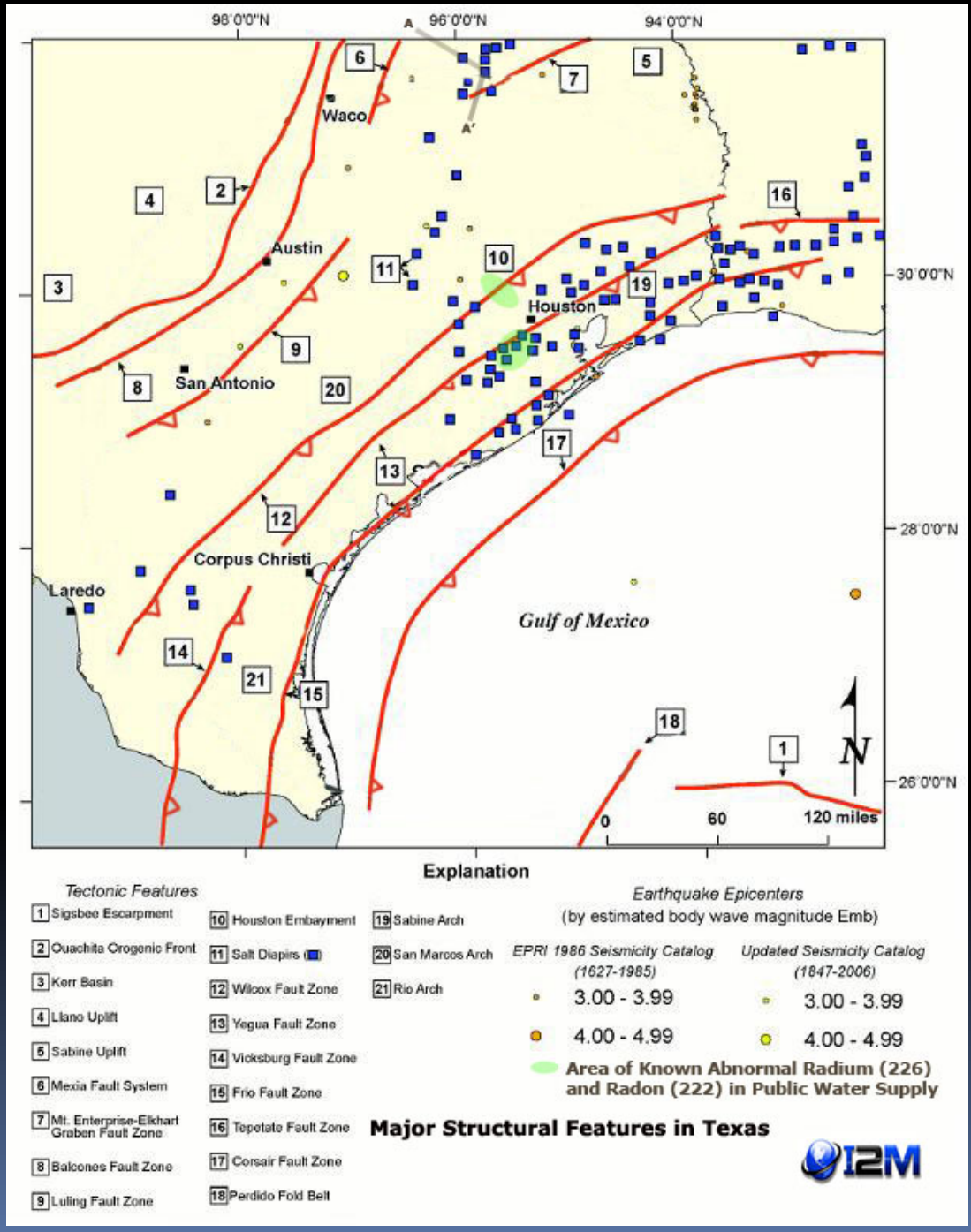
Proposed Mechanism of Growth Fault Formation and Movement

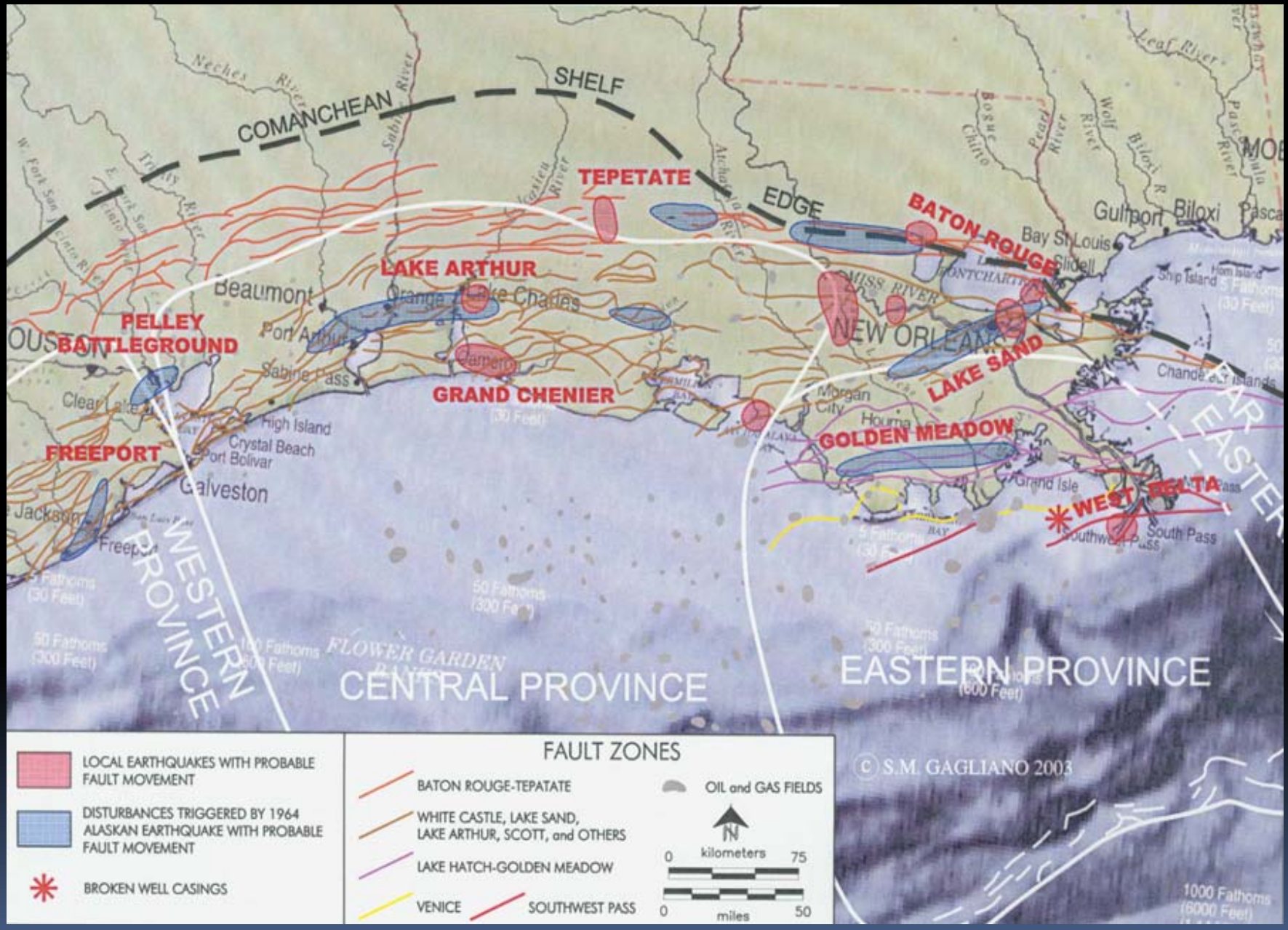
Horizontal Scale Exagerated

Main Growth Fault Systems at Surface in State

Locations of Salt Domes, Some Near Surface

Earthquake Epicenters



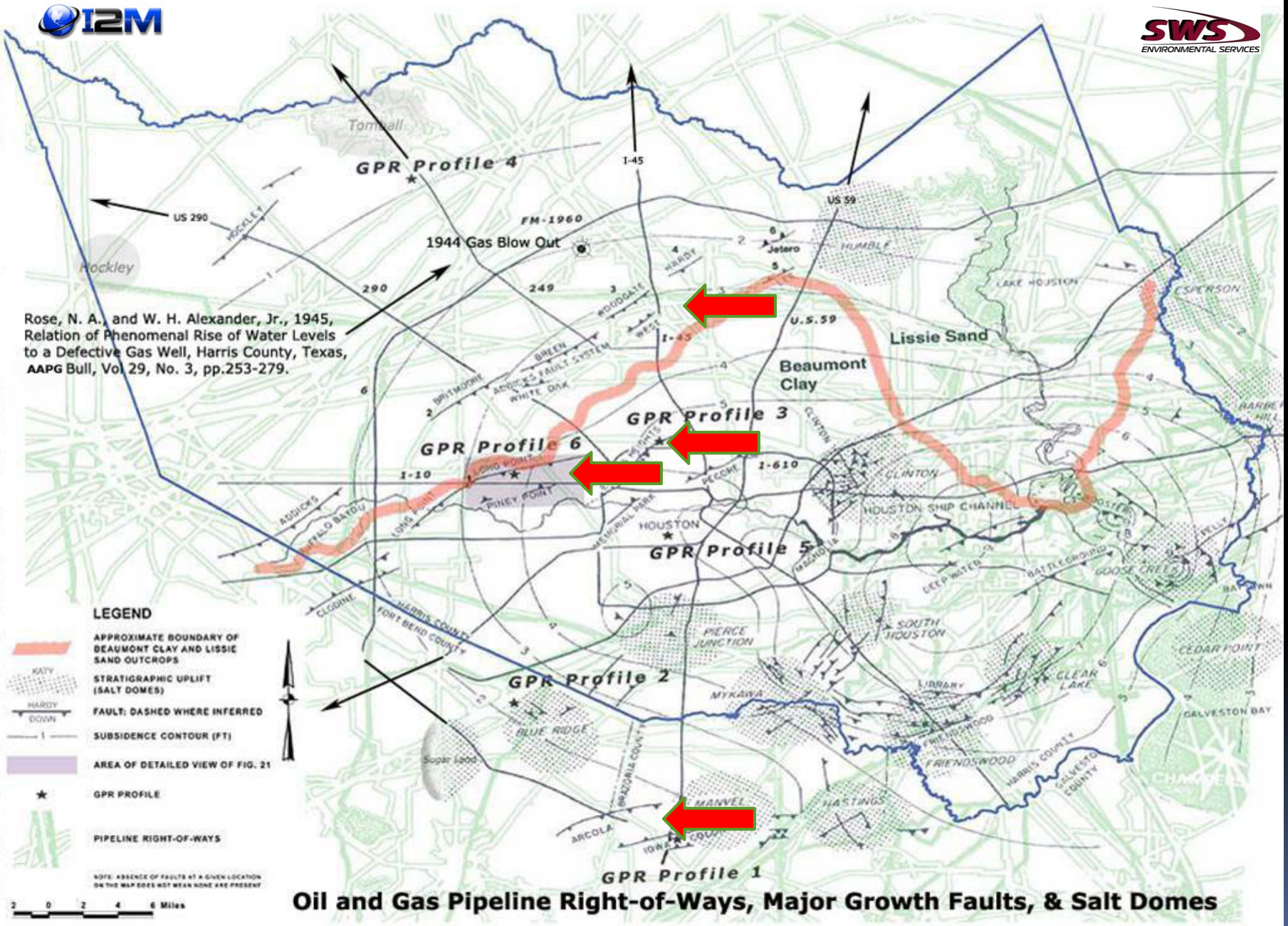


However !!

Growth Faults at the Surface can Impact Pipelines.

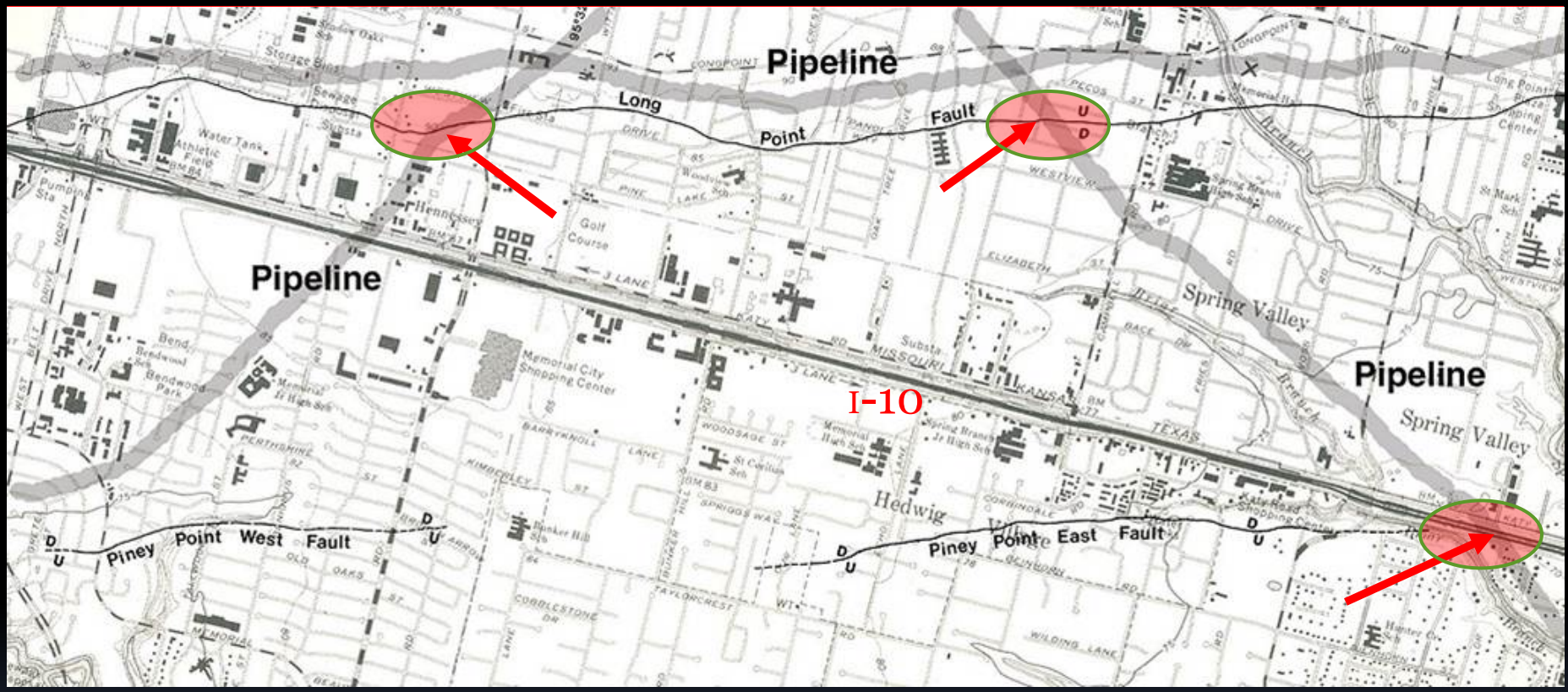
Growth Faults in the Shallow Surface can impact the integrity of Landfills and old Dumps, leading to groundwater contamination.

Previously Unknown Growth Faults may be located by GPR and other shallow geophysical methods.



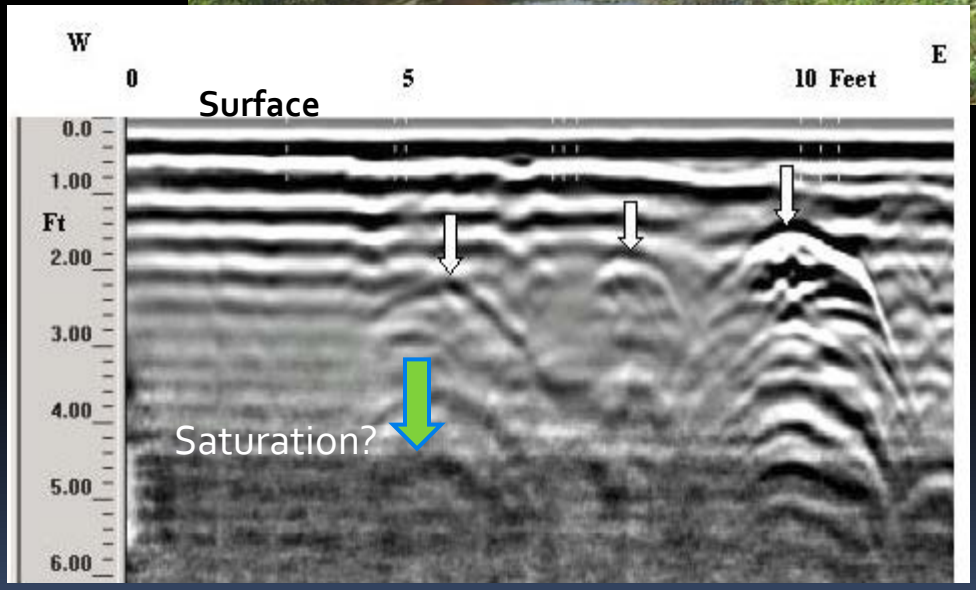
Oil and Gas Pipeline Right-of-Ways, Major Growth Faults, & Salt Domes

Example of Hazard Zones to Be Monitored



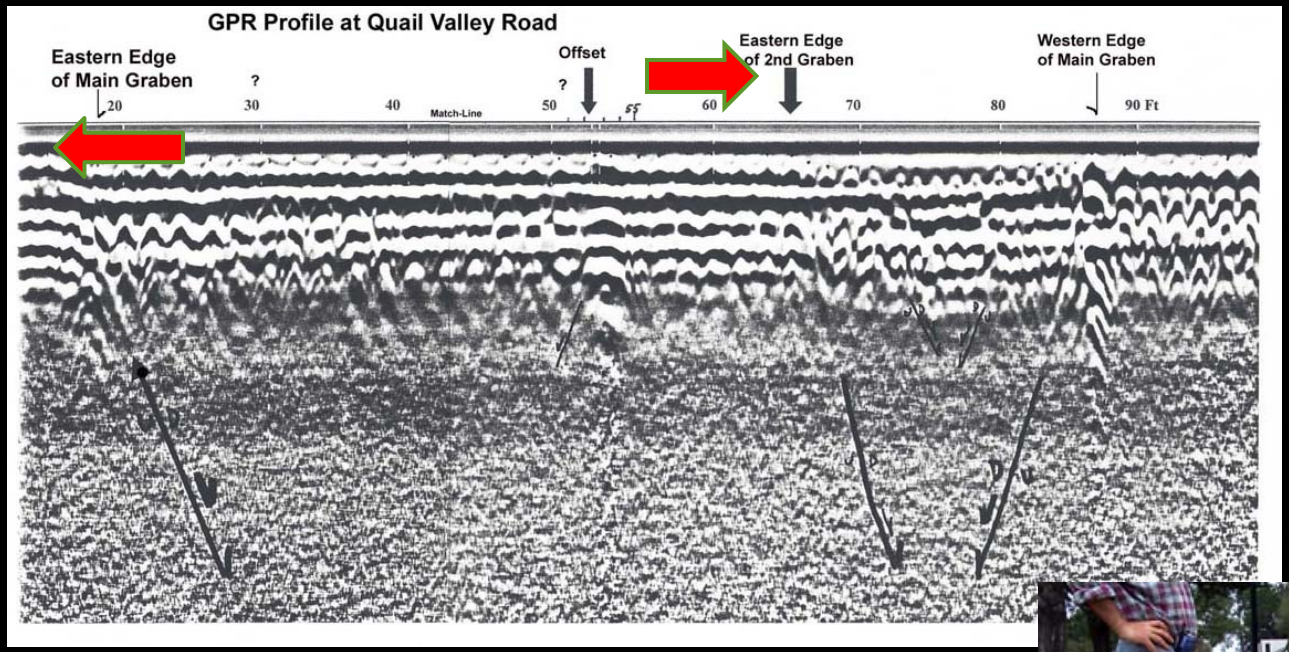
Note: Location of Zones have been Approximated and Require Field Confirmation

Base Map After: O'Neil and Van Siclen, 1984



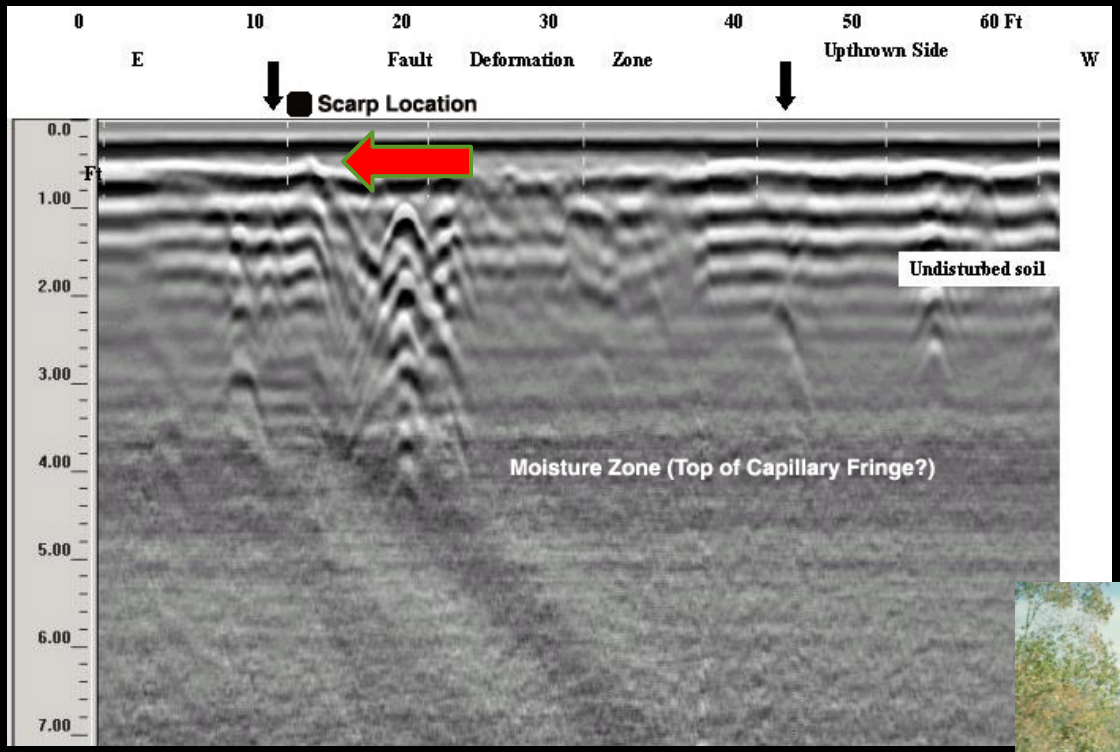
Using GPR in Houston Area by Mustafa Saribudak, P.G., Geophysicist

GPR Depth Calibration Site. Highway 249, South of Tomball, Texas



Subsurface movement will impact pipelines, water lines, sewer lines and building foundations.

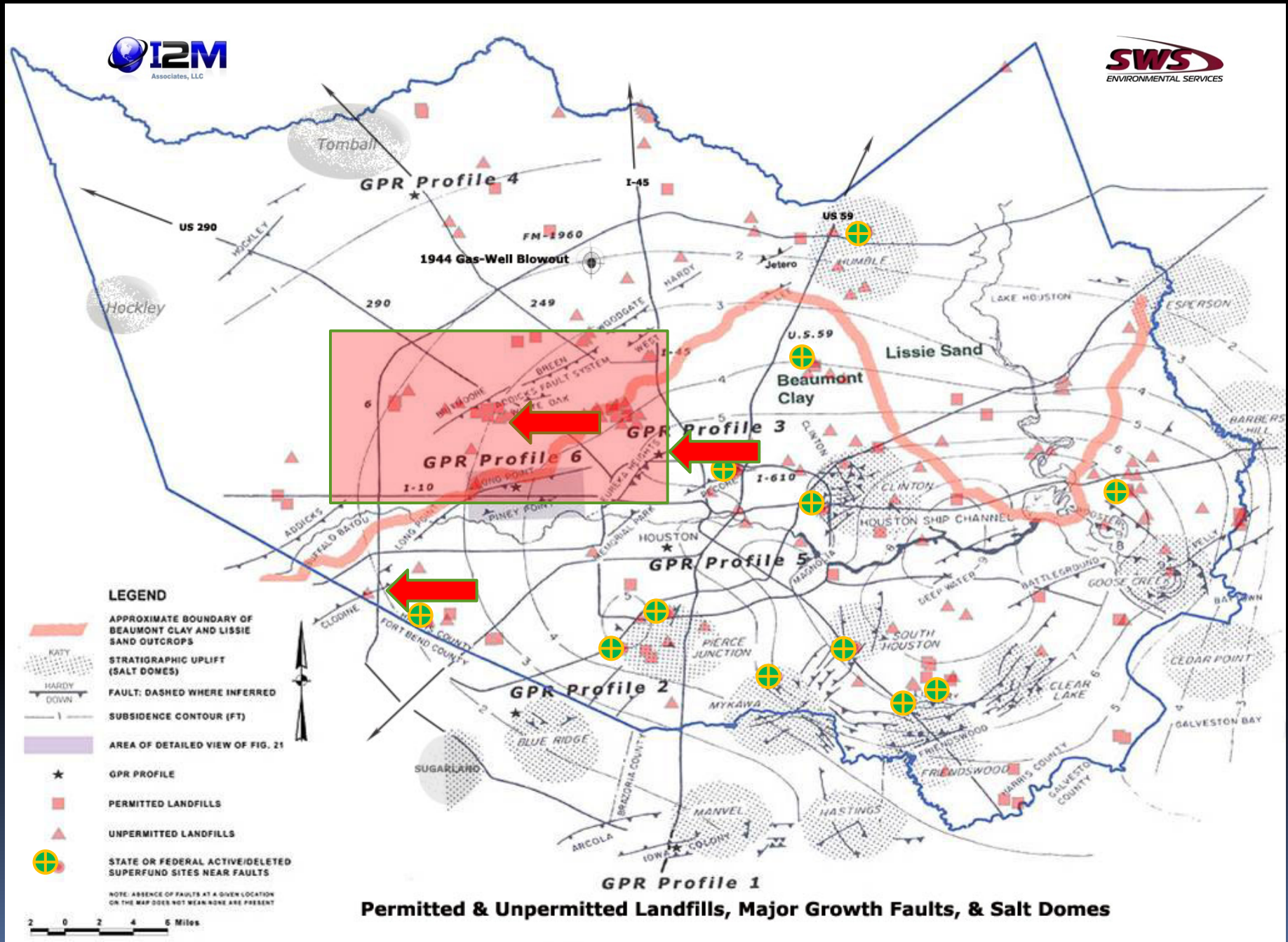
Using GPR in Houston Area by Mustafa Saribudak, P.G., Geophysicist



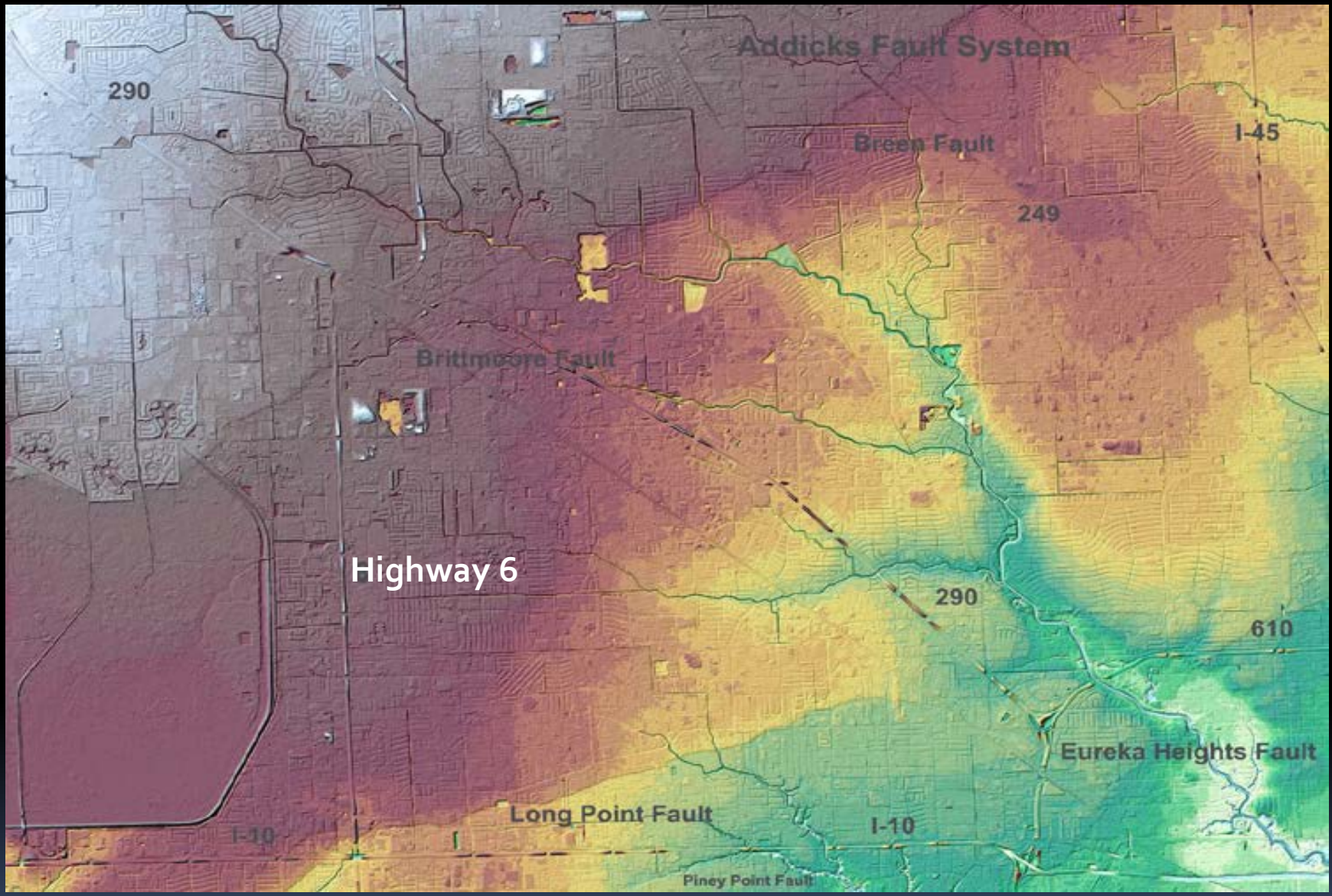
Eureka Heights Area

Subsurface movement will impact street pavements and curbing.

Using GPR in Houston Area by Mustafa Saribudak, P.G., Geophysicist



Permitted & Unpermitted Landfills, Major Growth Faults, & Salt Domes



LIDAR Map of Northwest Quadrant of Harris County.

(Courtesy of Dodson & Associates, Inc.) **Vertical Control: ~ 10 cm**

Uranium, Radium, Radon, Methane
and
Surface Faults
in the
Houston Area?

They are to be expected in the area, and can be dealt with by employing appropriate monitoring, technology, mapping, and geotechnical engineering.

Note: Professional Geoscience Licensing in Texas and elsewhere encourages the Professional to advise the Public of Potential Geological Hazards, when indicated.

References: http://www.i2massociates.com/Downloads/HGSReferences2013.pdf

On other matters, AAPG-EMD Memoir 101 has been released. Get your copy via AAPG online bookstore, See:

http://i2massociates.com/Downloads/AAPG_Memoir_101-July18-2012.pdf

Chapter 9: Nuclear Power and Associated Environmental Issues in the Transition of Exploration and Mining on Earth to the Development of Off-World Natural Resources in the 21st Century…

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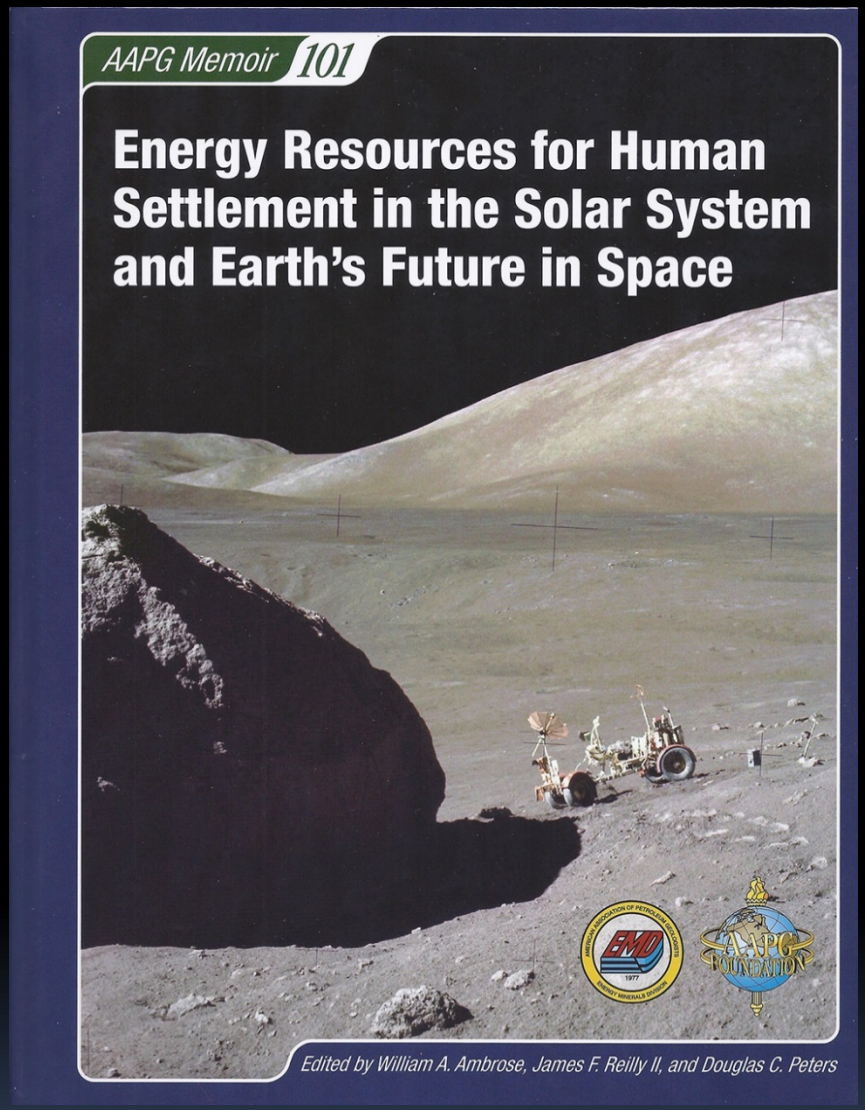
For SWS Environmental Services, see: http://www.swsenvironmental.com/index.html



Memoir 101

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