Gas Well/Water Well Subsurface Contamination: Tools of Investigation*

Rick Railsback[1]

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*Adapted from oral presentation given at Pacific Section AAPG, SEG and SEPM Joint Technical Conference, Monterey, California, April 19-25, 2013

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Abstract

With the advent of horizontal drilling and frac technologies which allow the commercial production of oil and gas from very low permeability rocks, onshore North America is undergoing a historic drilling boom. The industry is now drilling in areas never drilled before, in densely populated areas and often with significant, beneficial use aquifers in the shallow subsurface. Are oil and gas drilling, fracing, and production endangering the nation's groundwater supplies? Are water wells and aquifers being contaminated with oil and gas, drilling mud, and/or frac fluids?

Numerous tools and methods of investigation can be used to answer these questions: proximity; timing of the impact; other contaminant sources; oil and gas well records; pressure data from the gas well and water well; data on frac geometry; natural gas, condensate, and water composition; seismic data; cement bond logs; noise logs; temperature logs; gamma ray logs; radioactive tracers; pressure interference tests; and installation of monitoring wells. Effective use of these tools will solve the problem of whether or not an oil or gas well has contaminated a water well. Operators can utilize these tools to educate the public and landowners, promote and defend drilling programs, and in litigation support.

GAS WELL/WATER WELL SUBSURFACE CONTAMINATION

Rick Railsback

Professional Geoscientist

CURA Environmental & Emergency Services

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“And ye shall know the truth and the truth shall make you free.”

- Oil companies – “it has never been proven that an oil or gas well has contaminated an aquifer.”

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- Environmentalists – “every oil and gas well has contaminated all our aquifers.”

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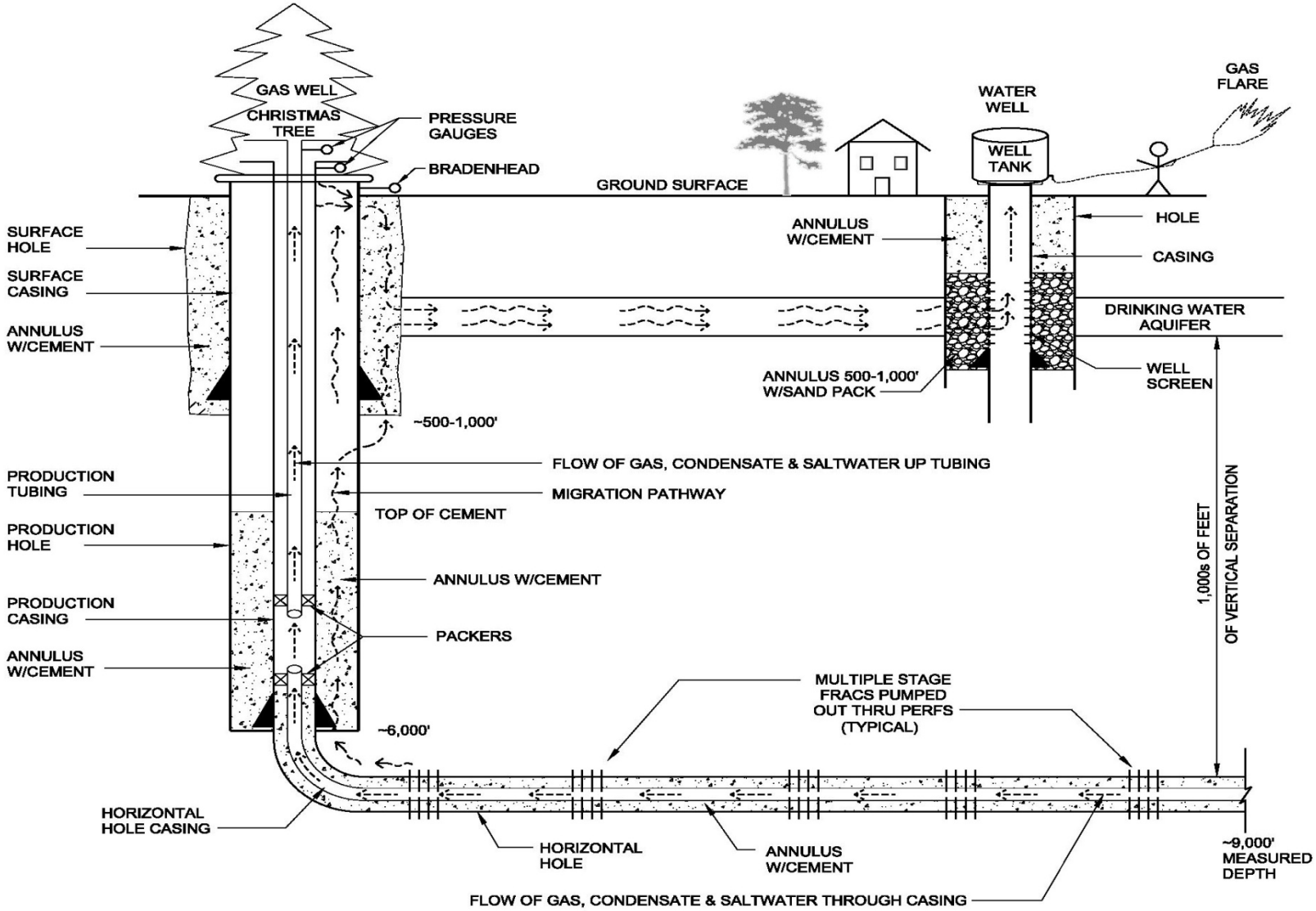
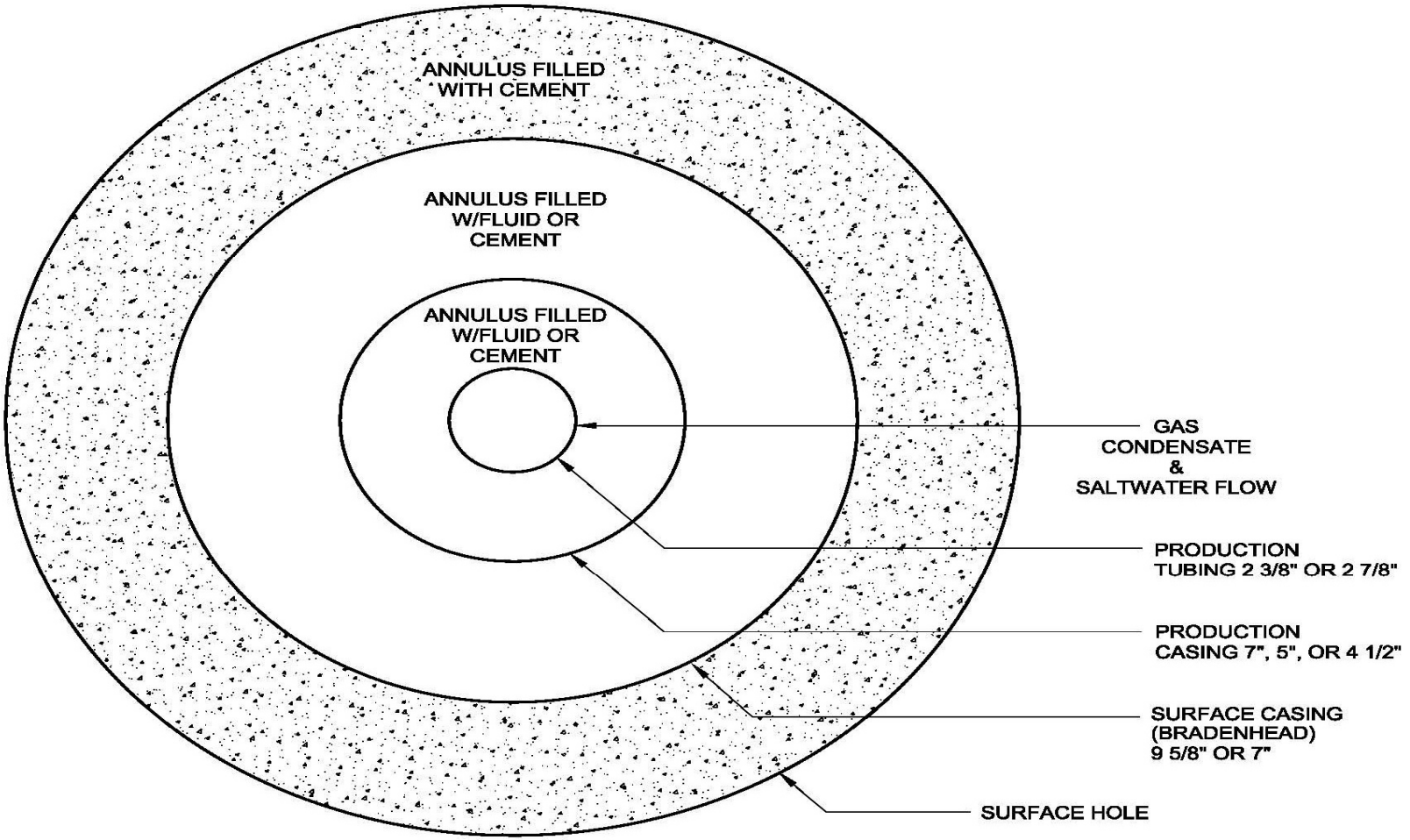
The Physical System



Well Geometry
(view looking down on the wellhead)



Litigation Support

- Tools & methods for investigation
- Generally presented from
  simplest tools to more complex
  least expensive to most expensive

Plan for Investigation

- Proximity
- Timing of the impact
- Other contaminant sources
- Oil & gas well records
- Pressure data from the gas well
- Pressure data from the water well

Plan for Investigation

- Data on frac geometry
- Natural gas composition
- Condensate composition
- Water composition
- Seismic data
- Cement bond logs

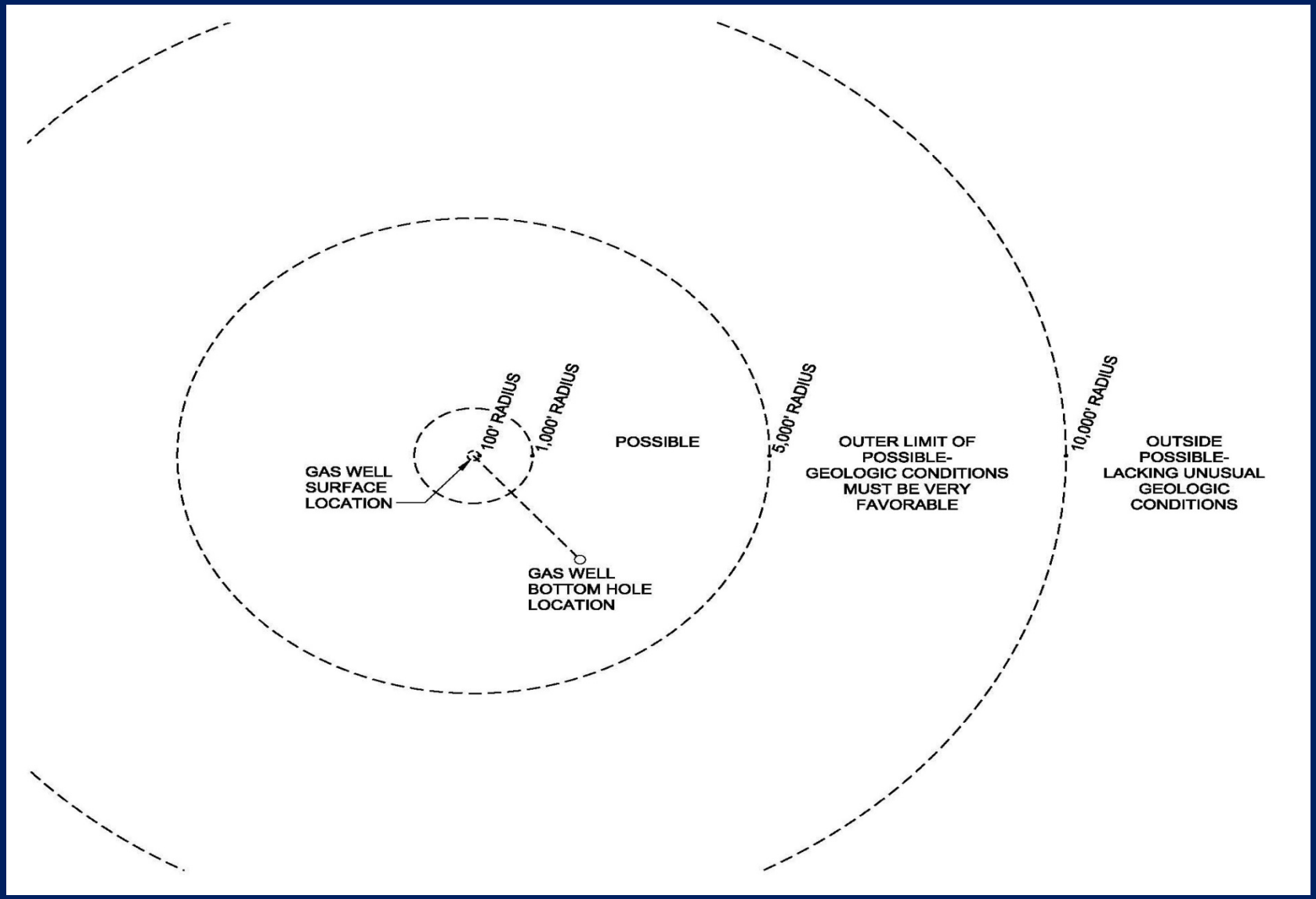
Plan for Investigation

- Noise logs
- Temperature logs
- Gamma ray logs
- Radioactive tracers
- Pressure interference tests
- Installation of monitoring wells

Proximity

- Radius of influence of wells dependent upon geology:
  - Porosity (void space in the rock that is filled with fluids and/or gas)
  - Permeability (ability of the rock to transmit fluids and/or gas
  - Pressure gradients
  - Special geologic conditions (faults, fractures, etc.)

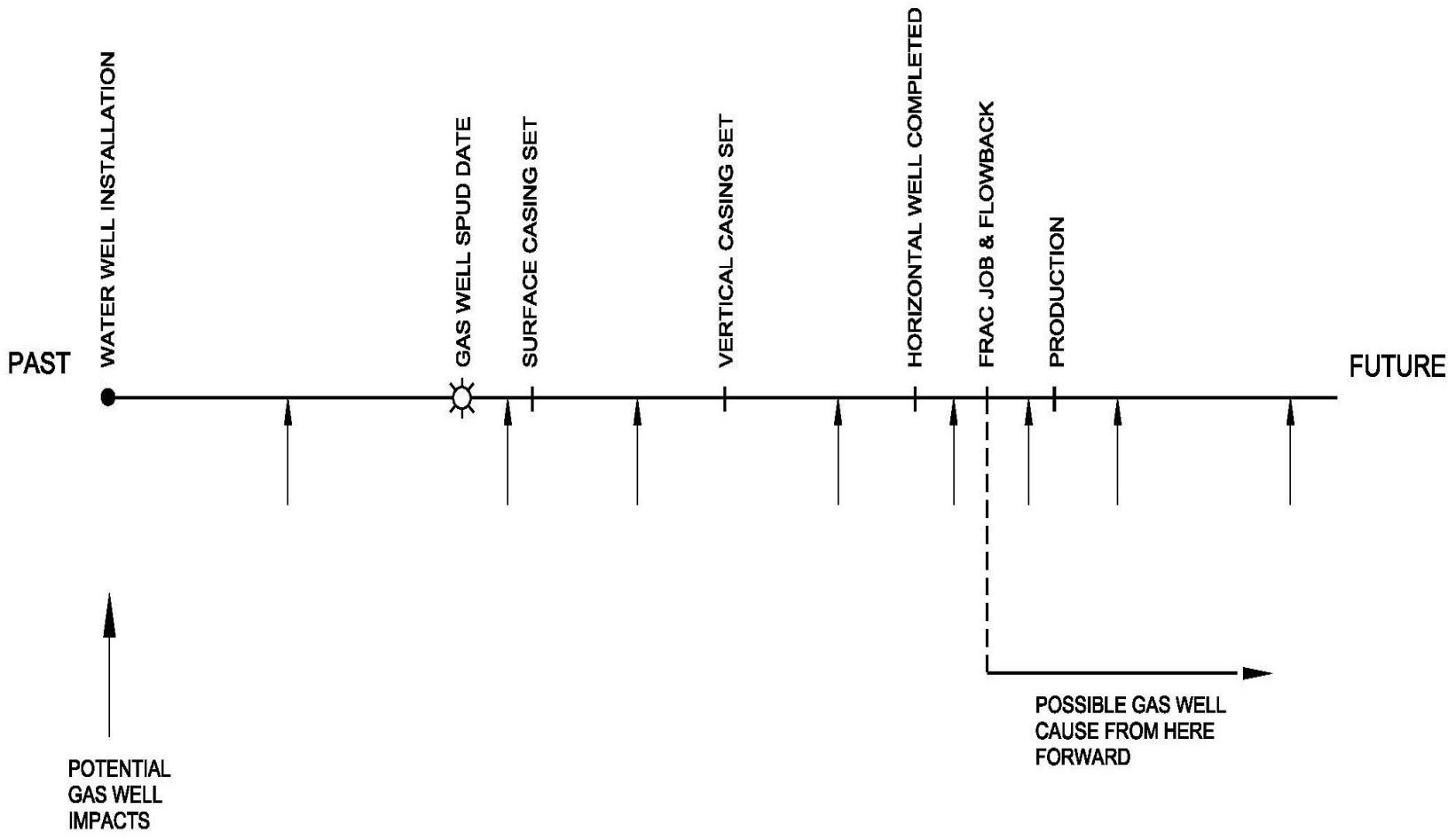
Proximity


100' RADIUS
1,000' RADIUS
5,000' RADIUS
10,000' RADIUS
GAS WELL
SURFACE
LOCATION
POSSIBLE
GAS WELL
BOTTOM HOLE
LOCATION
OUTER LIMIT OF
POSSIBLE-
GEOLOGIC CONDITIONS
MUST BE VERY
FAVORABLE
OUTSIDE
POSSIBLE-
LACKING UNUSUAL
GEOLOGIC
CONDITIONS

Timing

- Water well installation
- Gas well installation:
  - Spud date
  - Surface casing set
  - Vertical casing set
  - Horizontal well completed & casing set
  - Frac job and flow back
  - Production
- Time of impact to water well

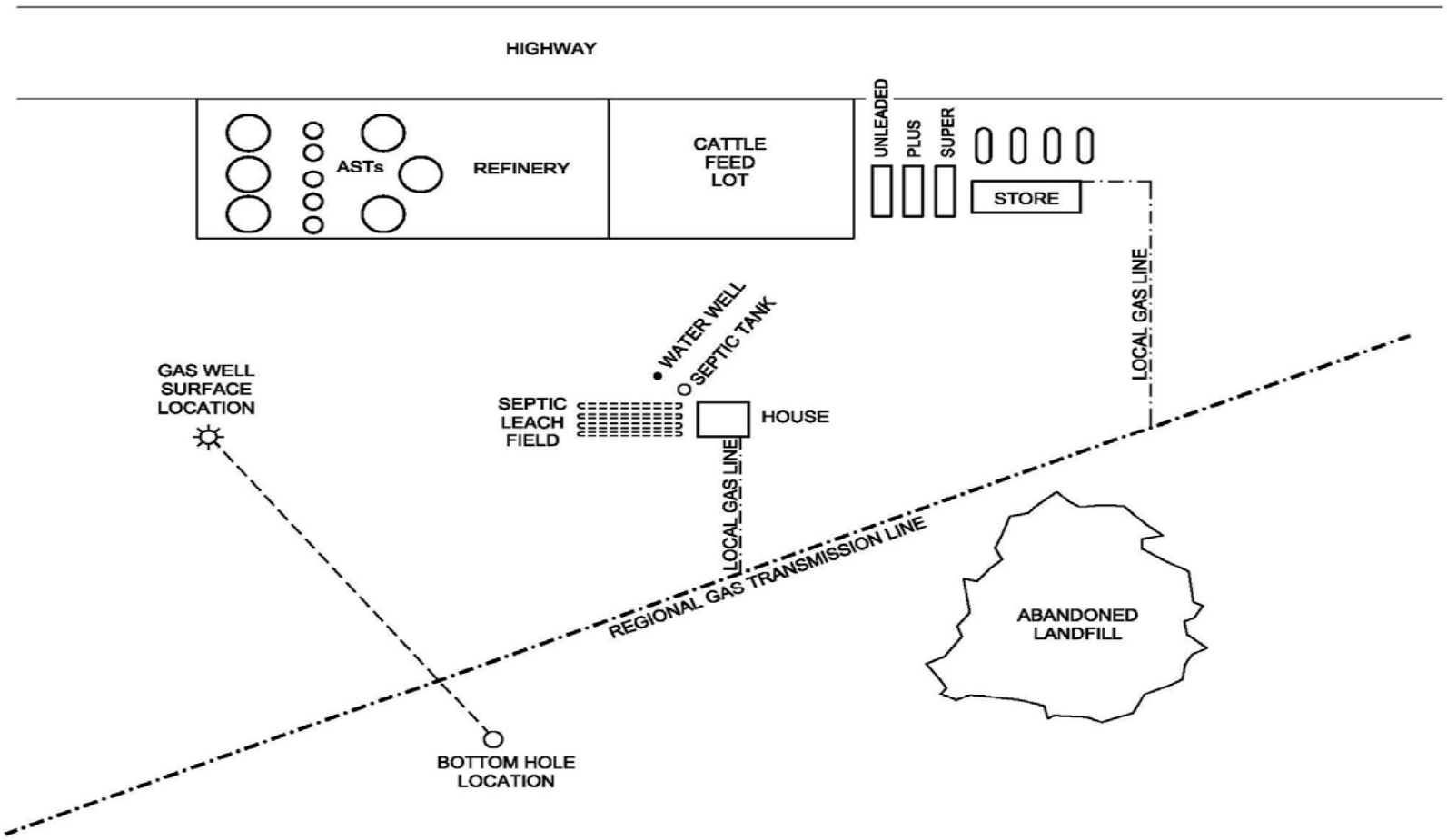
Timing


PAST
WATER WELL INSTALLATION
GAS WELL SPUD DATE
SURFACE CASING SET
VERTICAL CASING SET
HORIZONTAL WELL COMPLETED
FRAC JOB & FLOWBACK
PRODUCTION
FUTURE
POTENTIAL GAS WELL IMPACTS
POSSIBLE GAS WELL CAUSE FROM HERE FORWARD

Other Contaminant Sources

- A variety of other sources may be available
- Common sources are usually shallow – within 50 feet of surface
- Impact to deeper aquifers from shallow sources unlikely due to shallow water table & impermeable layers
- Minor amounts of methane occur naturally in aquifers & may be generated by organics in the water well & equipment

Other Contaminant Sources



Oil & Gas Well Records

- W-1 Drilling Permit Application
- G-1 or W-2 - Gas or Oil Well Completion Test
- G-5 Gas Well Classification Report
- Railroad Commission Online Research
  - http://www.rrc.state.tx.us/data/index.php
- Railroad Commission Public GIS Map Viewer
  - http://gis2.rrc.state.tx.us/public/startit.htm

Type or print only

483-047

RAILROAD COMMISSION OF TEXAS
Oil and Gas Division

Form G-1
Rev. 4/1/83 DBC1297

API No. 42- 221-31812

RECEIVED
CENTRAL RECORDS
MAR 02 2010
AUSTIN, TEXAS

Gas Well Back Pressure Test, Completion or Recompletion Report, and Log

7. RRC District No: 09	
8. RRC Gas ID No.: 253732	
1. FIELD NAME (as per RRC Records or Wildcat): Newark, East (Barnett Shale)	2. LEASE NAME: Butler Unit
9. Well No.: 1H	
3. OPERATOR'S NAME (Exactly as shown on Form P-5, Organization Report): Range Production Company	RRC Operator No.: 691703
10. County of well site: Hood	
4. ADDRESS: 100 Throckmorton, Suite 1200, Fort Worth, TX 76102	11. Purpose of filing: Initial Potential [X]; Retest [ ]; Reclass [ ]; Well record only (Explain in remarks) [ ]
5. Location (Section, Block, and Survey): Sec Blk Atwood, J B A-802	5b. Distance and direction to nearest town in this county.: 13.8 miles S from Weatherford
6. If operator has changed within last 60 days, name former operator	12 If workover or reclass, give former field (with reservoir) & Gas ID or oil lease no. FIELD & RESERVOIR / GAS ID or OIL LEASE # / Oil--O Gas--G / WELL #
13. Pipe Line Connection: Peregrine Pipeline Company L.P.	
14. Completion or recompletion date: 08/14/2009	15. Any condensate on hand at time of workover or recompletion? [ ] Yes [ ] No
	16. Type of Electric or other Log Run.: GR

Section I — GAS MEASUREMENT DATA

Date of Test: 08/31/2009
Gas Measurement Method (Check One): Orifice Meter [X] Flange Taps [X] Pipe Taps [ ] Positive Choke [ ] Orifice Vent Meter [ ] Pitot Tube [ ] Critical-flow Prover [ ]
Gas produced during test: 7224 MCF

Run No	Line Size	Orif. or Choke Size	24 Hr Coeff Orif. or Choke	Static P_m or Choke Press	Diff. h_w	Flow Temp. °F	Temp. Factor Ftf	Gravity Factor Fg	Compress Factor Fpv	Volume MCF/DAY
1	4.026	1.750	19764.05	232	82	117	0.9493	0.9054	1.020	2390
2										
3										
4										

Section II — FIELD DATA AND PRESSURE CALCULATIONS

Gravity (Dry Gas)	Gravity Liquid Hydrocarbon	Gas-Liquid Hydro Ratio	Gravity of Mixture	Avg. Shut-in Temp	Bottom Hole Temp.
.732	Deg. API	CF/Bbl	G_{mix} = .732	150 °F	163°F @ 9097' (Depth)

$D_{eff}^{8/3}$ = 26.149

$\sqrt{T_f}$ = $\sqrt{600}$ = 24.49

$\sqrt{GL}$ = $\sqrt{}$ = 65.24

$C = \frac{1118 \times (D_{eff})^{8/3}}{\sqrt{T}}$ = 1193.50 =

$\frac{\sqrt{GL}}{C} = \frac{65.24}{1193.50} = 0.0547$

Run No	Time of Run Min.	Choke Size	Wellhead Press. PSIA P_w	Wellhead Flow Temp. °F	P_w^2 (Thousands)	R	R^2 (Thousands)	P_1	P_w/P_1
Shut-In			850	150	723				
1	4320	64/64	330	117	109	130.6	17.1	354.9	0.9298
2									
3									
4									

Run No	F	K	$S = \frac{1}{z}$	E^{ks}	P_f and P_s	P_f^2 and P_s^2 (thousands)	$P_f^2 - P_s^2$ (thousands)	Angle of Slope
Shut-In		0.1294	1.134	1.1580	984	969		
1	0.9653	0.1284	1.105	1.1524	409	167	801.7	θ 45.0
2								n 1.000
3								Absolute Open Flow
4								2889 MCF/DAY

RECEIVED
RRC OF TEXAS
DEC 08 2009
O&G
AUSTIN TX

RECEIVED
RRC OF TEXAS
OCT 02 2009
O&G
ABILENE, TX

WELL TESTER'S CERTIFICATION: I declare under penalties prescribed in Sec 91.143, Texas Natural Resources Code, that I conducted or supervised this test and that data and facts shown in Sections I and II above are true, correct, and complete, to the best of my knowledge. Bottomhole temperature and the diameter and length of flow string were furnished by the operator of the well.

Cetco Services, Inc.
Signature: Well Tester — Name of Company — RRC Representative

OPERATOR'S CERTIFICATION: I declare under penalties prescribed in Sec. 91.143, Texas Natural Resources Code, that I am authorized to make this report, that I prepared or supervised and directed this report, and that data and facts stated therein are true, correct, and complete, to the best of my knowledge.

Melanie Dennis — Signature, Operator's representative
Regulatory Analyst, 09/30/2009 — Title
Tel: (817) 869-4158

SECTION III — DATA ON WELL COMPLETION AND LOG (Not Required on Retest)

17 Type of Completion: ✓ New Well [X] Deepening [ ] Plug Back [ ] Other [ ]

18 Permit to Drill, Plug Back or Deepen — DATE 05/20/2009 — PERMIT NO. 679671
Rule 37 Exception — DATE 05/20/2009 — CASE NO. 0261368
Water Injection Permit — PERMIT NO.
Salt Water Disposal Permit — PERMIT NO
Other — PERMIT NO.

19. Notice of Intention to Drill this well was filed in Name of
Range Production Company

20. Number of producing wells on this lease in this field (reservoir) including this well: 1

21. Total number of acres in this lease: 202.980

22. Date Plug Back, Deepening, WorkOver or Drilling Operations — Commenced: 06/15/2009 — Completed: 06/29/2009

23. Distance to nearest well, Same Lease & Reservoir: NA

24. Location of well, relative to nearest lease boundaries of lease on which this well is located: 666 Feet From N Off Lease Line and 986 Feet from SE Off Lease Line of the Butler Unit Lease

25. Elevation (DF, RKB, RT, GR, ETC.): 789' GR

26. Was directional survey made other than inclination (Form W-12)? [X] Yes [ ] No

27. Top of Pay: 5719'TVD 5814'MD

28. Total Depth: ~~5852'TVD~~ 9097'MD

29. P.B. Depth: 5855'TVD 9027'MD

30. Surface Casing Determined by: Field Rules [ ] — Recommendation of T.D.W.R. [X] — Railroad Commission (Special) [ ] — Dt. of Letter 05/26/2009 — Dt of Letter

31. Is well multiple completion? [ ] Yes [X] No

32. If multiple completion, list all reservoir names (completions in this well) and Oil Lease or Gas ID No

FIELD & RESERVOIR	GAS ID or OIL LEASE #	Oil-O Gas-G	WELL #

33. Intervals Drilled by — Rotary Tools: X — Cable Tools:

34. Name of Drilling Contractor: Hi Tex

35 Cementing Affidavit Attached? [X] Yes [ ] No

36 CASING RECORD (Report All Strings Set in Well)

CASING SIZE	WT #/FT.	DEPTH SET	MULTISTAGE TOOL DEPTH	TYPE & AMOUNT CEMENT (sacks)	HOLE SIZE	TOP OF CEMENT	SLURRY VOL cu ft.
✓ 7"	20#	✓ 394' GR	43 Sx	35:65 Poz A	✓ 9 7/8"	✓ Surface	✓ 307
			191 Sx	2% Ca Cl A			
✓ 4 1/2"	11.6#	✓ 9073'	409 Sx	50:50 Poz H	✓ 6 1/8"	✓ 4580'	✓ 606

37. LINER RECORD

Size	Top	Bottom	Sacks Cement	Screen
				–
				–

38. TUBING RECORD

Size	Depth Set	Packer Set

39. Producing Interval (this completion) Indicate depth of perforation or open hole

From	~~6253'MD~~/5821'TVD	To	6514'MD/5816'TVD
From	~~6565'MD~~/5814'TVD	To	6826'MD/5821'TVD
From	6877'MD/5822'TVD	To	7138'MD/5827'TVD
From	7189'MD/5828'TVD	To	7450'MD/5833'TVD

40. ACID, SHOT, FRACTURE, CEMENT SQUEEZE, ETC.

Depth Interval	Amount and Kind of Material Used
6253'MD/5821'TVD-8698'MD/5864'TVD	41K gal acid + 99K Bbls. water + 2.877mm # 100 mesh + 801K # 40/70

41 FORMATION RECORD (LIST DEPTHS OF PRINCIPAL GEOLOGICAL MARKERS AND FORMATION TOPS)

Formations	Depth	Formations	Depth
Base Cretaceous	175'MD/TVD		
Mid-Atoka	~~5458~~'MD/5457'TVD		
Barnett Shale	5814'MD/5719'TVD		

REMARKS #39 Producing Interval Continued: From: 7501'MD/5835'TVD To: 7762'MD/5843'TVD
7813'MD/5844'TVD 8074'MD/5853'TVD
8125'MD/5854'TVD ~~8386'MD~~/5861'TVD
8437'MD/5862'TVD 8698'MD/5864'TVD

12796

DEC 18 2009

VALID PERMIT

Corrected

RAILROAD COMMISSION OF TEXAS
Oil and Gas Division

READ INSTRUCTIONS ON BACK

GAS WELL CLASSIFICATION REPORT

Form G-5
Rev. 01/01/86
DBC1297

1. OPERATOR NAME (Exactly as shown on Form P-5 Organization Report) Range Production Company	3. RRC DISTRICT NO. 09	4. OIL LEASE NO. OR GAS WELL ID NO.
2. MAILING ADDRESS 100 Throckmorton, Suite 1200 Fort Worth,TX 76102	5. WELL NO. 1-H	6. API NO. 42- 221-31798
	7. COUNTY OF WELL SITE Hood	
8. FIELD NAME (as per RRC Records) Newark, East (Barnett Shale)	9. LEASE NAME Teal Unit	
10. LOCATION (Section, Block, and Survey) Sec Blk Atwood, J B A-802	11. PIPELINE CONNECTION OR USE OF GAS Peregrine Pipeline Company L.P.	

I. PRODUCTION TEST AT RATE ELECTED BY OPERATOR
(data on 24-hour basis)

A. Date of Test	08/31/2009	
B. Gas Volume	2015	(Mcf)
C. Oil or Condensate Volume	22.0	(Bbl)
D. Water Volume	898	(Bbl)
E. Gas/Liquid Hydrocarbon Ratio	91591	(CF/Bbl)
F. Flowing Tubing Pressure	365	(psig)
G. Choke Size	64/64	(in.)
H. Casing Pressure	1115	(psig)
I. Shut-in Wellhead Pressure–Tubing	1315	(psig)
J. Separator Operating Pressure	236	(psig)
K. Color of Stock Tank Liquid	green	
L. Gravity of Separator Liquid		°API
M. Gravity of Stock Tank Liquid	52.0 ✓	°API
N. Specific Gravity of the Gas (Air = 1)	.738	

II. A.S.T.M. DISTILLATION OF LIQUID SAMPLE.
Distillation test is required for gas wells ONLY if the producing gas-liquid hydrocarbon ratio is less than 100,000 CF/barrel.

Date Liquid Sample Obtained: 8/31/09

Where Obtained: ☐ Separator ☐ Stock Tank

% Over	Temp. (deg. F)	% Over	Temp. (deg. F)
Initial Boiling Temp	160	60	416
10	218	70	506
20	258	80	614
30	288	90	620
40	320	95	622
50	364	End Point	622 ✓

Total Recovery	95.00	percent
Residue	4.00 ✓	percent
Loss	1.00	percent

I declare under penalties prescribed in Sec. 91.143, Texas Natural Resources Code, that I am authorized to make this report, that this report was prepared by me or under my supervision and direction, and that data and facts stated therein are true, correct, and complete to the best of my knowledge.

9/23/09
DATE

Melanie Dennis
NAME (Type or Print)

Melanie Dennis
SIGNATURE

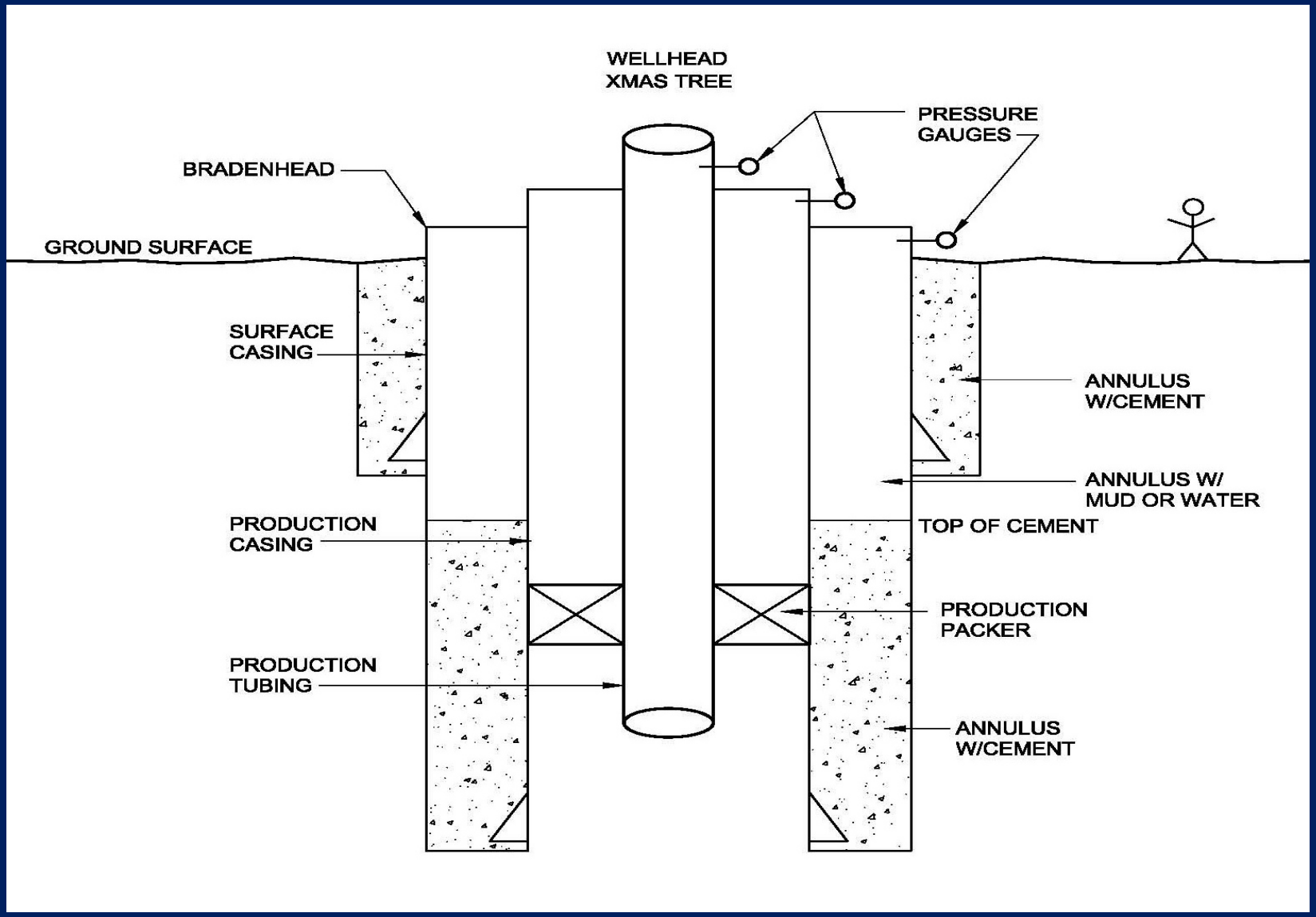
Regulatory Analyst
TITLE

Melanie Dennis
CONTACT PERSON

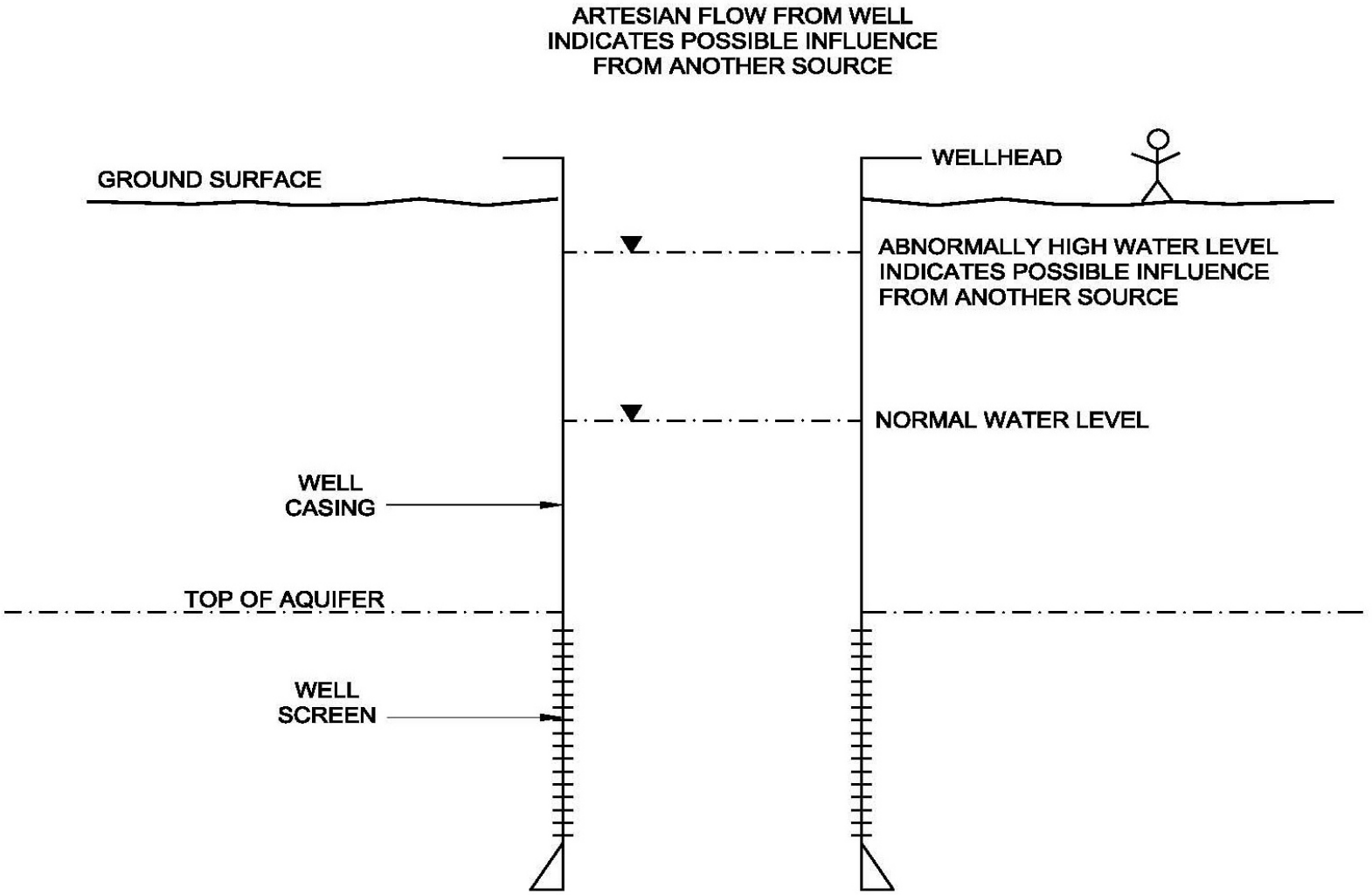
(817) 869-4158
PHONE NUMBER

RECEIVED
RRC OF TEXAS
JAN 06 2010
RECEIVED
RRC OF TEXAS
JAN 06 2010
O&G
AUSTIN TX
SJR 1/7/10

Pressure Data from Gas Well



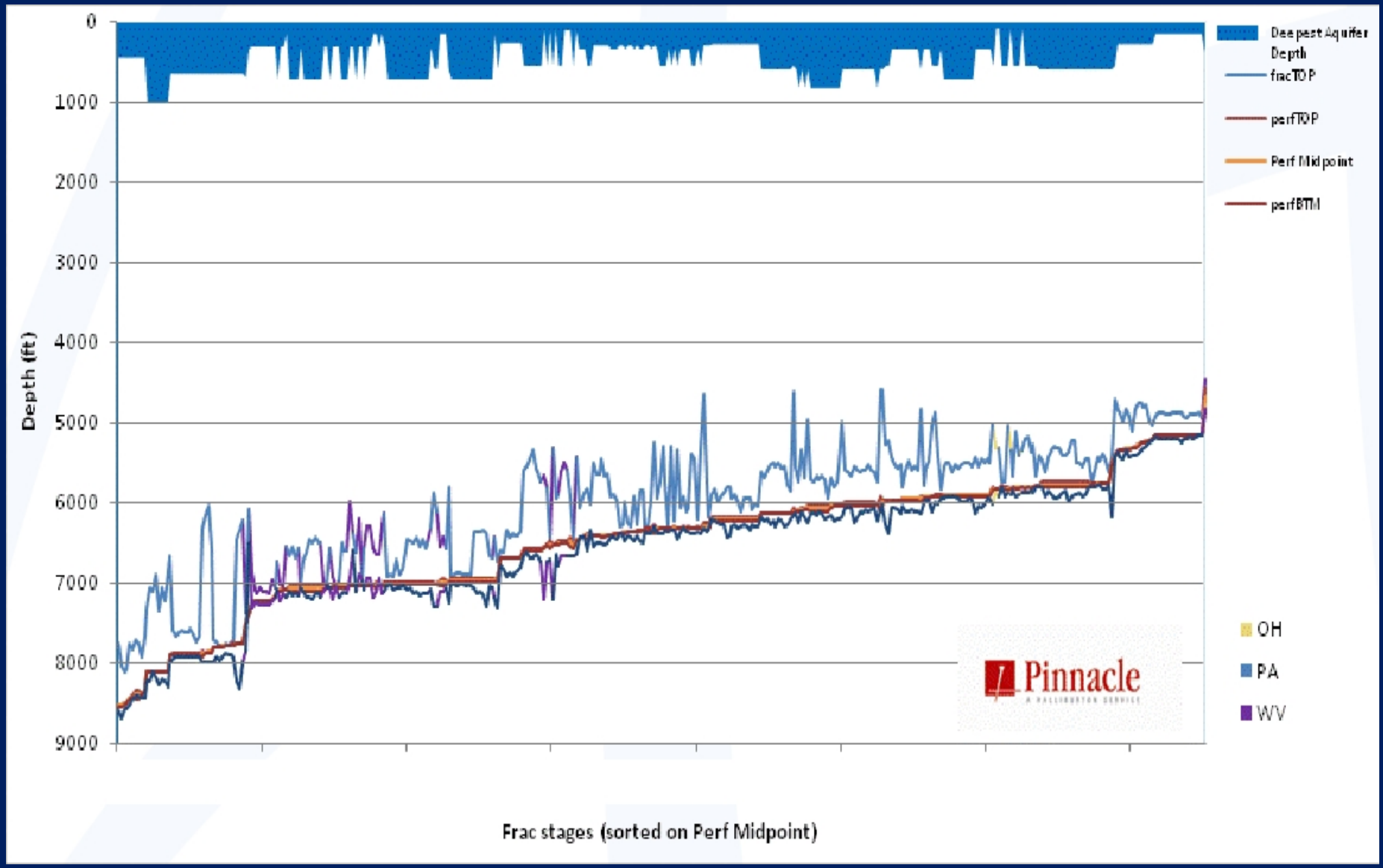
Pressure Data from Water Well



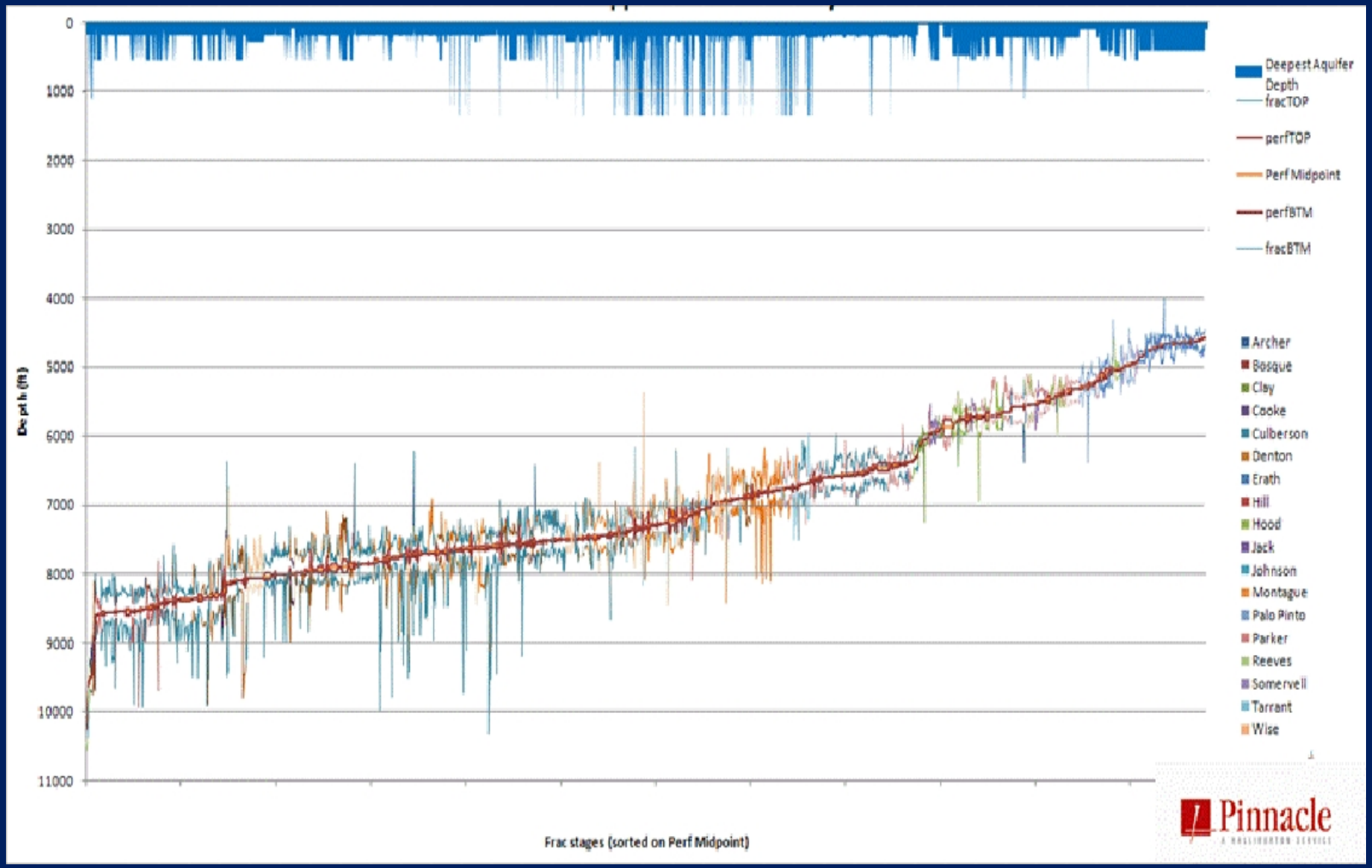
Data on Frac Geometry

- Microseismic records the location of the mini-earthquakes generated by frac creation
- Microseismic not routinely run on frac jobs
- Data presented by industry based on relatively few data points
- Fractures may extend a max of 2,000’ above or below perfs (usually only a few 100’)
- Fractures 3,000’ + below deepest aquifer

Marcellus Shale Microseismic Cross Section



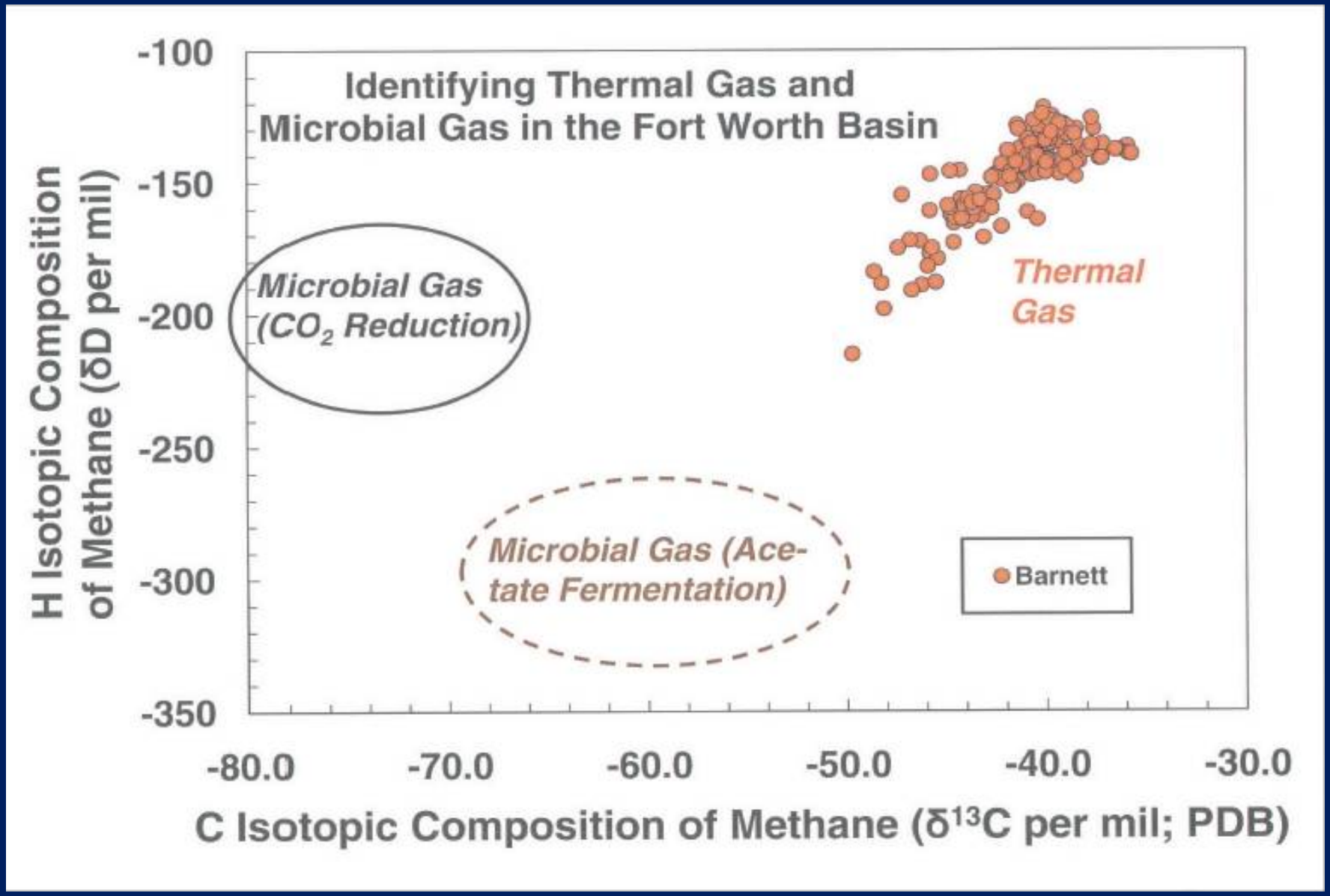
Barnett Shale Microseismic Cross Section



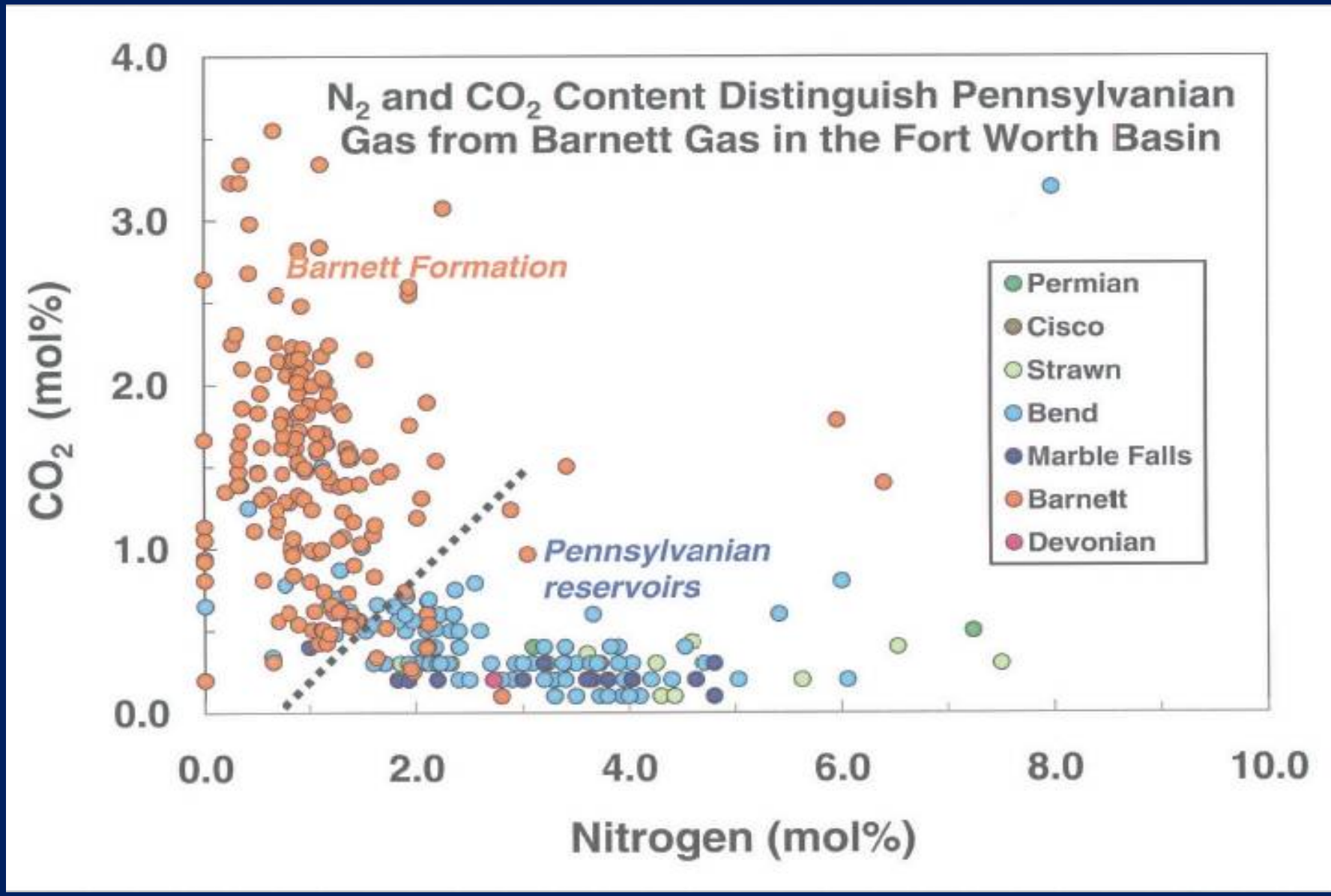
Natural Gas Composition

- Methane – CH_4 – natural gas
  - Microbial gas
  - Thermal gas
  - Carbon & hydrogen isotopic composition
- Heavier gases
- N_2 and CO_2 content

Natural Gas Composition



Natural Gas Composition



Condensate Composition

- Gas well condensate composed of:
  - TPH (total petroleum hydrocarbons) mainly gasoline range organics
  - BTEX (benzene, toluene, ethylbenzene, xylenes) – marker constituents
  - VOC (volatile organic compounds)
  - PAH (polycyclic aromatic hydrocarbons)

Water Composition
(dissolved constituents)

- TPH - gas, diesel, & oil range organics
- BTEX – benzene, toluene, ethylbenzene, xylenes
- VOC – volatile organic compounds
- PAH – polycyclic aromatic hydrocarbons
- TPH, BTEX, VOC, & PAH not normally present in water well water

Water Composition
(dissolved constituents)

- Methane – CH_4 – natural gas
  - Lab analysis for methane & other gases
  - Flame ionization detector with carbon filter
  - Methane meter
  - Explosimeter
  - Light it?
  - Methane not normally present in high concentrations in water well water

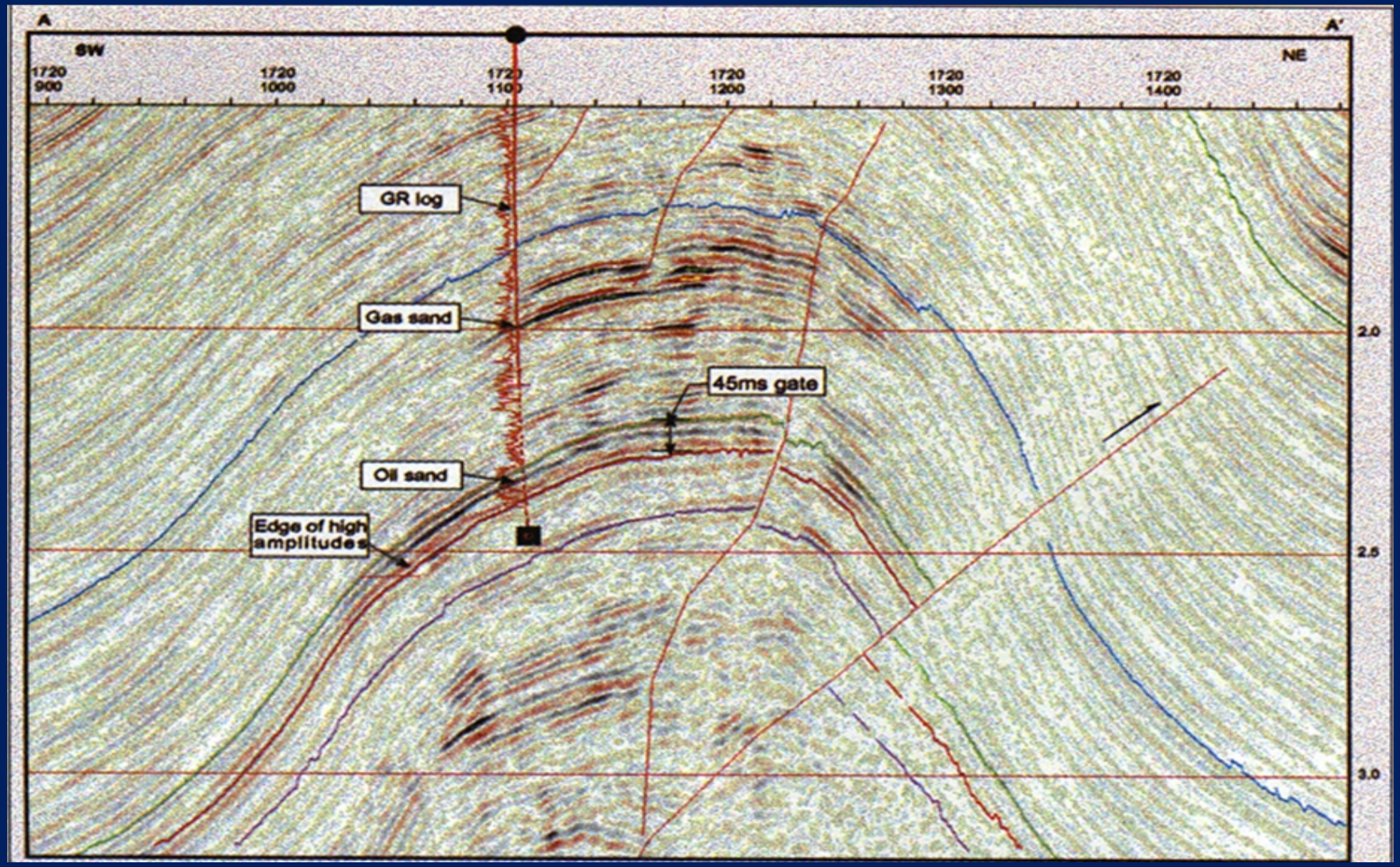
Water Composition
(dissolved constituents)

- Minerals & salts – naturally occurring
- TDS (total dissolved solids) & chlorides measure dissolved minerals & salts in water
- TDS – total dissolved solids
  - Water wells (500 – 1,800 ppm)
  - Gas wells (typically > 20,000 ppm)
- Chlorides
  - Water wells (20 - 500 ppm)
  - Gas wells (typically > 20,000 ppm)

Seismic Data

- Seismic or sound waves used to image the subsurface
- Analogous to sonograms
- Gas accumulations give a “bright spot” amplitude anomaly
- 3D seismic is available over most oilfields

Seismic “Bright Spots”



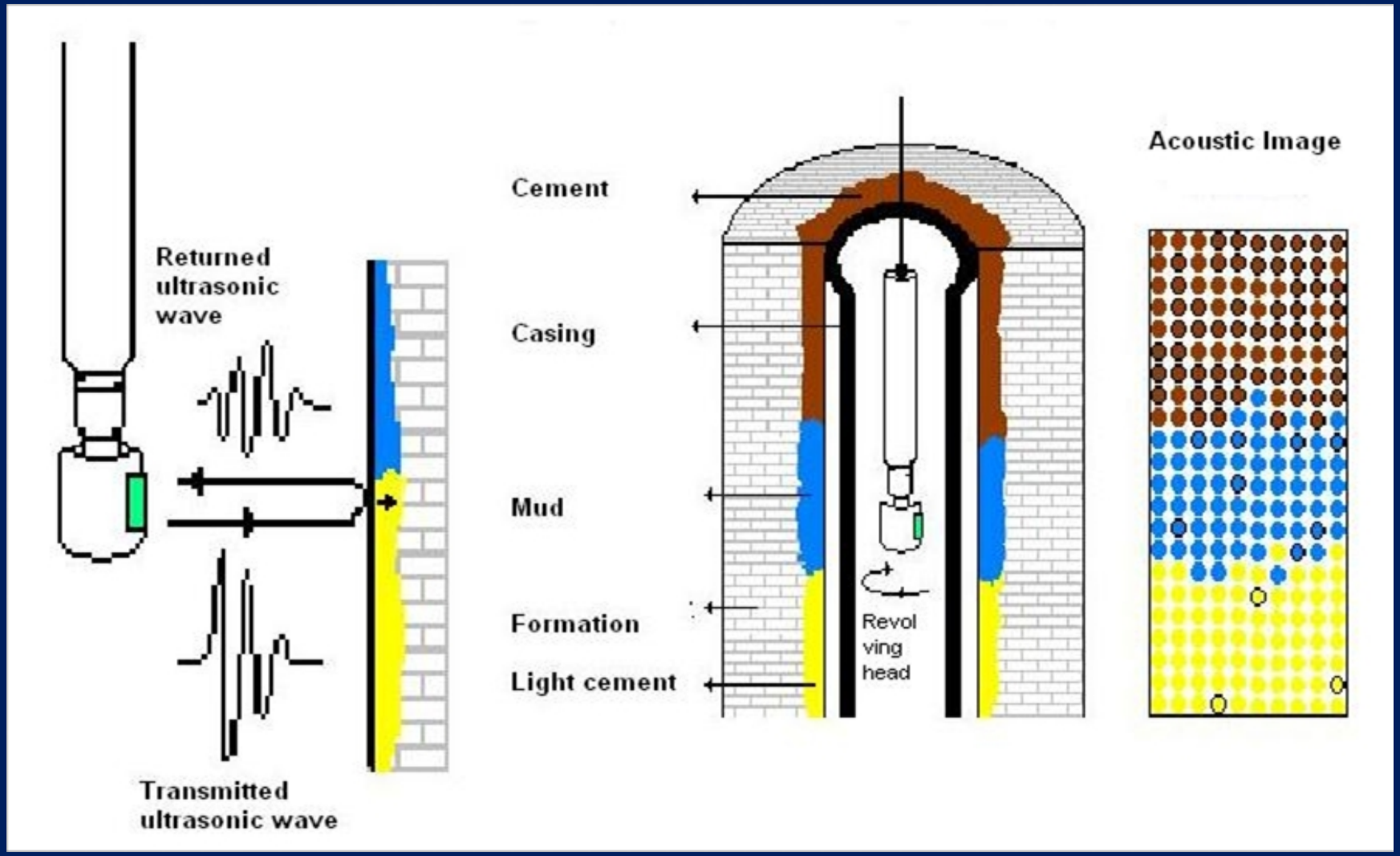
Seismic Data
(Potential Problems)

- Timing of data acquisition relative to gas accumulation
- Seismic data focus may not yield useable data in shallow subsurface
- Zone of gas accumulation too thin for seismic resolution
- “Bright spot” not a unique solution for gas

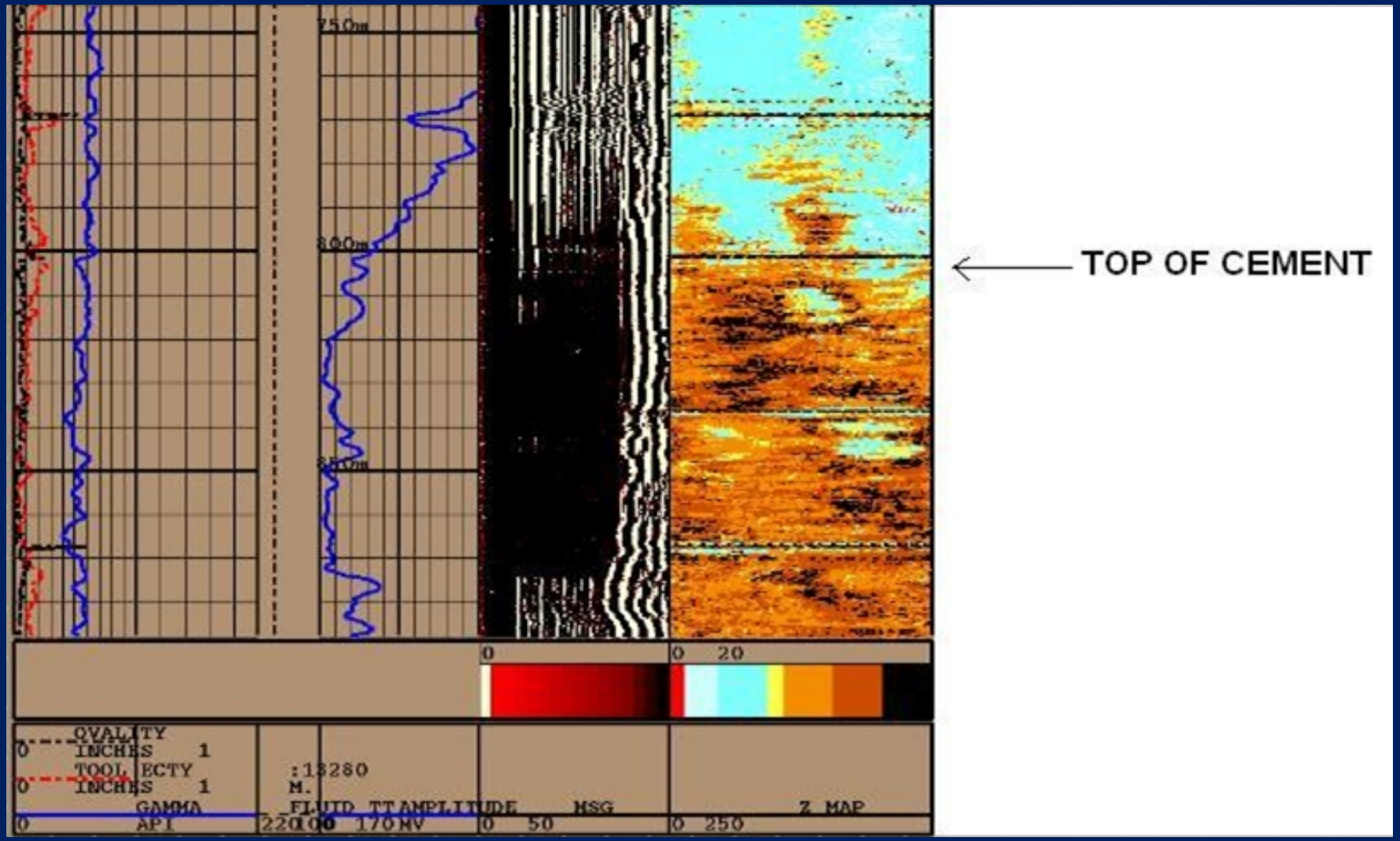
Cement Bond Logs

- Acoustic (sonic) device utilizes sound waves to image
- Analogous to sonograms
- Free pipe returns a much greater amplitude signal than cemented pipe
- Amplitude display
- VDL (variable density log) display

Principles of the Cement Bond Log



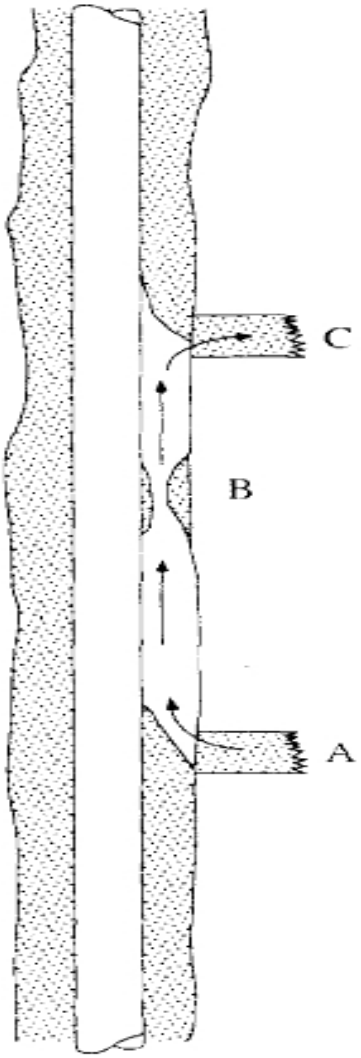
Cement Bond Log Presentation

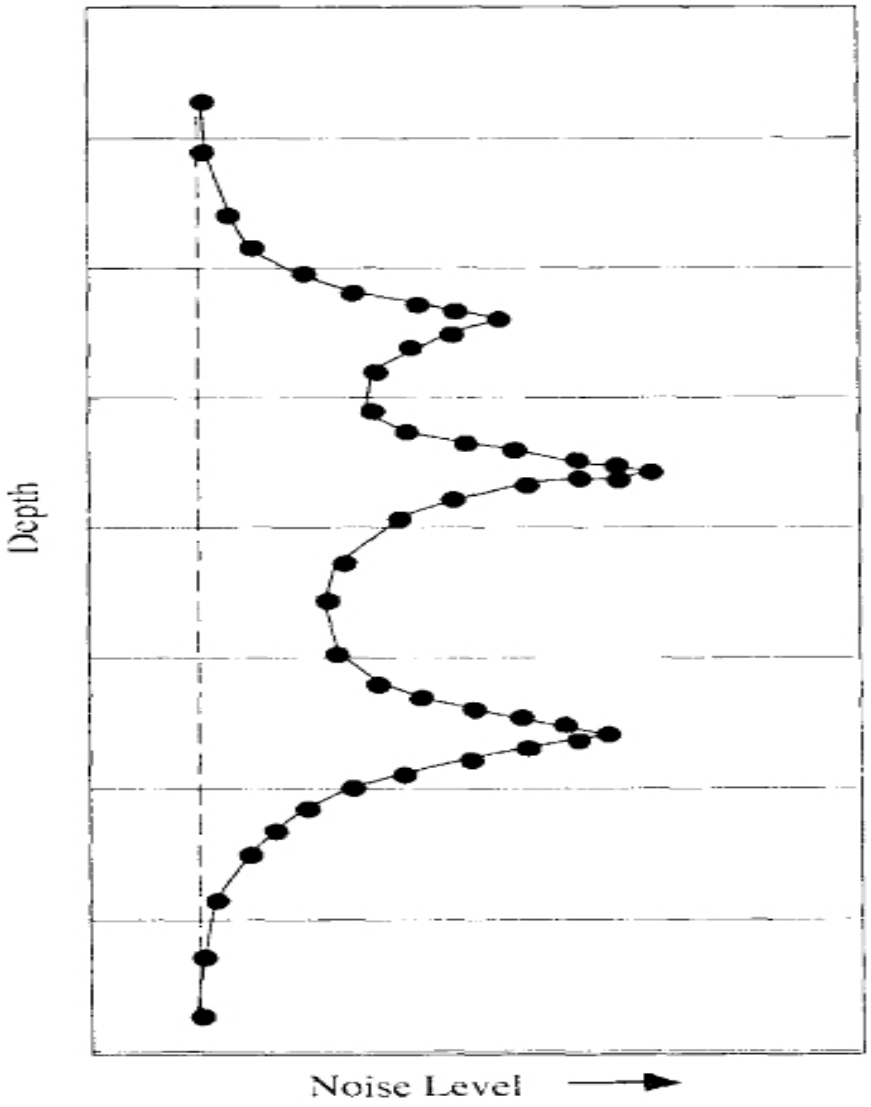


Noise Logs (Sound Surveys)

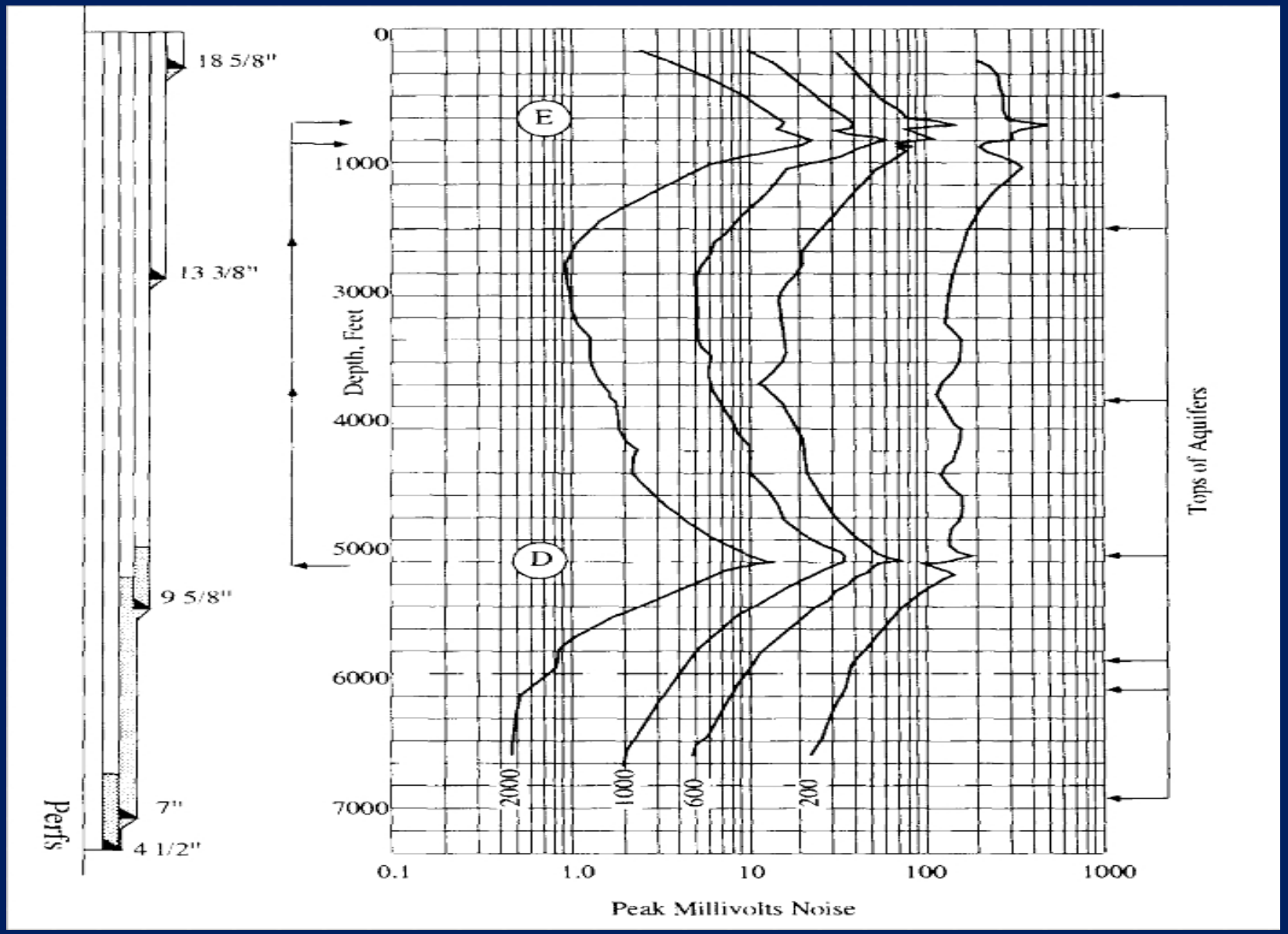
- Sensor is an underwater microphone (hydrophone)
- Will detect flow within wellbore or behind pipe
- Turbulent fluid flow
- Gas expansion
- Disturbance of gas/liquid interface

Noise Logs (Sound Surveys)





Noise Logs (Sound Surveys)



Temperature Logs

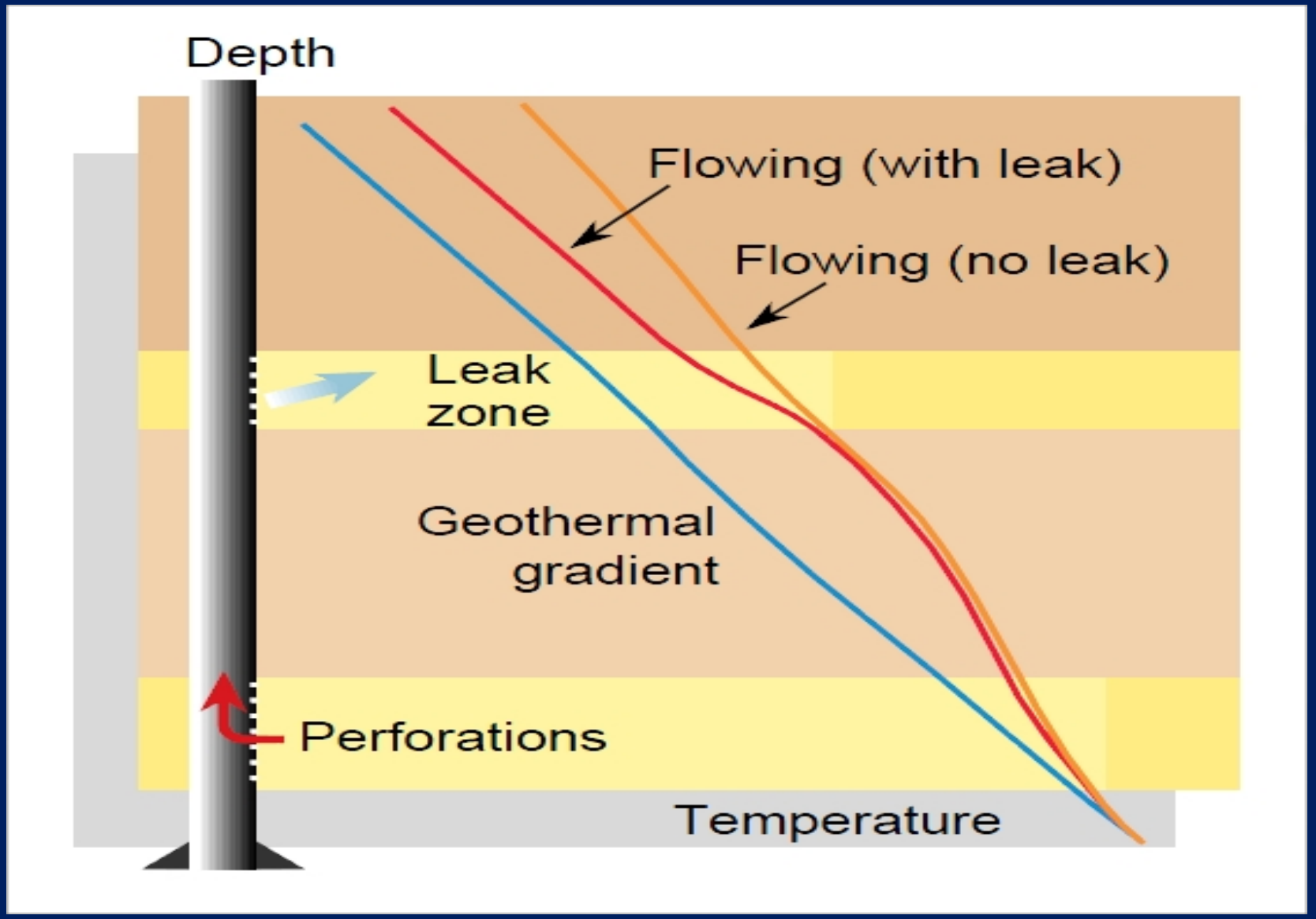
- Temperature increases with depth – normal geothermal gradient
- Anomalies created by fluids or gas entering wellbore or annulus or exiting into formation
- Identify zones producing or taking fluid
- Evaluating cement jobs
- Evaluating frac jobs

Temperature Logs

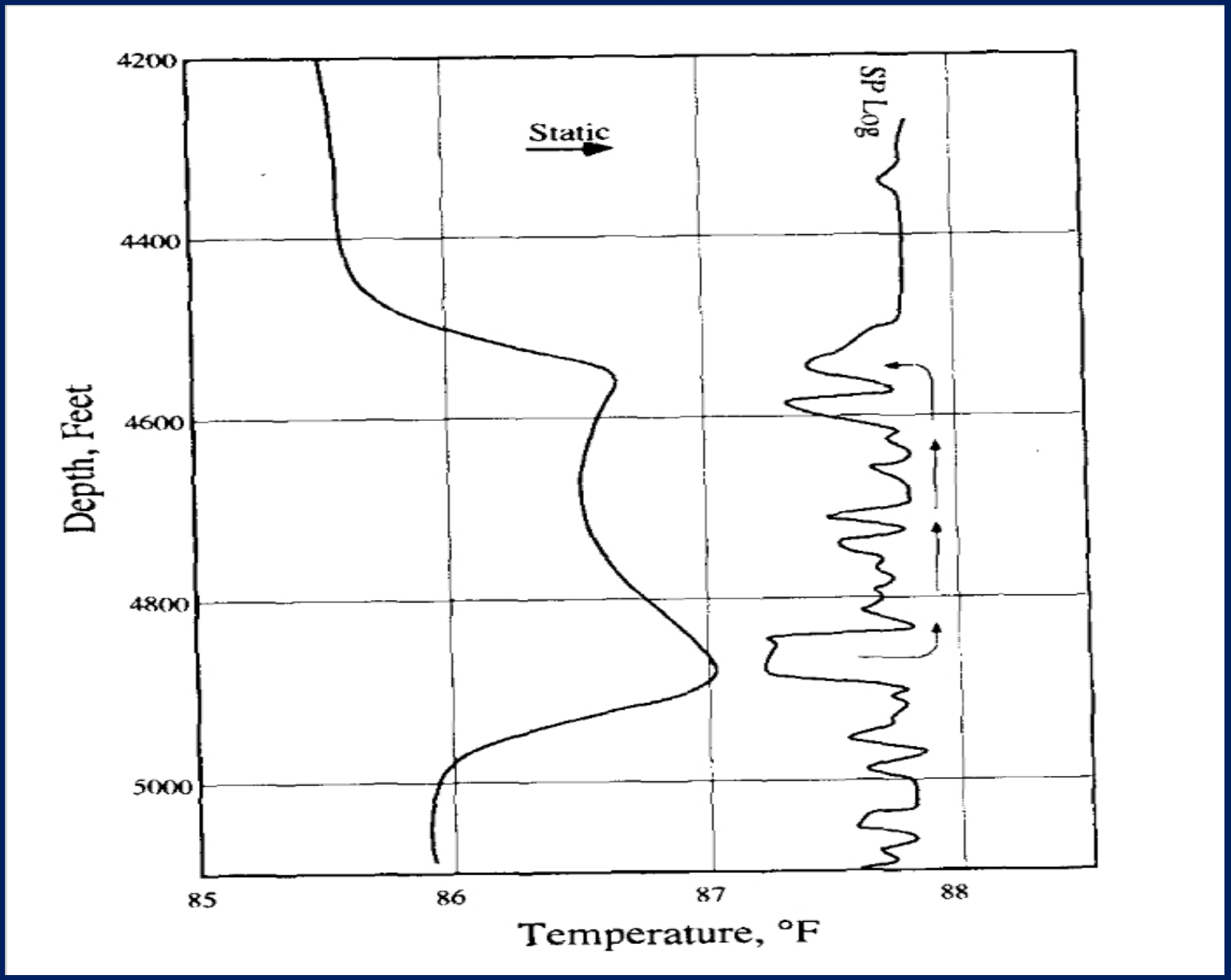
- EPA Underground Injection Control (UIC) program approves temperature logs to demonstrate well mechanical integrity –

  “no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the injection wellbore”.

Temperature Logs



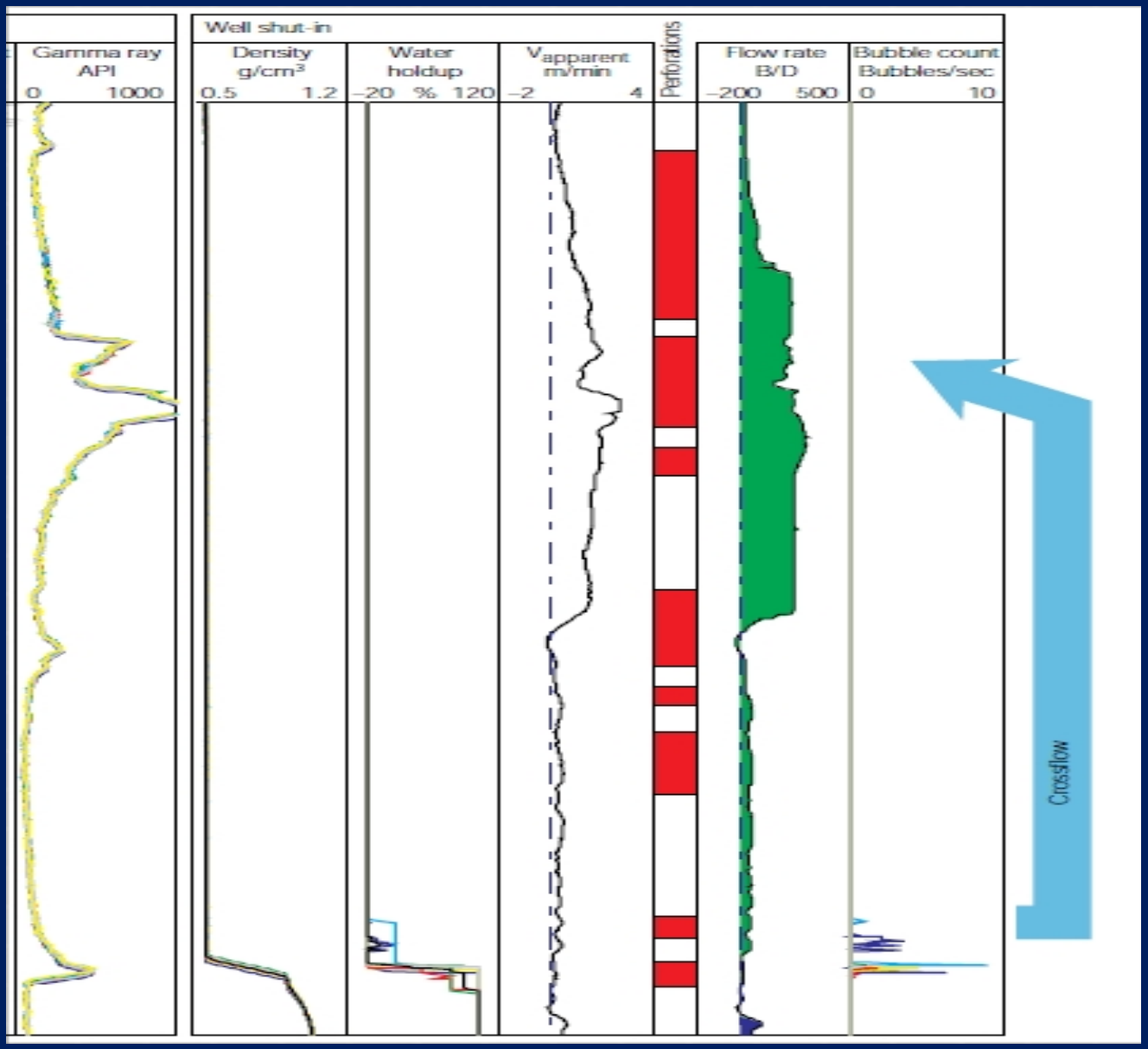
Temperature Logs



Gamma Ray Logs

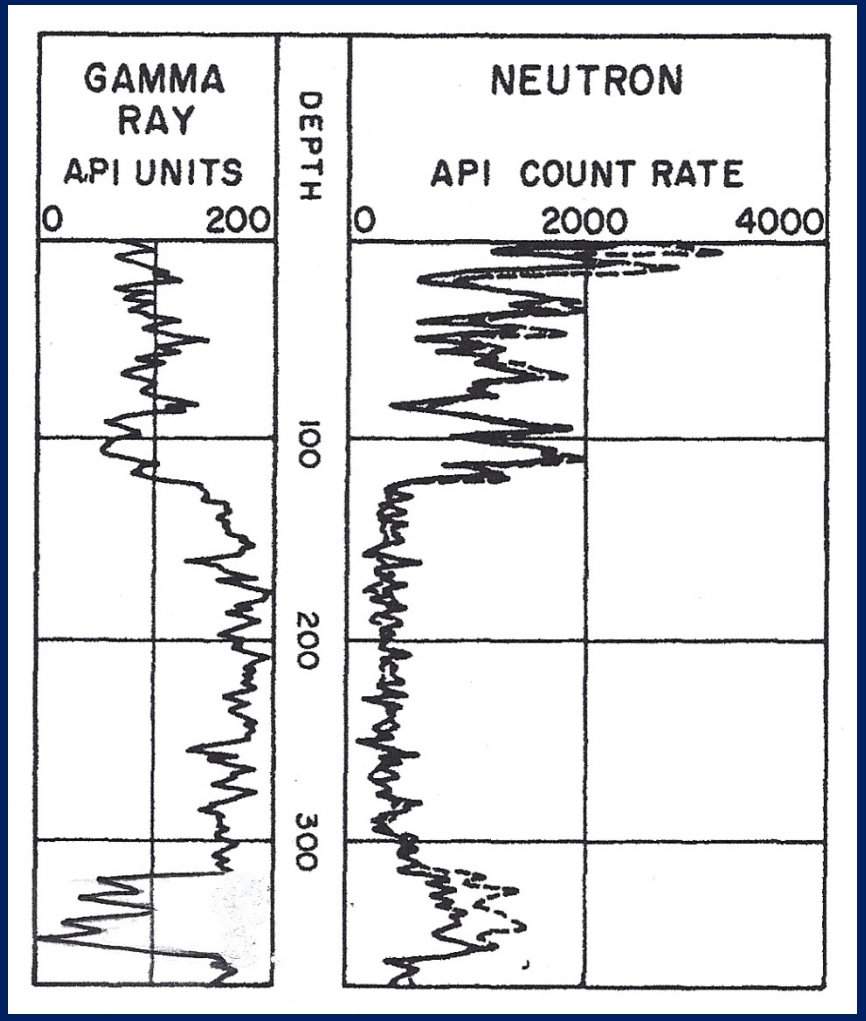
- Measures natural gamma ray emissions from the formation
- Shales – high gamma ray emissions
- Sands, limestones – low gamma ray emissions
- Migration of fluids within & adjacent to the wellbore deposits radioactive salts & zones of migration often marked by high gamma ray emissions

Gamma Ray Logs

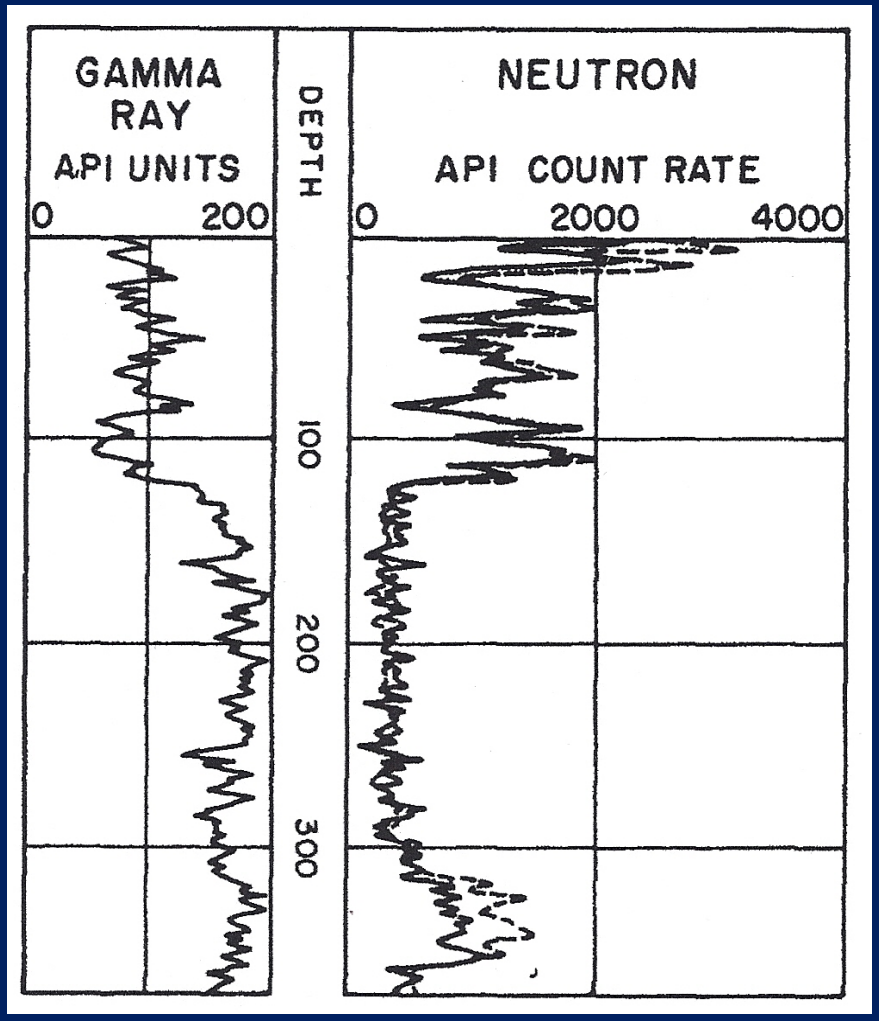


Gamma Ray/Neutron Logs

2000



2010



Radioactive Tracers

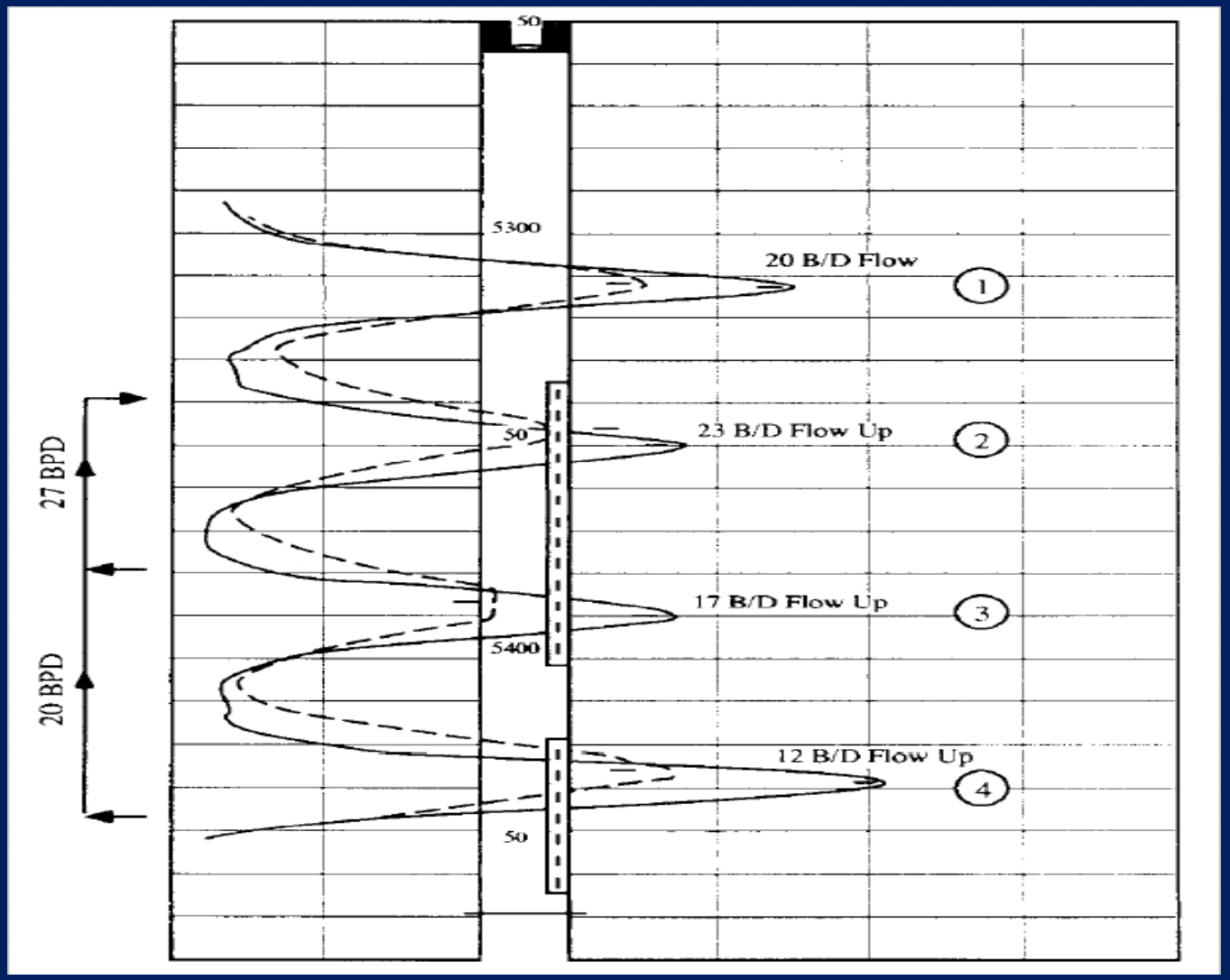
- Tracer is a radioactive isotope that is soluble in gas, oil, and water (iodine; half life 8.1 days)
- Gamma radiation emitted by the tracer is detected by a gamma ray tool
- Gamma radiation penetrates steel, PVC pipe, cement, & formation
- 90% of gamma radiation recorded originates within 1 foot of the detector

Radioactive Tracers

- Tool can inject tracer and record gamma emissions simultaneously
- Fluid movement & velocity & volume can be monitored within a well, behind casing, & between wells

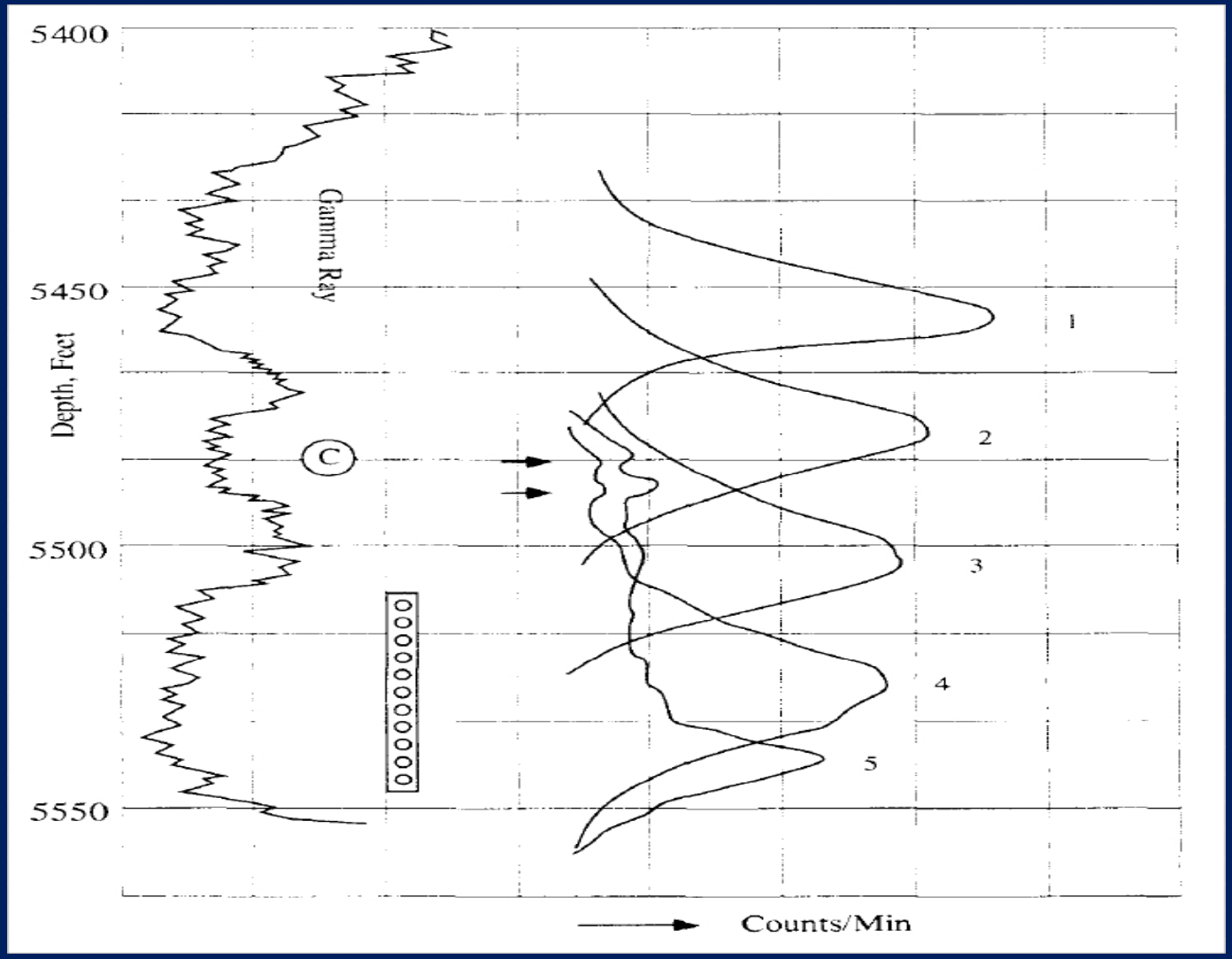
Radioactive Tracers

(well shut in; 4 injection points;
dashed log run 5 mins after solid log)



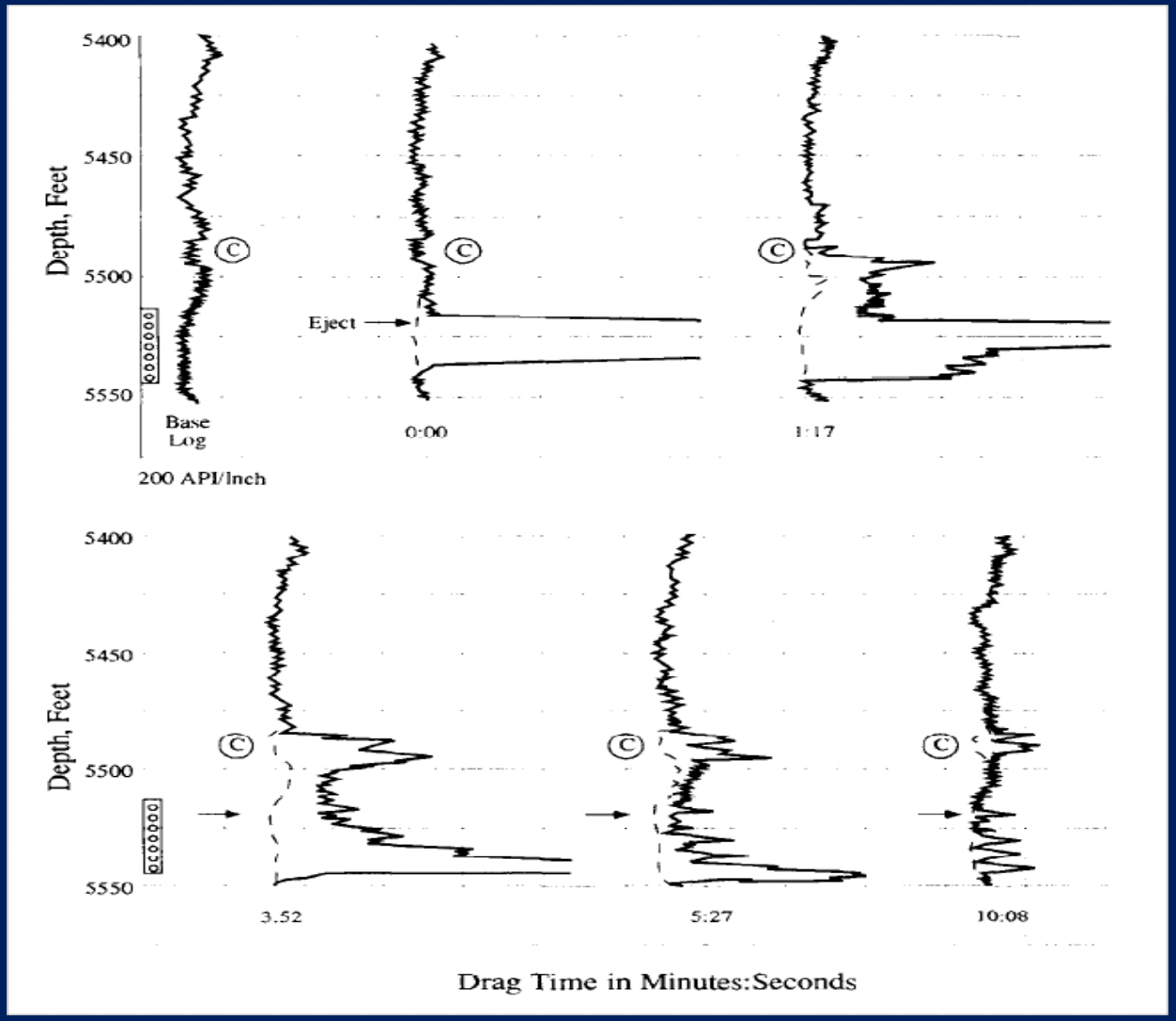
Radioactive Tracers

(Well on injection into perfs; tracer at point 1; 5 logs run 30 mins apart; flow behind casing into Sand C)



Radioactive Tracers

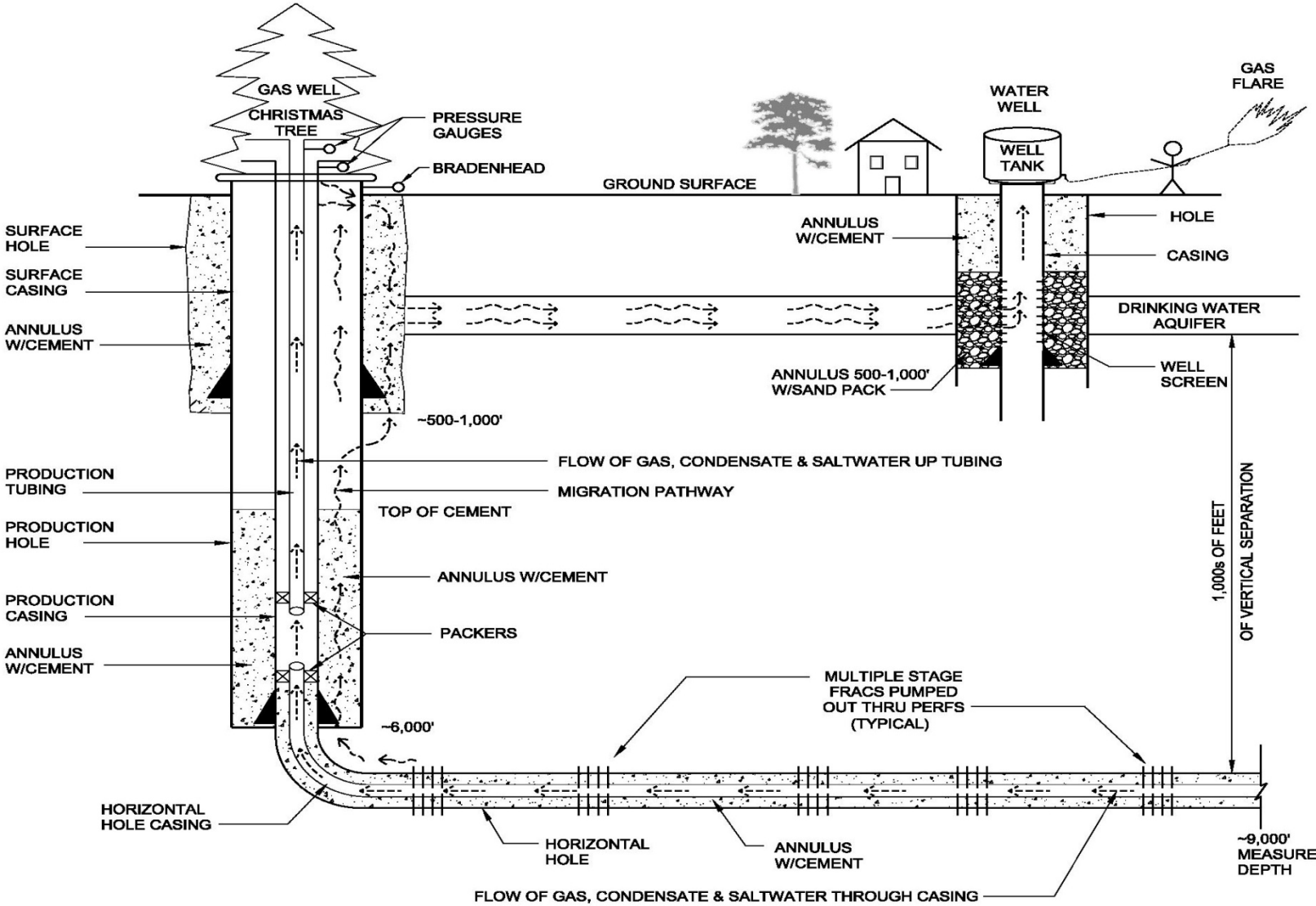
(Well on injection into perfs; 5 logs runs presented on separate logs; flow behind casing into Sand C)



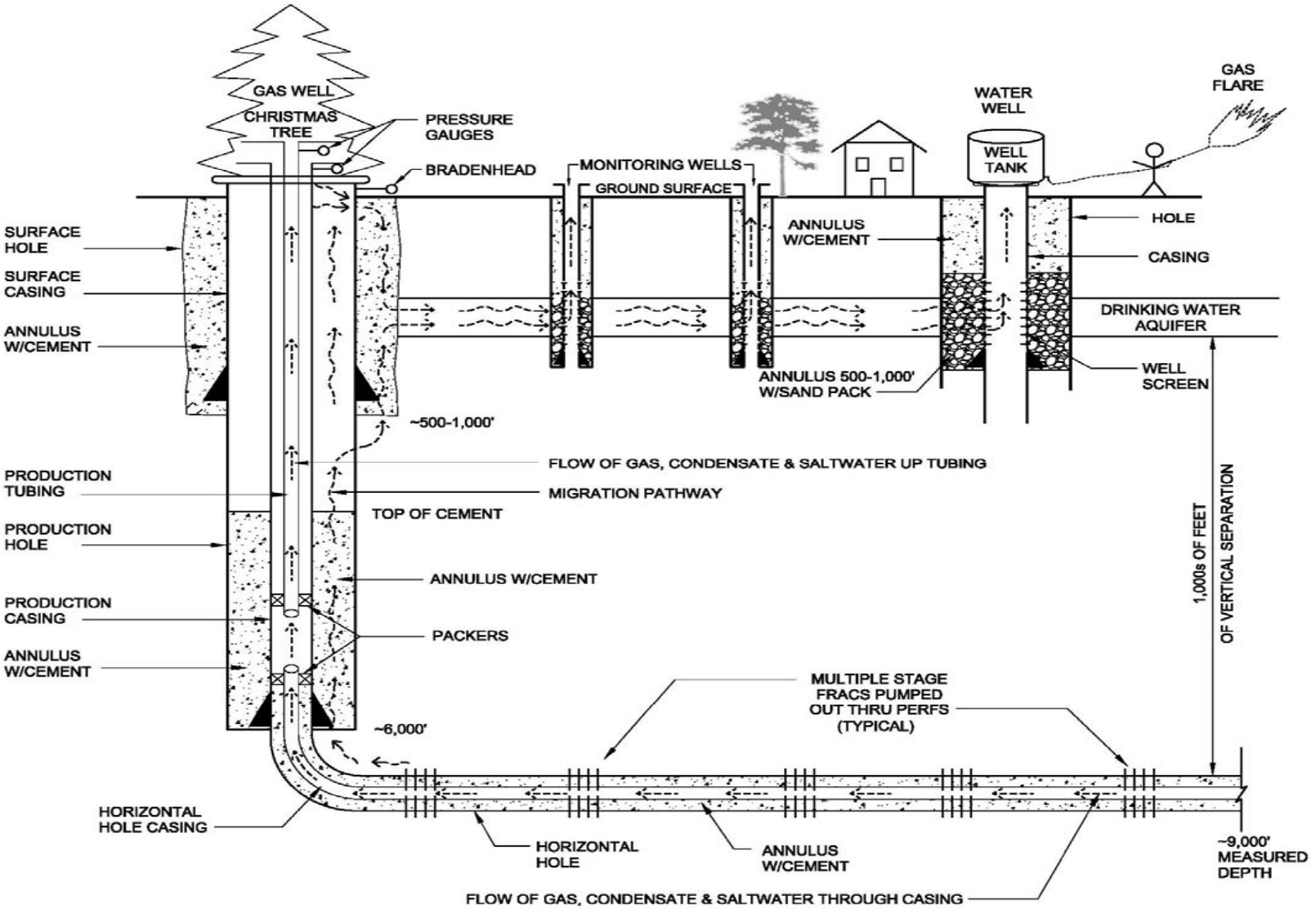
Pressure Interference Tests

- Downhole pressure gauge installed in the water well
- Pressure wave created in gas well by producing well & shutting it in intermittently
- Pressure changes recorded in water well
- Cross contamination requires hydraulic connection between gas well & water well

Pressure Interference Tests



Installation of Monitoring Wells



Summary

- 18 different investigative tools – can we solve the contamination problem??
- Choose the most time effective tools
- Choose the most cost effective tools
- Choose the tools that will support our case
- Find the “truth”

“And ye shall know the truth and the truth shall make you free.”

- Oil companies – “it has never been proven that an oil or gas well has contaminated an aquifer.”

- Environmentalists – “every oil and gas well has contaminated all our aquifers.”

GAS WELL/WATER WELL SUBSURFACE CONTAMINATION

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