Natural Gas Explosions in Hutchinson, Kansas: Geologic Factors

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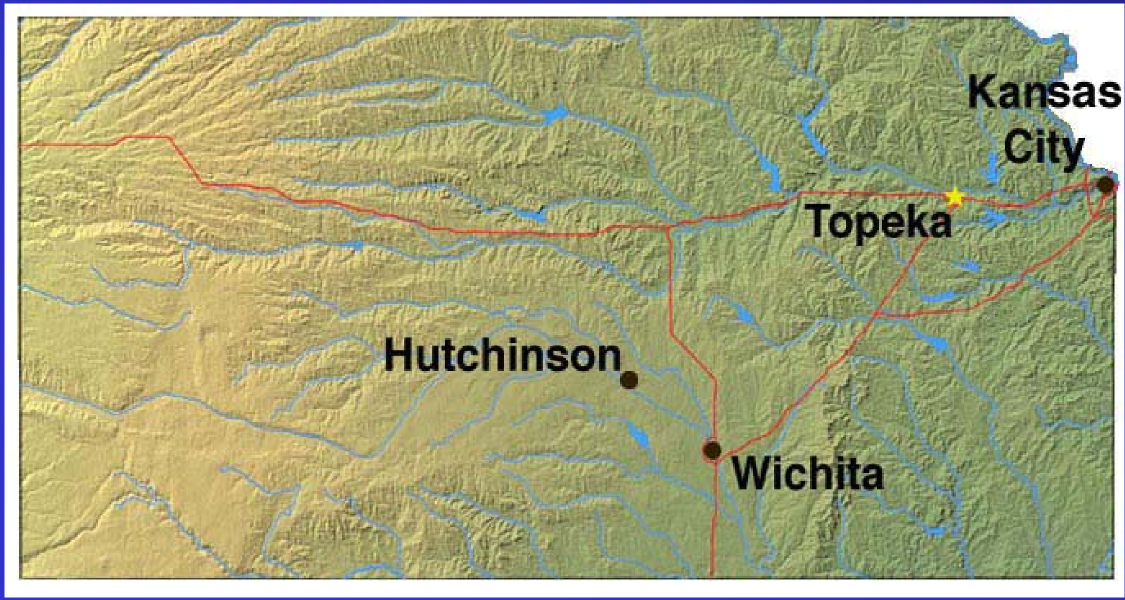
Lawrence, KS 66047

North-Central GSA - March 24, 2003



Please note:

This slide set was updated on August 20, 2004 to incorporate new data. New slides include: #15, #20-26, and #31.

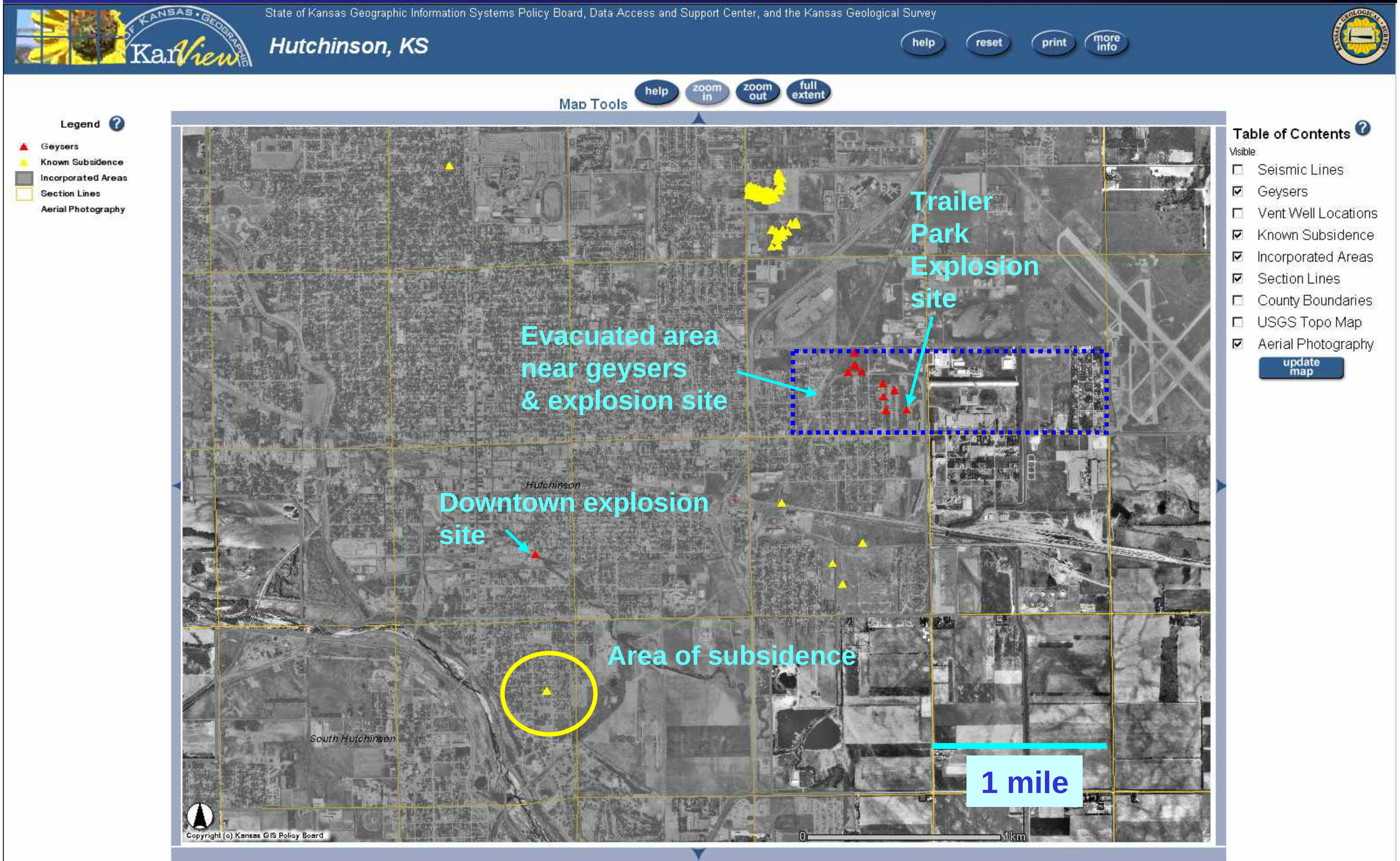
Summary

- Gas leaked from hole in casing at 595 ft depth in S-1 gas storage well
- Gas encountered in vent wells at depths ranging from 420 ft (Yaggy) to 240 ft below surface (eastern Hutch)
- Gas zone confined to 15-ft thick interval
  - three thin (2-3 ft) beds of dolomicrite
- Gas zone is located at the top of Lower Permian Upper Wellington Shale
- Vent wells closely follow crest of narrow, low-relief, asymmetric, northwesterly-plunging anticline
- Fractures/joints trending along crest of structure appear to be responsible for gas migration between Yaggy and Hutchinson

Geological Data

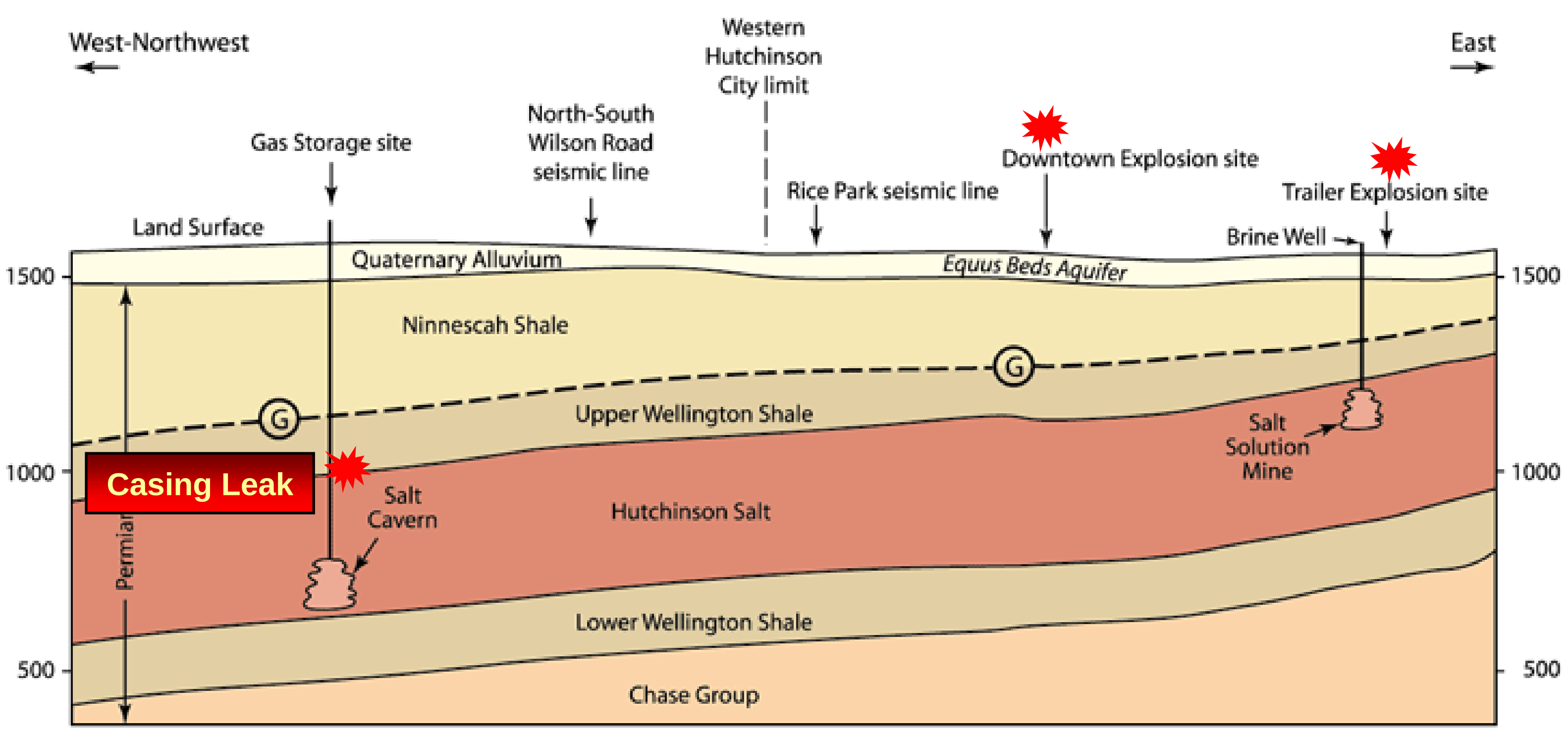
- Completion data and wireline logs from 54 vent and observation wells in and around Hutchinson
- 2 cores along Wilson Road between Hutchinson and Yaggy Gas Storage Facility
- Core (Q-5) and log data from Yaggy Gas Storage Facility
- Core from AEC #1 Test Hole in Lyons, Co. (20 mi NW of Hutchinson)
- Archived strat/sed database encompassing Lower Permian Stone Corral Formation to Top Chase Group
- Surface exposures
- Integration with seismic and engineering data

Locations of explosion sites, geysers, and areas of known subsidence in Hutchinson



From Interactive KanView ESRI MapServer at Kansas Geological Survey (www.kgs.ukans.edu)

Cross Section Showing Hutchinson Salt Member in Relation to other Geologic Strata

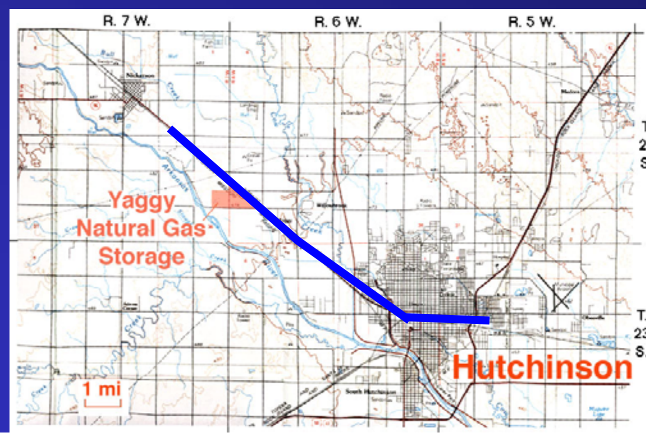


G Gas-bearing horizon

1 mile

Index map

2 mi.

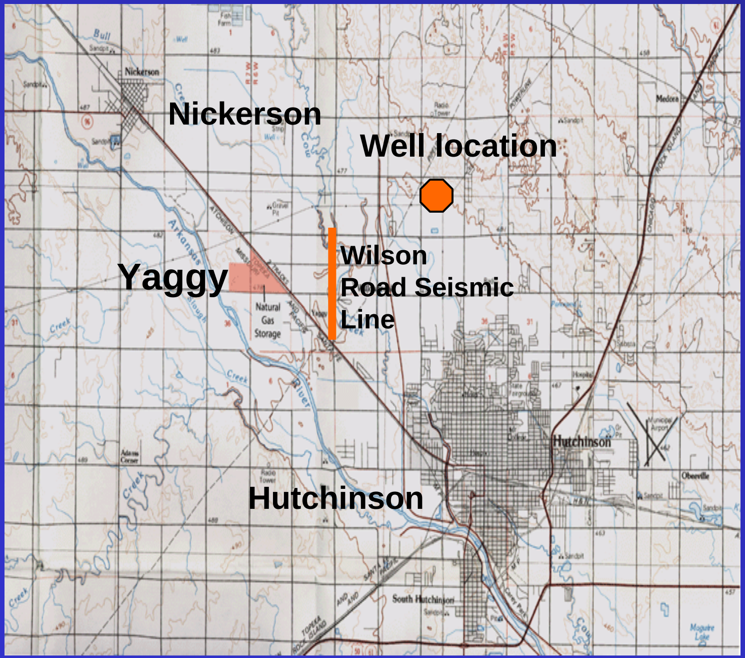


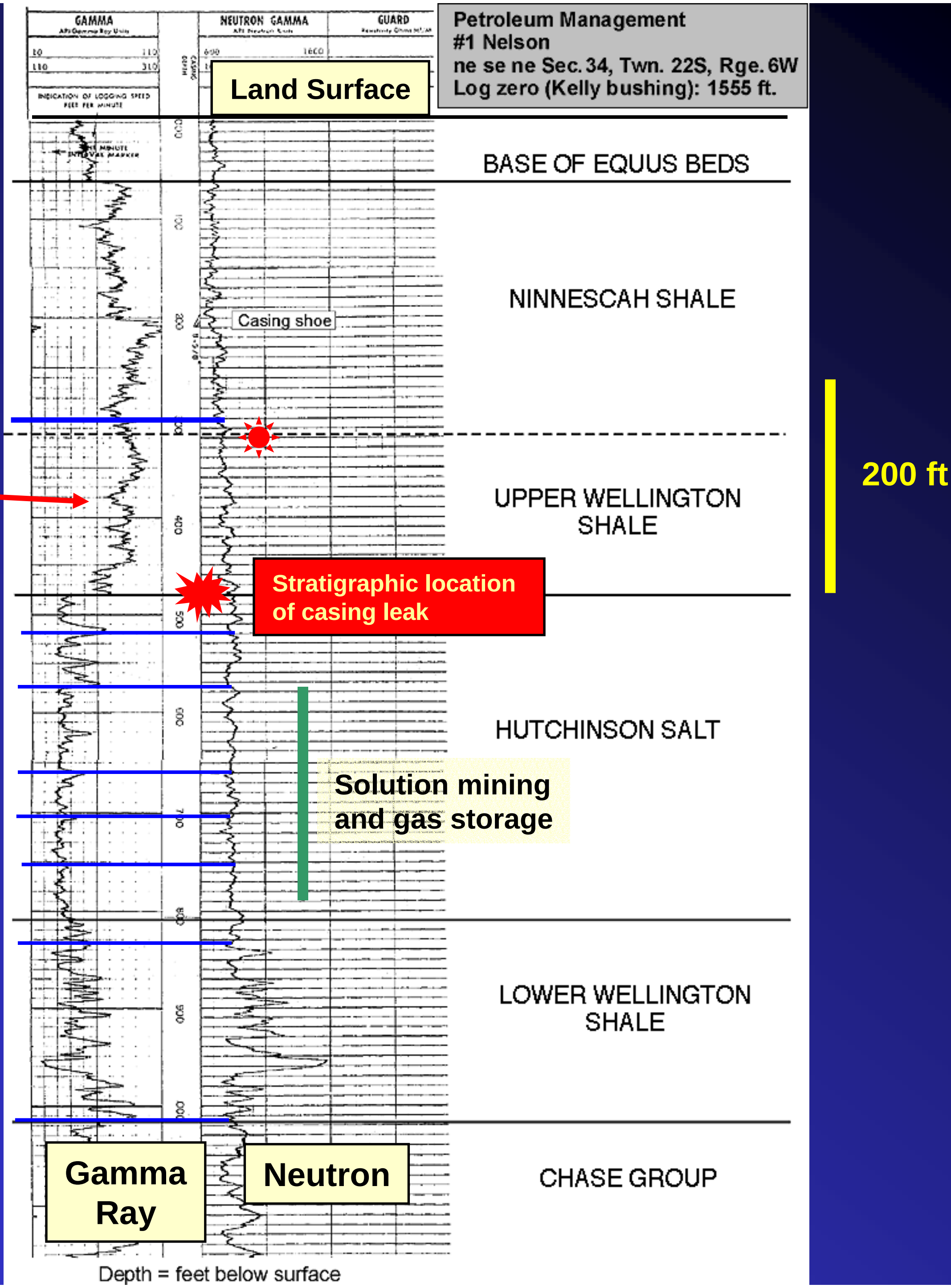
Well log showing major geologic strata important in Hutchinson incident

Previously mapped intervals from Watney et al. (1988) - (archived data)

Primary gas-bearing interval

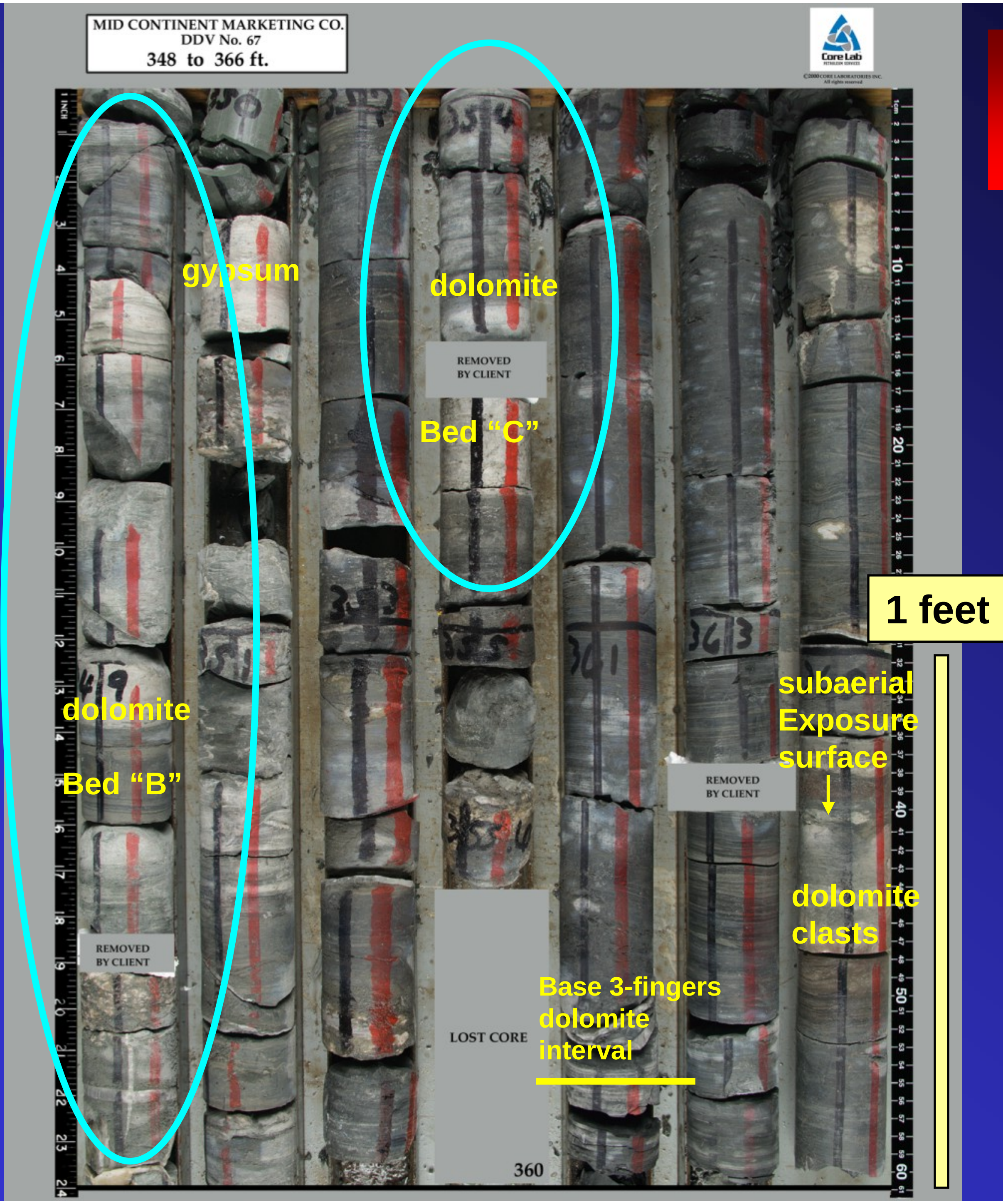
Secondary gas interval
(DDV #64 in 3-day blow-out in July, 2001)



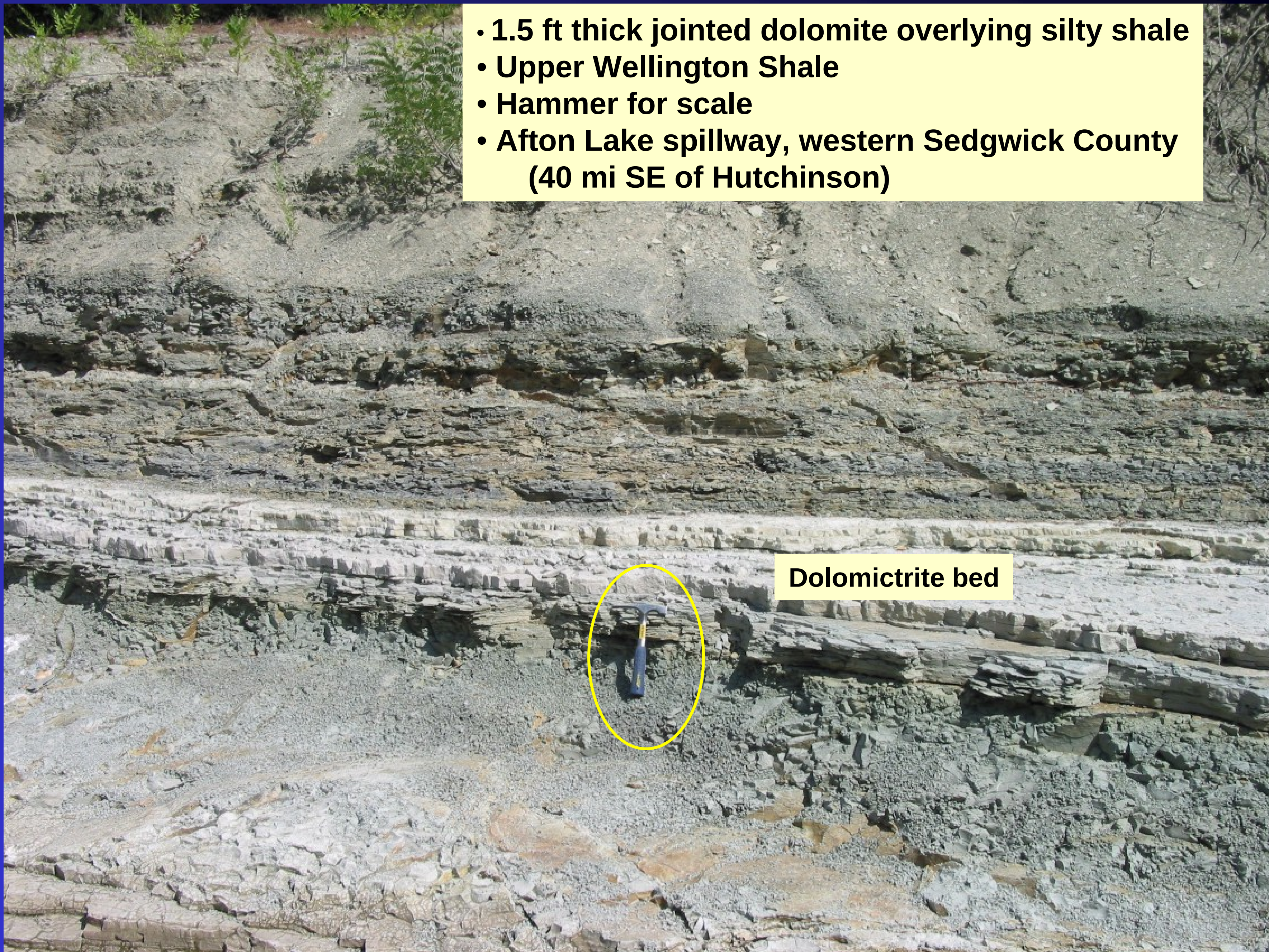


Core from DDV #67

3-finger dolomite interval



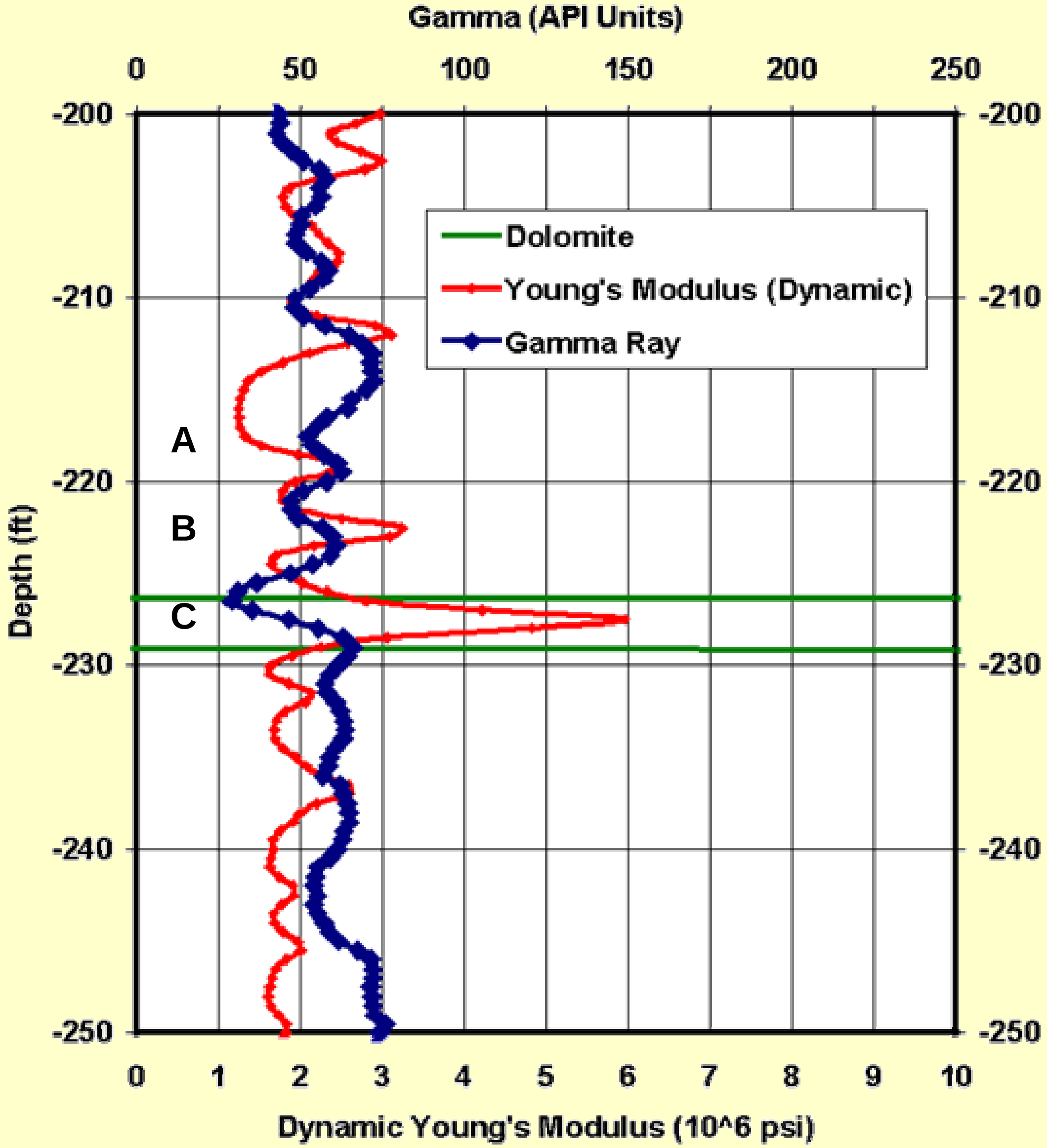
- 1.5 ft thick jointed dolomite overlying silty shale
- Upper Wellington Shale
- Hammer for scale
- Afton Lake spillway, western Sedgwick County (40 mi SE of Hutchinson)

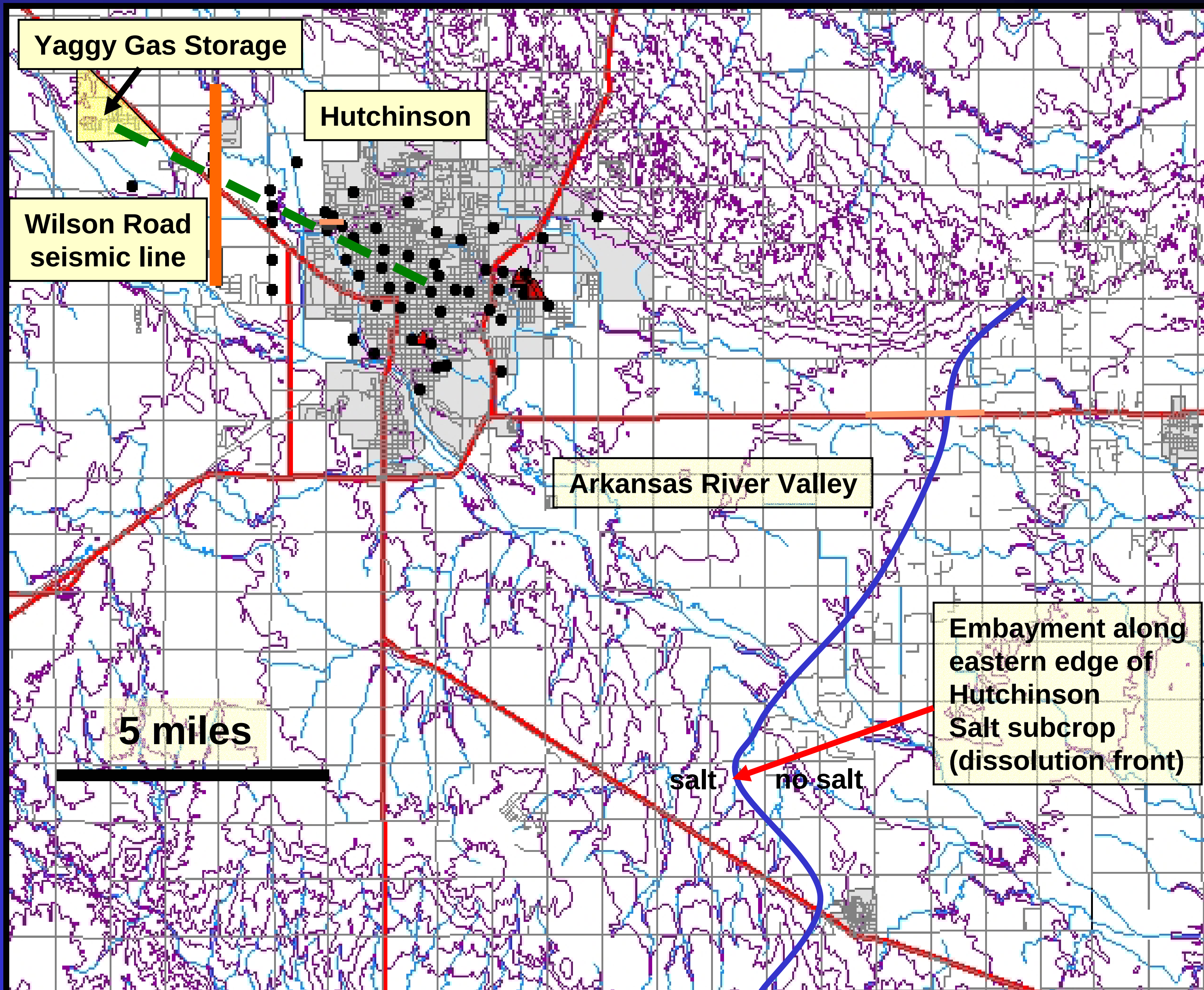


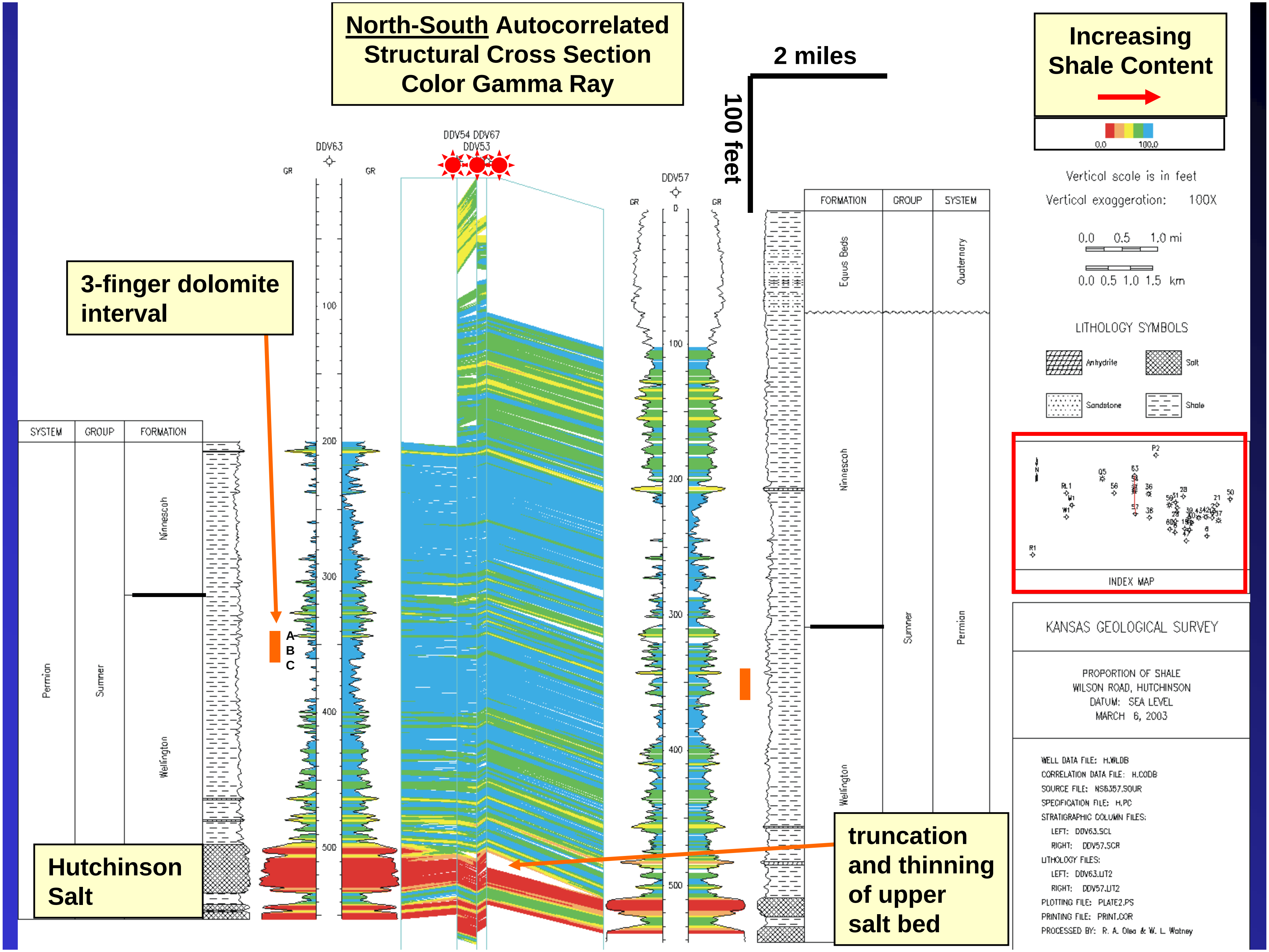
Orthogonal NW-SE and NE-SW trending joints along the upper surface of the dolomite at Afton Lake spillway

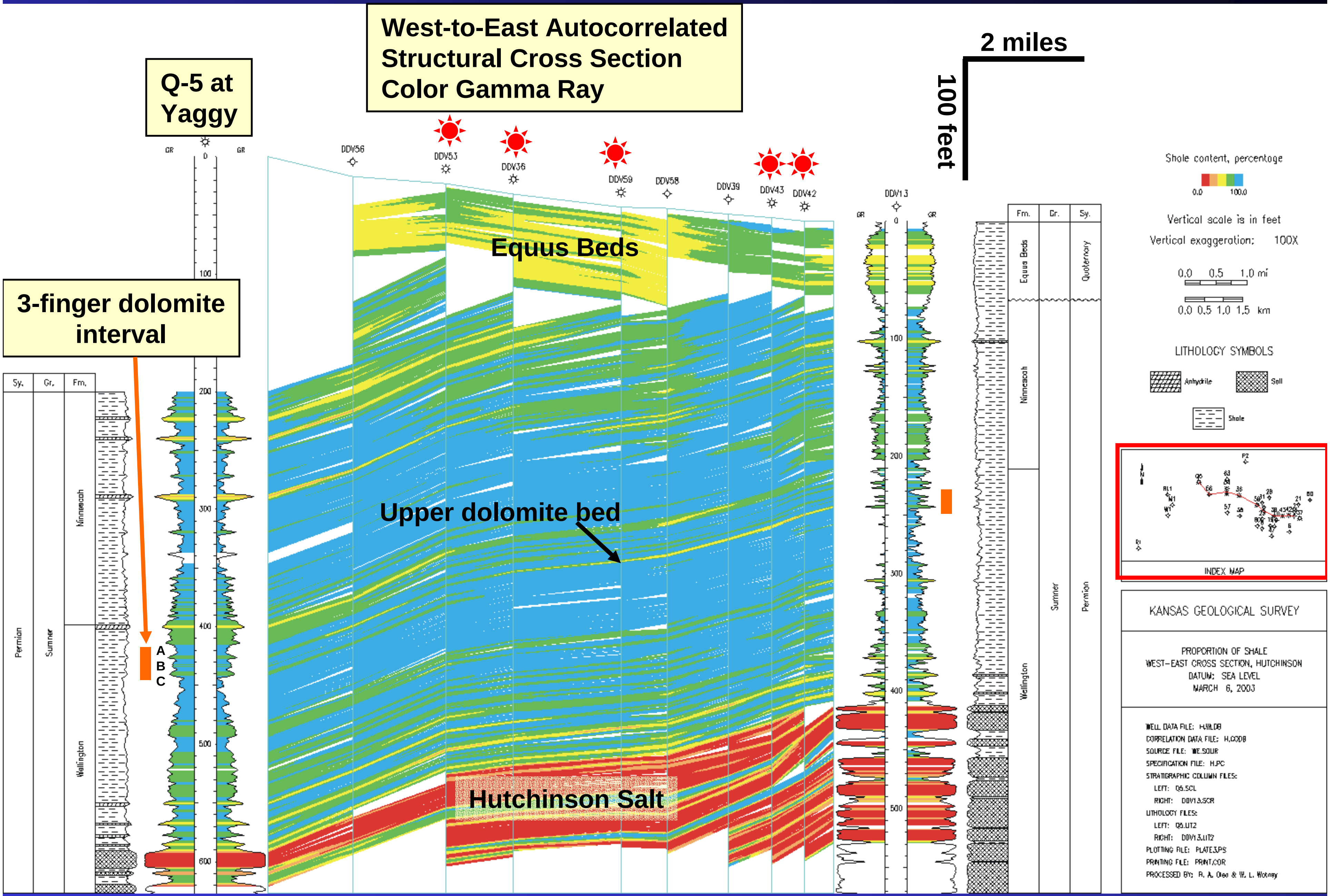
Data from IMC Salt Co., Hutchinson
provided by J. Radigan

IMC Salt Well No. 124
Hutchinson, Kansas

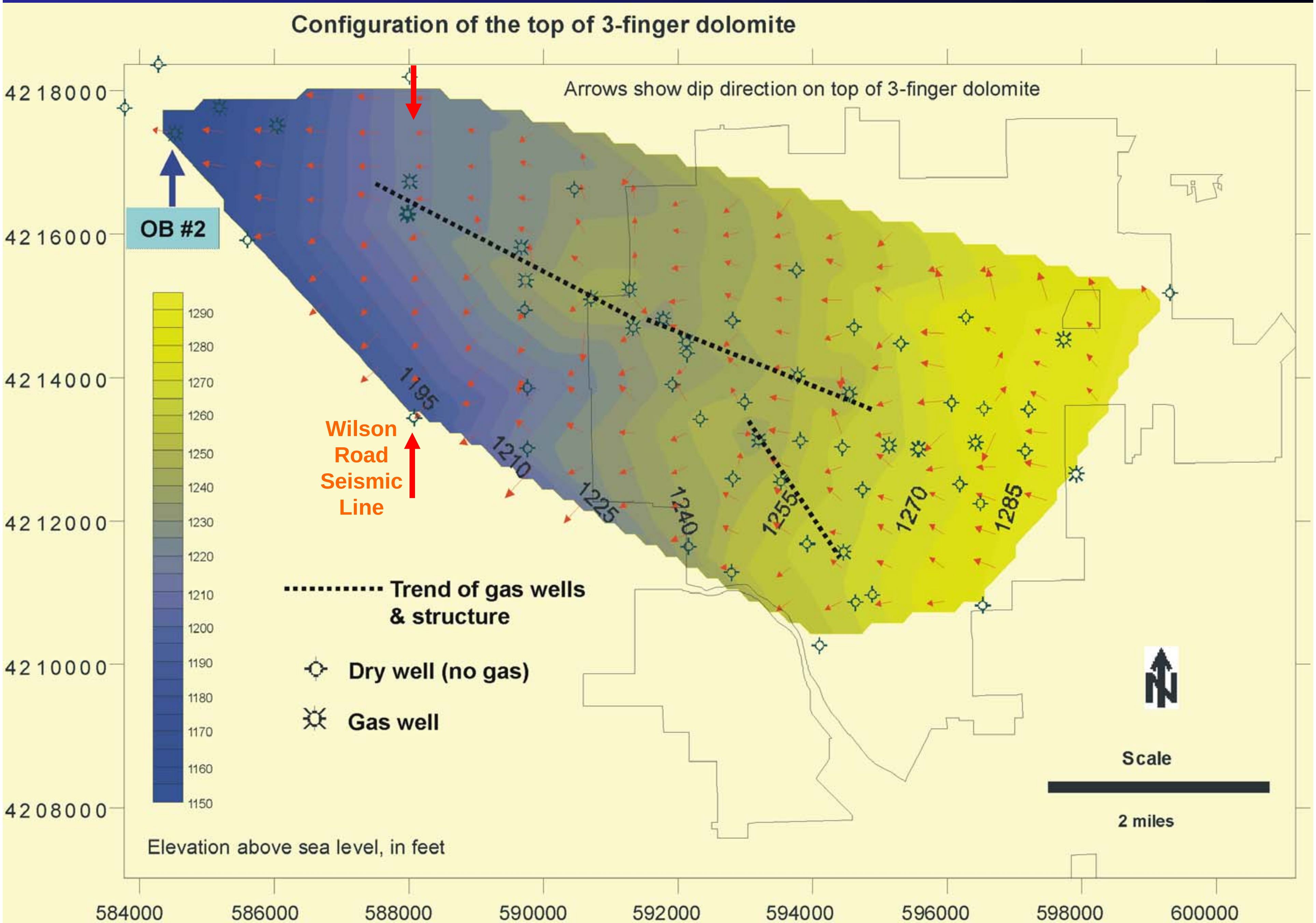



Yaggy Gas Storage
Hutchinson
Wilson Road
seismic line
Arkansas River Valley
Embayment along
eastern edge of
Hutchinson
Salt subcrop
(dissolution front)
salt
no salt
5 miles


North-South Autocorrelated Structural Cross Section Color Gamma Ray
2 miles
100 feet
Increasing Shale Content
0.0
100.0
Vertical scale is in feet
Vertical exaggeration: 100X
0.0 0.5 1.0 mi
0.0 0.5 1.0 1.5 km
LITHOLOGY SYMBOLS
Anhydrite
Salt
Sandstone
Shale
INDEX MAP
KANSAS GEOLOGICAL SURVEY
PROPORTION OF SHALE
WILSON ROAD, HUTCHINSON
DATUM: SEA LEVEL
MARCH 6, 2003
WELL DATA FILE: H.WLDB
CORRELATION DATA FILE: H.CODB
SOURCE FILE: NS6357.SOUR
SPECIFICATION FILE: H.PC
STRATIGRAPHIC COLUMN FILES:
LEFT: DDV63.SCL
RIGHT: DDV57.SCR
LITHOLOGY FILES:
LEFT: DDV63.LIT2
RIGHT: DDV57.LIT2
PLOTTING FILE: PLATE2.PS
PRINTING FILE: PRINT.COR
PROCESSED BY: R. A. Olea & W. L. Watney
3-finger dolomite interval
A
B
C
Hutchinson Salt
truncation and thinning of upper salt bed
SYSTEM
GROUP
FORMATION
Permian
Sumner
Ninnescah
Wellington
Equus Beds
Quaternary
DDV63
DDV54 DDV67
DDV53
DDV57
GR
100
200
300
400
500

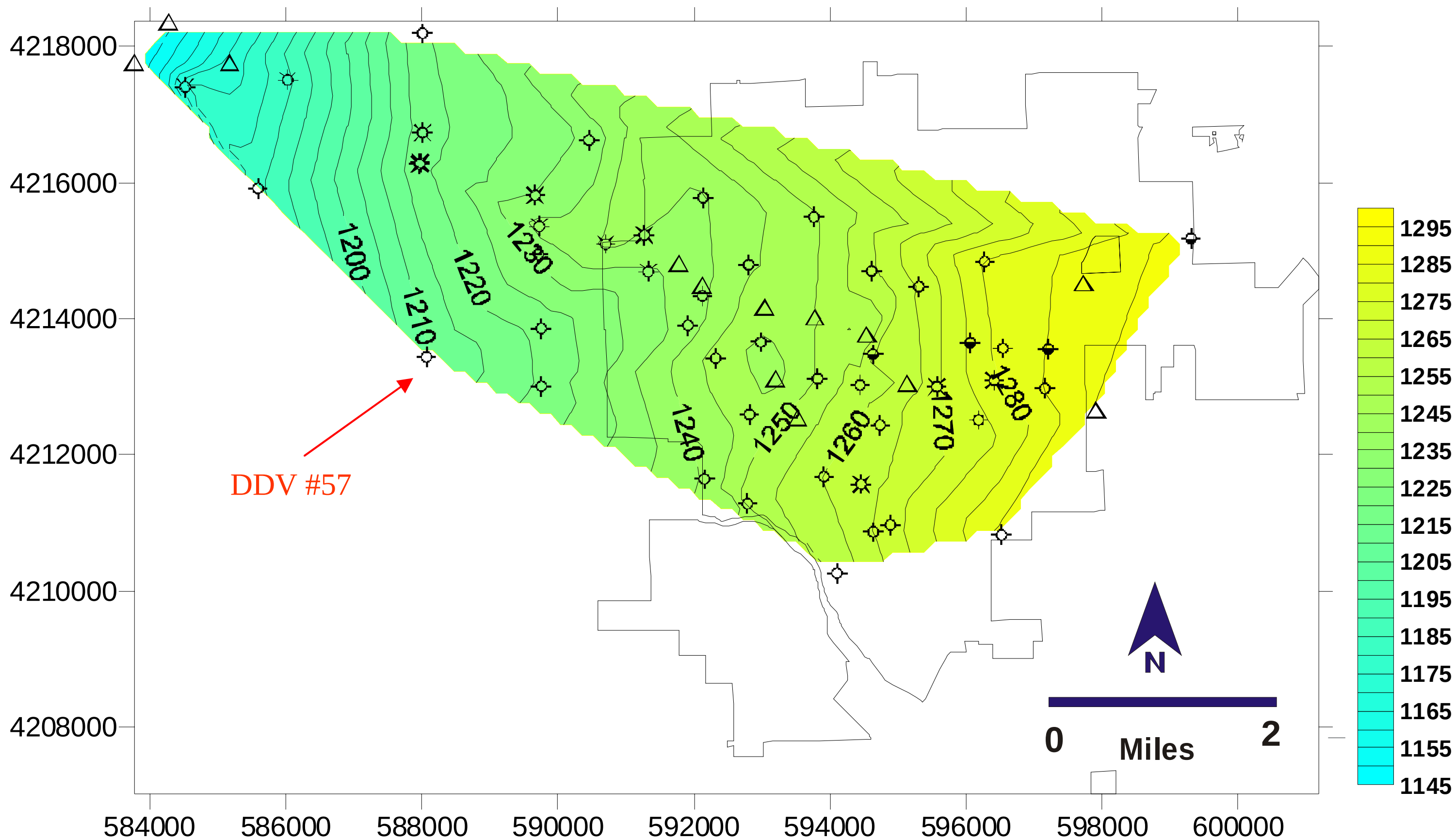


West-to-East Autocorrelated Structural Cross Section Color Gamma Ray
Q-5 at Yaggy
2 miles
100 feet
3-finger dolomite interval
Equus Beds
Upper dolomite bed
Hutchinson Salt
DDV56
DDV53
DDV36
DDV59
DDV58
DDV39
DDV43
DDV42
DDV13
Shale content, percentage
Vertical scale is in feet
Vertical exaggeration: 100X
LITHOLOGY SYMBOLS
Anhydrite
Salt
Shale
INDEX MAP
KANSAS GEOLOGICAL SURVEY
PROPORTION OF SHALE
WEST-EAST CROSS SECTION, HUTCHINSON
DATUM: SEA LEVEL
MARCH 6, 2003
Permian
Sumner
Wellington
Ninnescah
Quaternary

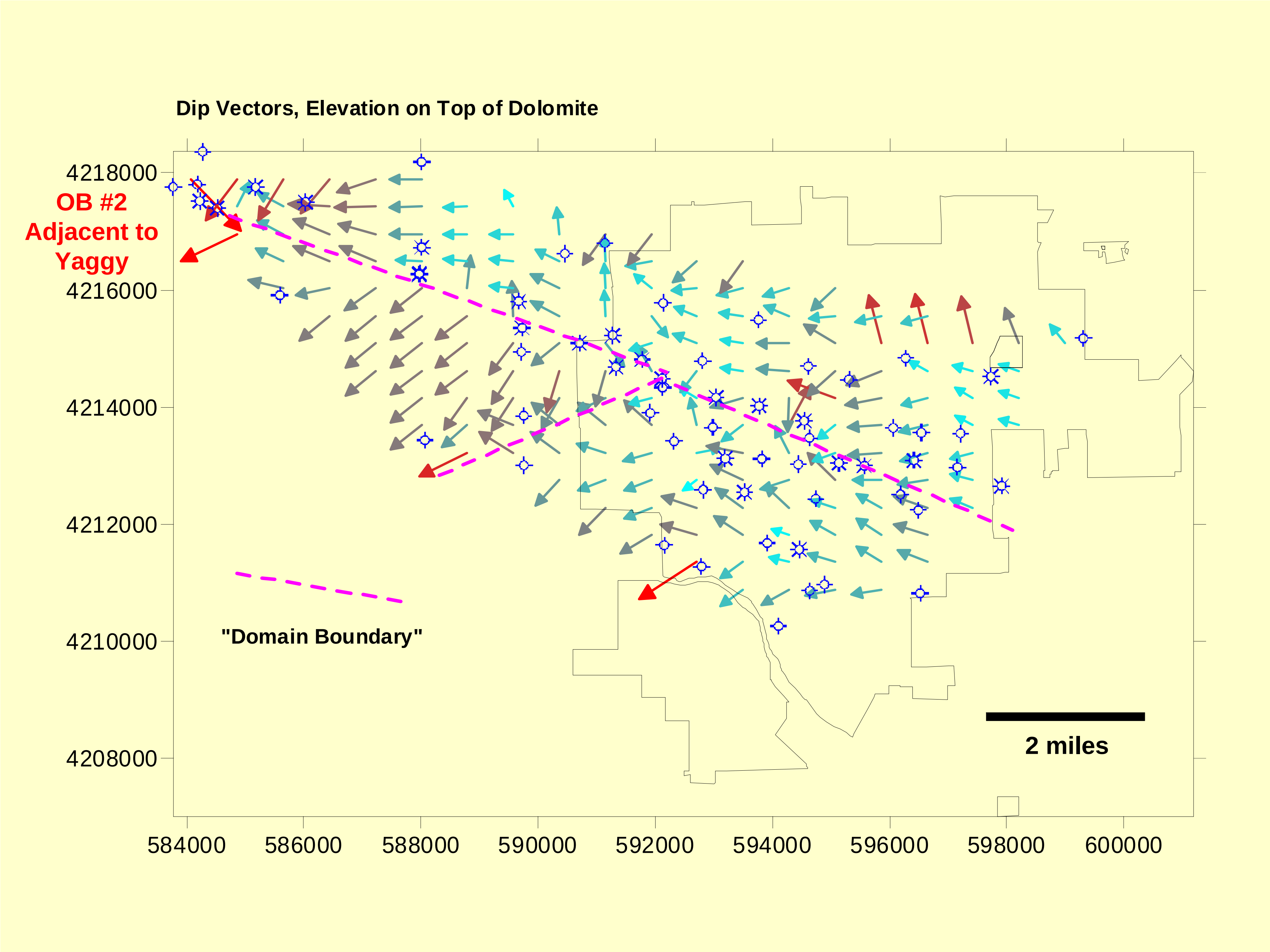

Configuration of the top of 3-finger dolomite
Arrows show dip direction on top of 3-finger dolomite
OB #2
Wilson Road Seismic Line
1195
1210
1225
1240
1255
1270
1285
Trend of gas wells & structure
Dry well (no gas)
Gas well
Scale
2 miles
Elevation above sea level, in feet
1290
1280
1270
1260
1250
1240
1230
1220
1210
1200
1190
1180
1170
1160
1150
4218000
4216000
4214000
4212000
4210000
4208000
584000
586000
588000
590000
592000
594000
596000
598000
600000
N

Revised graphic for previous figure, "basic configuration on top of 3-finger dolomite" based on updated information (see below) – wlw/8-20-04

Elevation of surface on top of 3-finger dolomite

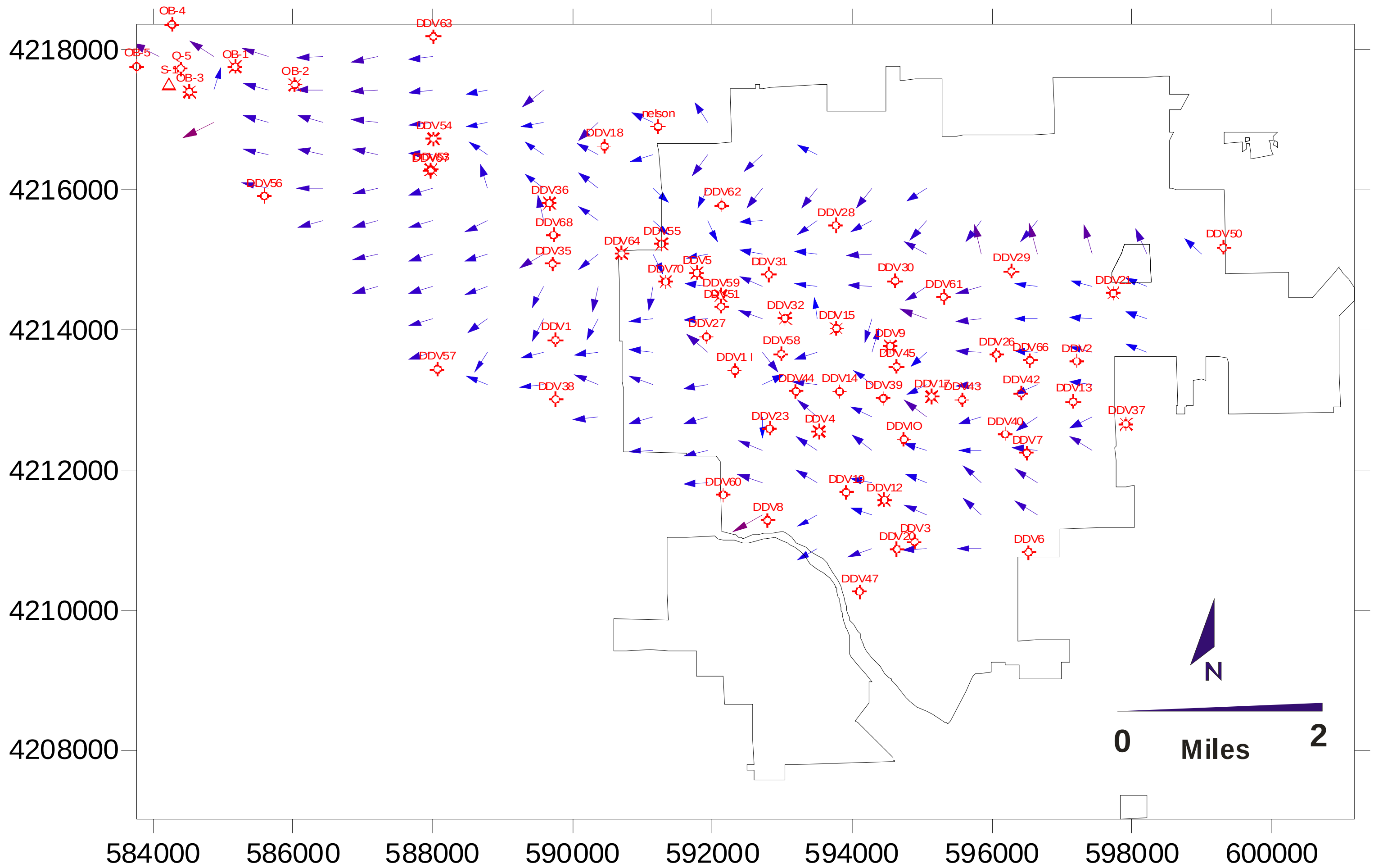


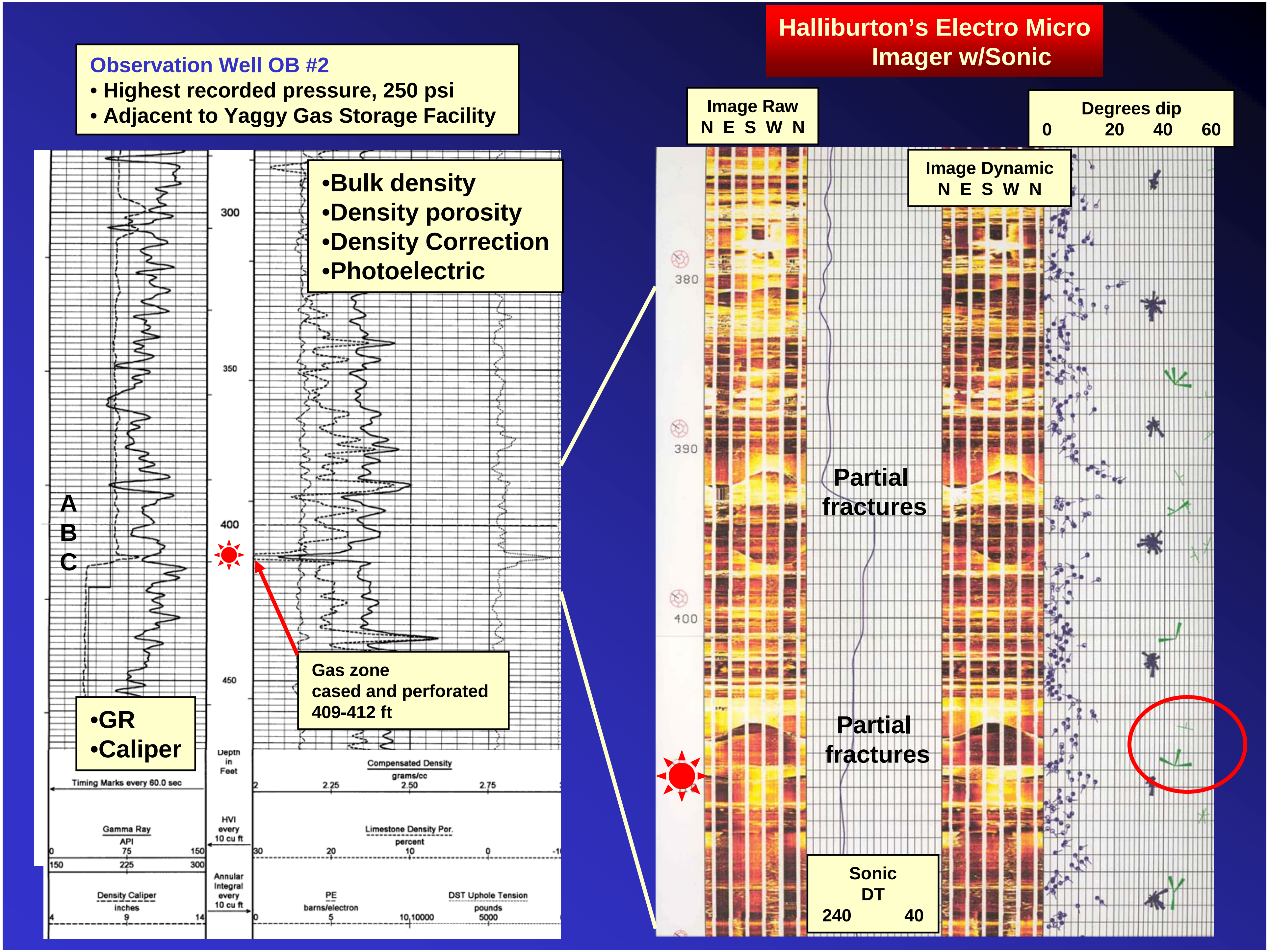
Revision: Surface elevation used as datum for DDV 57 modified from 1532 to 1551.32. Thus, elevation of top of 3-finger dolomite is 1209.3 ft compared to previous value of 1190 ft., i.e., 19.7 ft lower in elevation. This results in minor change to structural configuration.

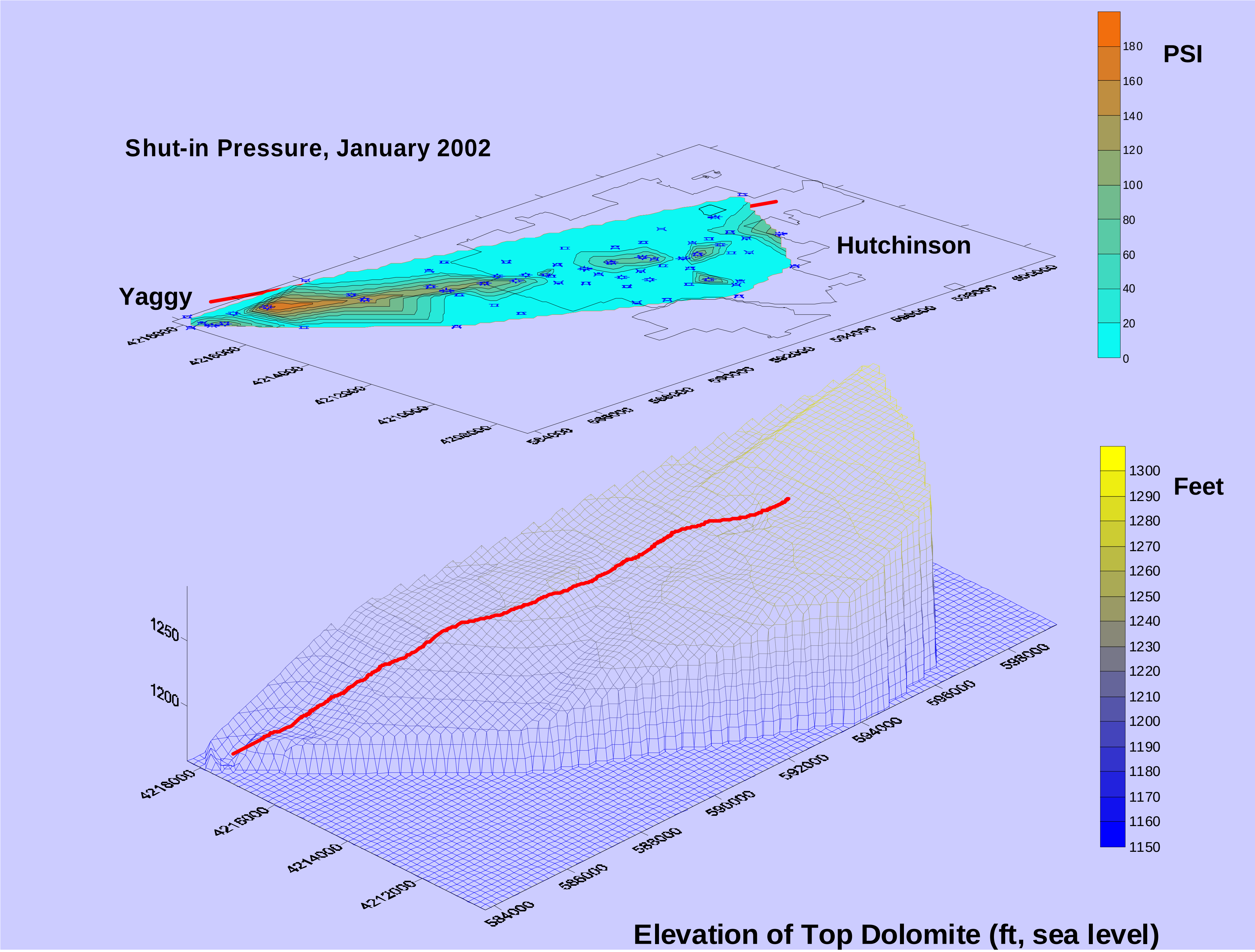

Dip Vectors, Elevation on Top of Dolomite
OB #2
Adjacent to
Yaggy
"Domain Boundary"
2 miles
4218000
4216000
4214000
4212000
4210000
4208000
584000
586000
588000
590000
592000
594000
596000
598000
600000

Modification of previous slide, "Dip Vector", based on new surface datum for DDV #57 resulting in minor changes to vectors. (see slide #15)

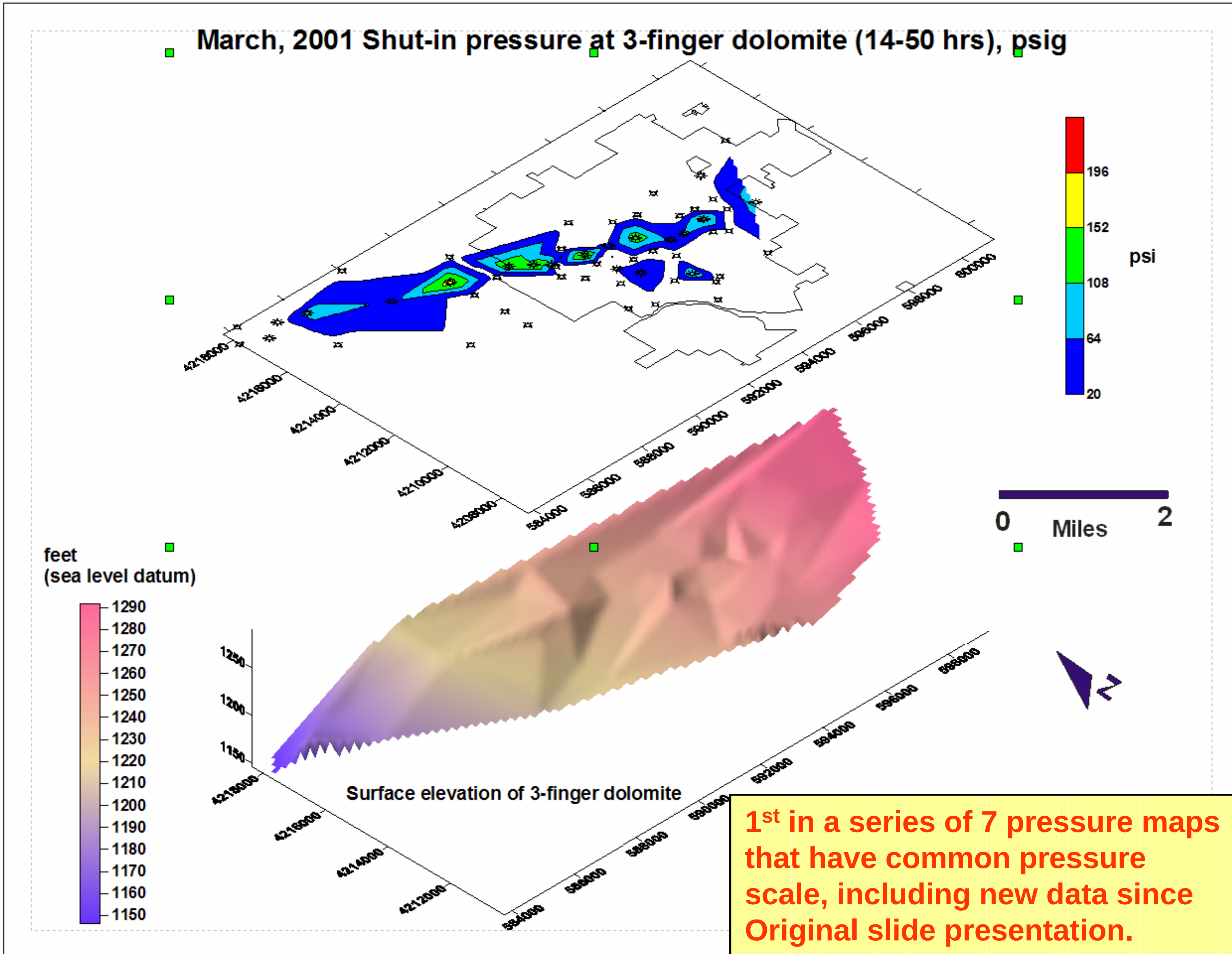
Dip vector map, top 3-finger dolomite



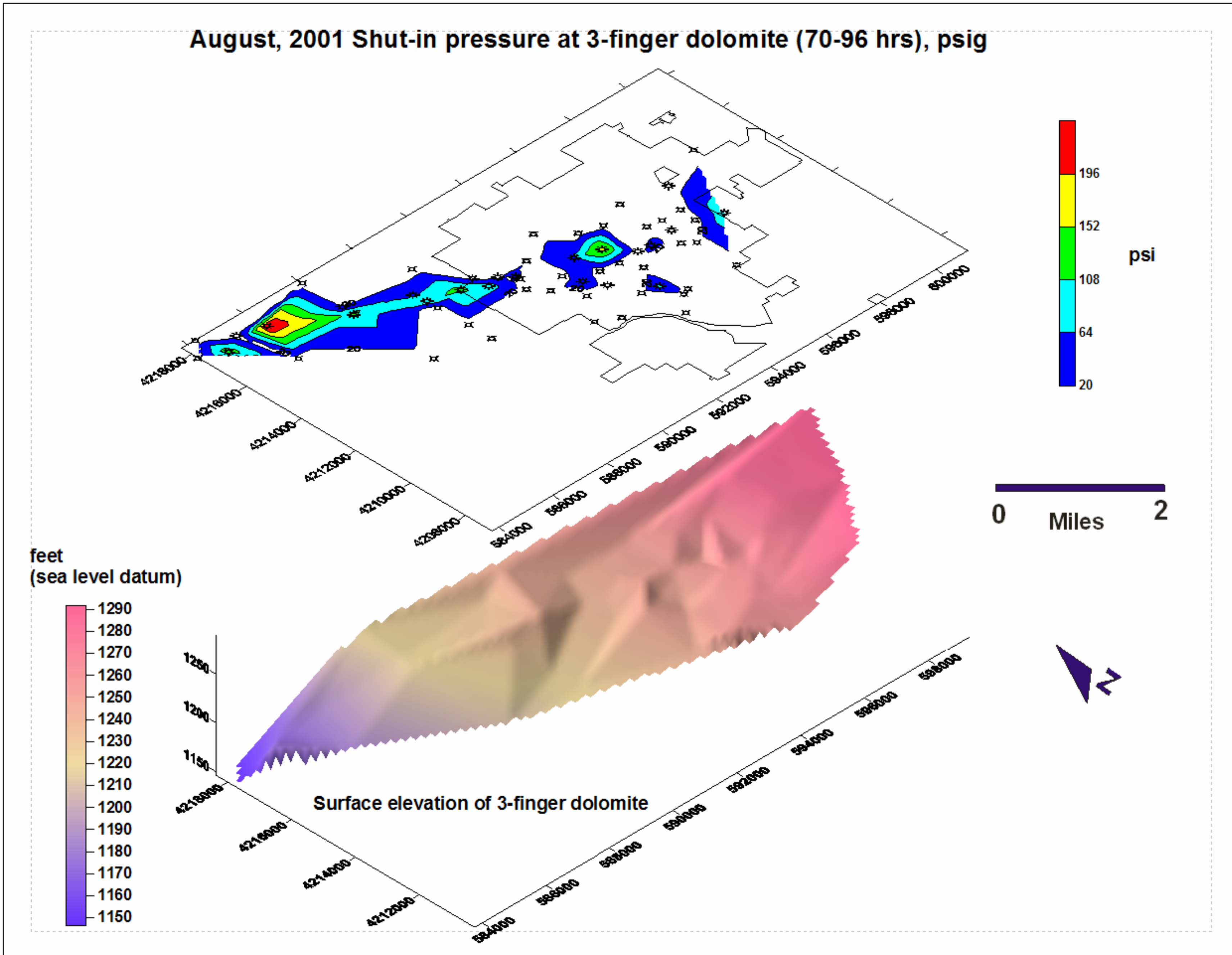

Halliburton's Electro Micro Imager w/Sonic
Observation Well OB #2
• Highest recorded pressure, 250 psi
• Adjacent to Yaggy Gas Storage Facility
•Bulk density
•Density porosity
•Density Correction
•Photoelectric
A
B
C
•GR
•Caliper
Gas zone
cased and perforated
409-412 ft
Image Raw
N E S W N
Degrees dip
0 20 40 60
Image Dynamic
N E S W N
Partial fractures
Partial fractures
Sonic
DT
240 40
Timing Marks every 60.0 sec
Gamma Ray
API
Density Caliper
inches
Depth in Feet
Compensated Density
grams/cc
Limestone Density Por.
percent
PE
barns/electron
DST Uphole Tension
pounds



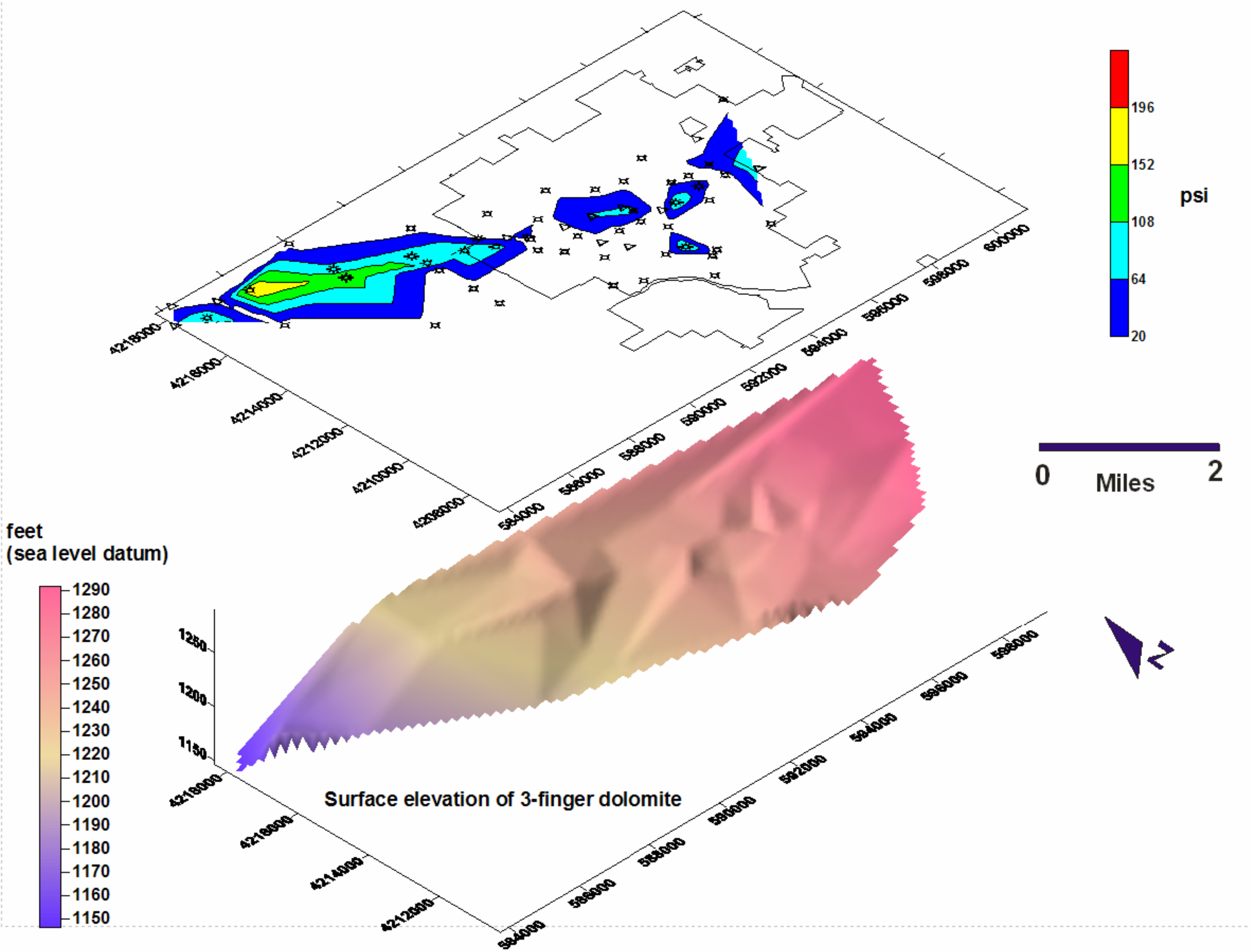
Shut-in Pressure, January 2002
Yaggy
Hutchinson
PSI
180
160
140
120
100
80
60
40
20
0
4218000
4216000
4214000
4212000
4210000
4208000
584000
586000
588000
590000
592000
594000
596000
598000
600000
Feet
1300
1290
1280
1270
1260
1250
1240
1230
1220
1210
1200
1190
1180
1170
1160
1150
1250
1200
Elevation of Top Dolomite (ft, sea level)



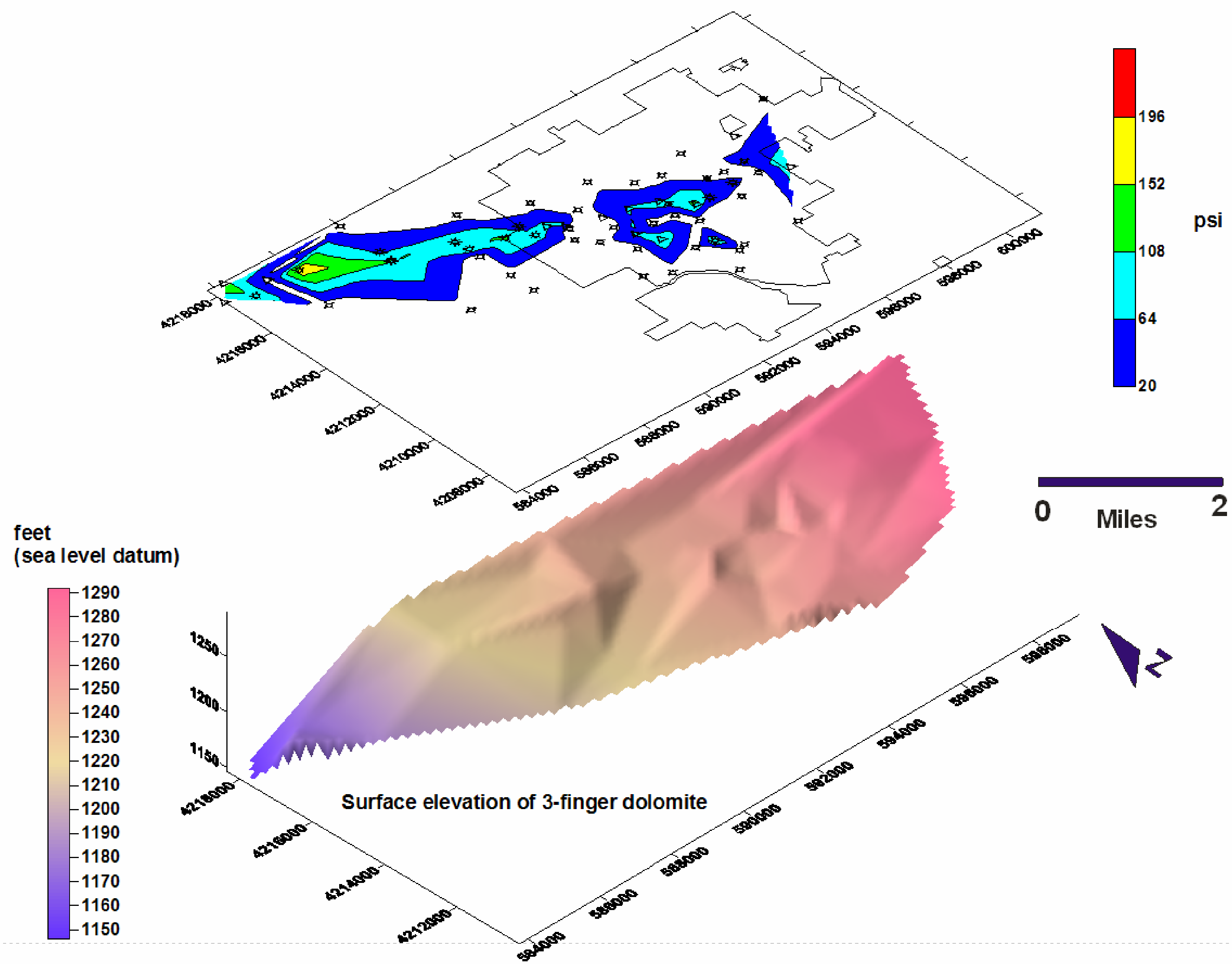
1st in a series of 7 pressure maps that have common pressure scale, including new data since Original slide presentation.

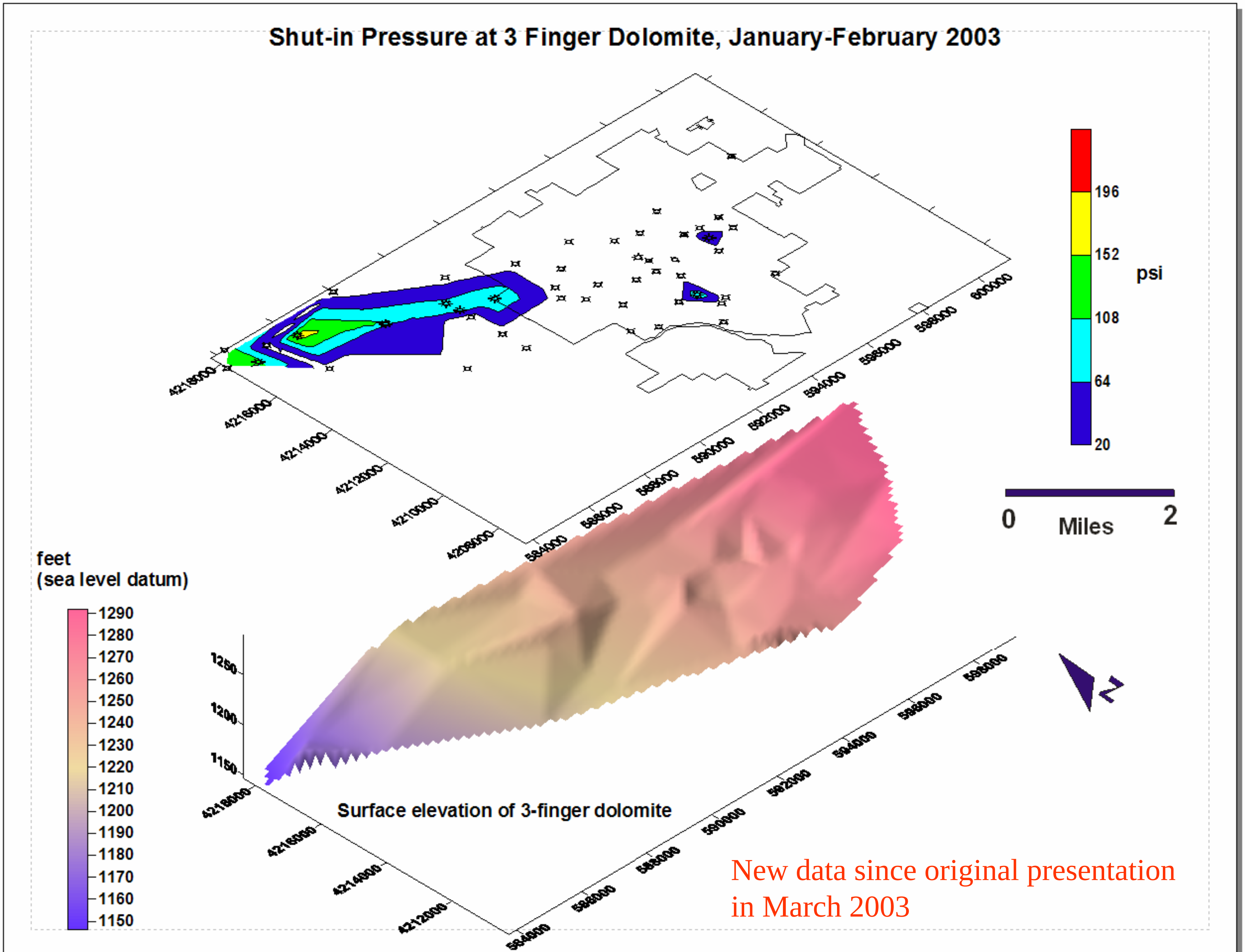

August, 2001 Shut-in pressure at 3-finger dolomite (70-96 hrs), psig
196
152
108
64
20
psi
0
Miles
2
feet
(sea level datum)
1290
1280
1270
1260
1250
1240
1230
1220
1210
1200
1190
1180
1170
1160
1150
Surface elevation of 3-finger dolomite

January, 2002 Shut-In Pressure at 3-finger dolomite (at approx. 75 hrs.)



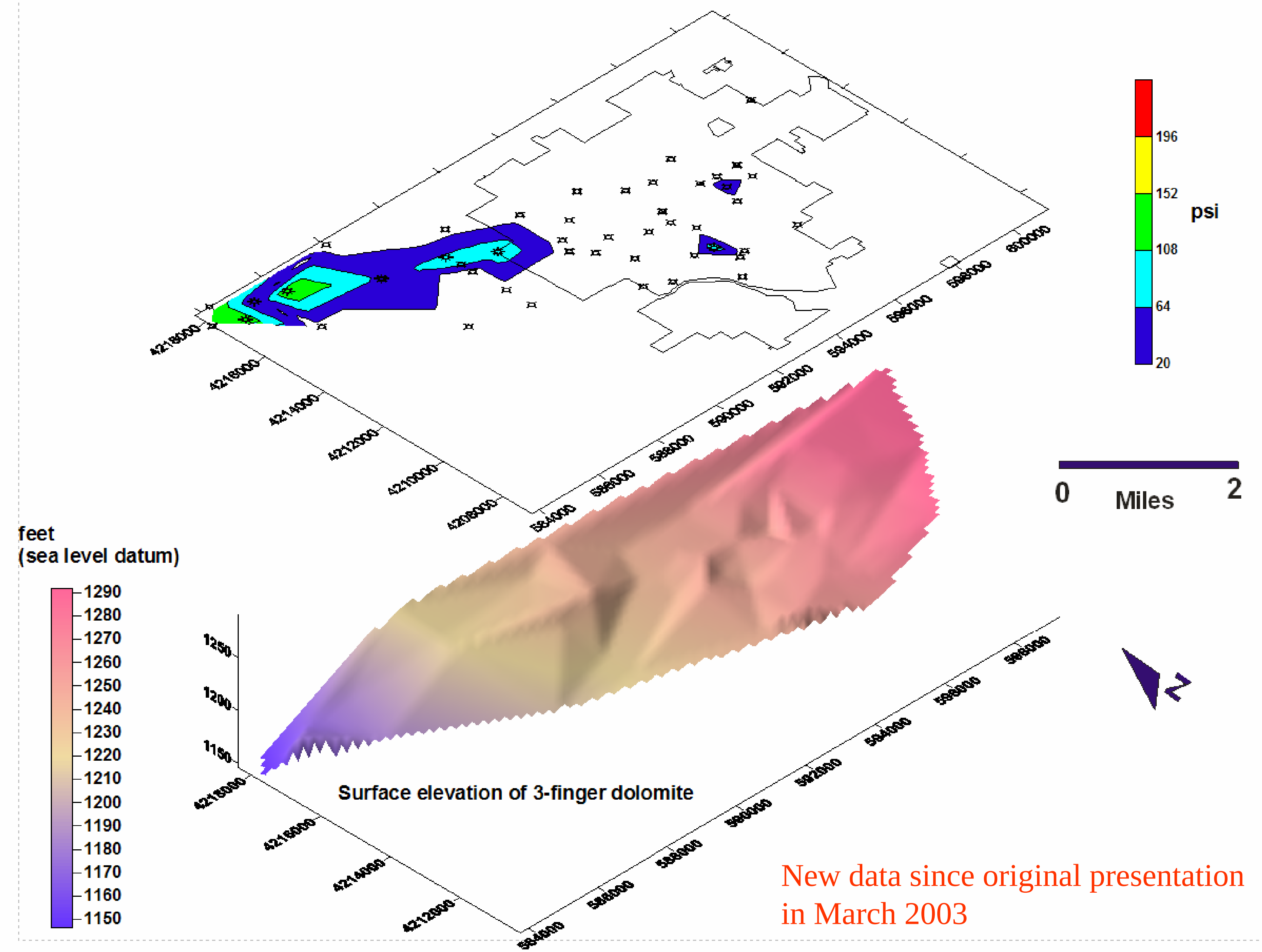
July 2002 Shut-in Pressure at 3-Finger Dolomite (75-95 hrs)





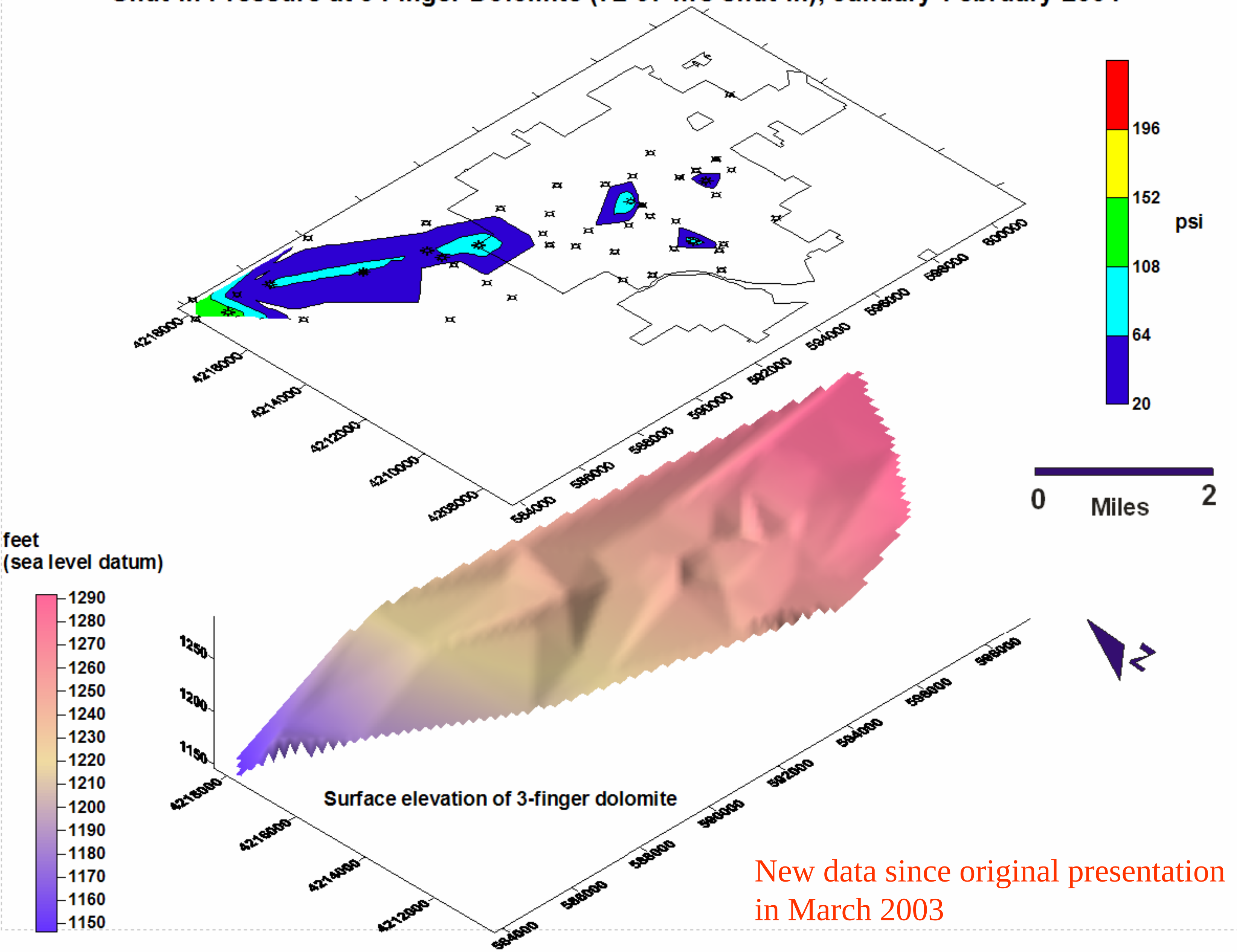
New data since original presentation in March 2003

Shut-in Pressure at 3 Finger Dolomite (72-97 hrs shut-in), July-August 2003



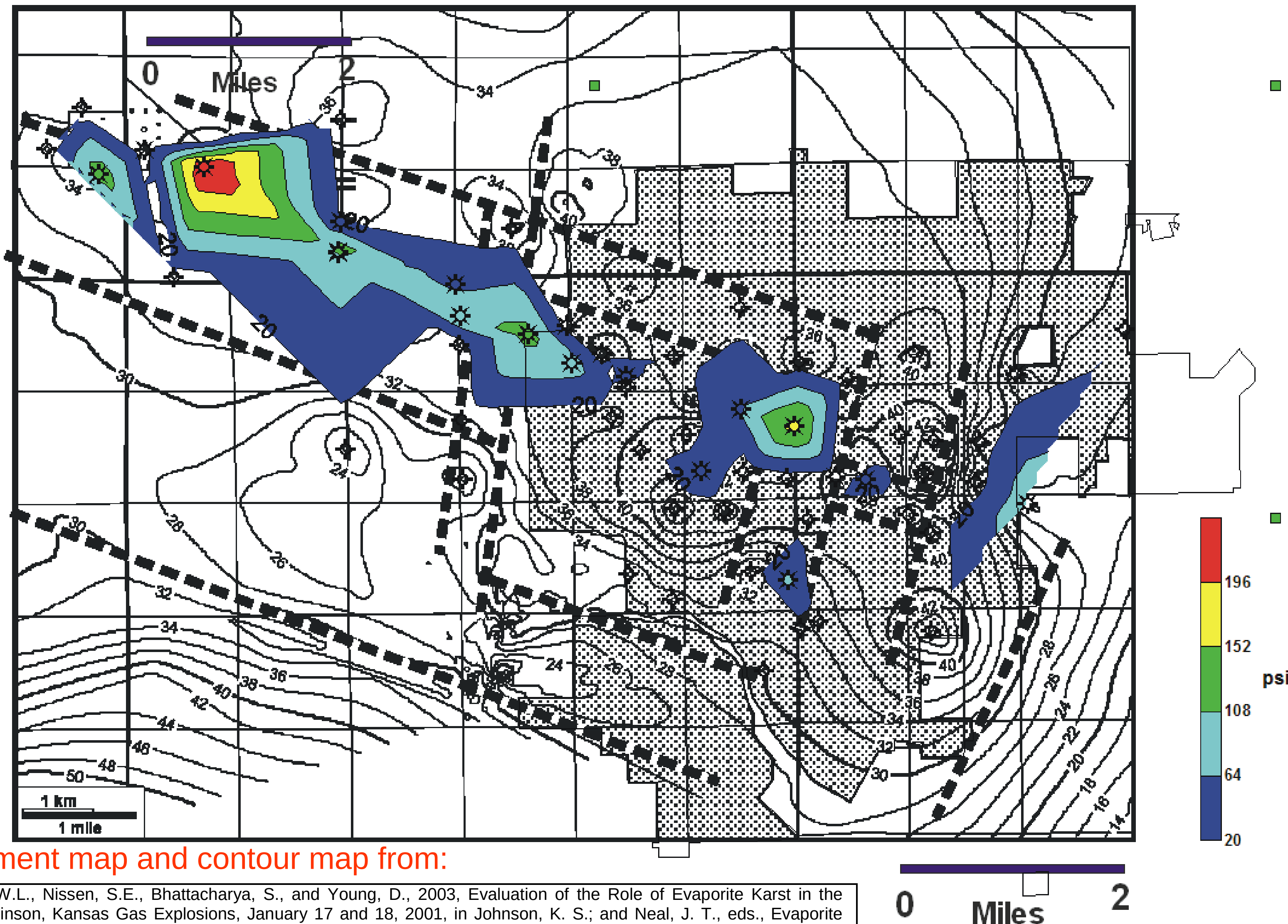
New data since original presentation in March 2003

Shut-in Pressure at 3 Finger Dolomite (72-97 hrs shut-in), January-February 2004



New data since original presentation in March 2003

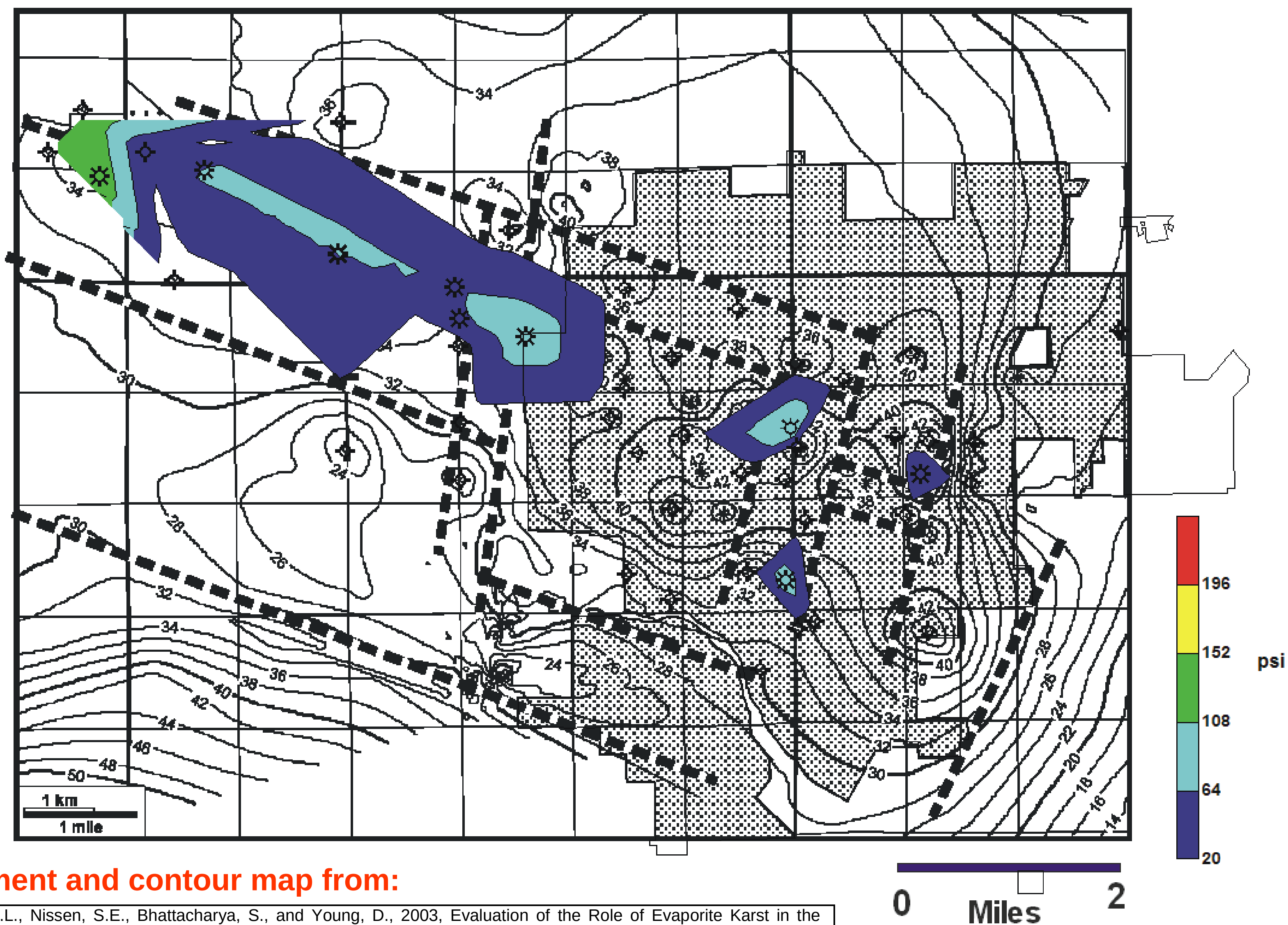
August, 2001 Shut-in pressure at 3-finger dolomite (70-96 hrs), psig
With Isopach of upper layer of Hutchison Salt and composite lineaments (heavy dashed lines)



Lineament map and contour map from:

Watney, W.L., Nissen, S.E., Bhattacharya, S., and Young, D., 2003, Evaluation of the Role of Evaporite Karst in the Hutchinson, Kansas Gas Explosions, January 17 and 18, 2001, in Johnson, K. S.; and Neal, J. T., eds., Evaporite karst and engineering/environmental problems in the United States: Oklahoma Geological Survey Circular 109, p. 119-147.

Shut-in Pressure at 3 Finger Dolomite (72-97 hrs shut-in), January-February 2004
With Isopach of upper layer of Hutchison Salt and composite lineaments (heavy dashed lines)



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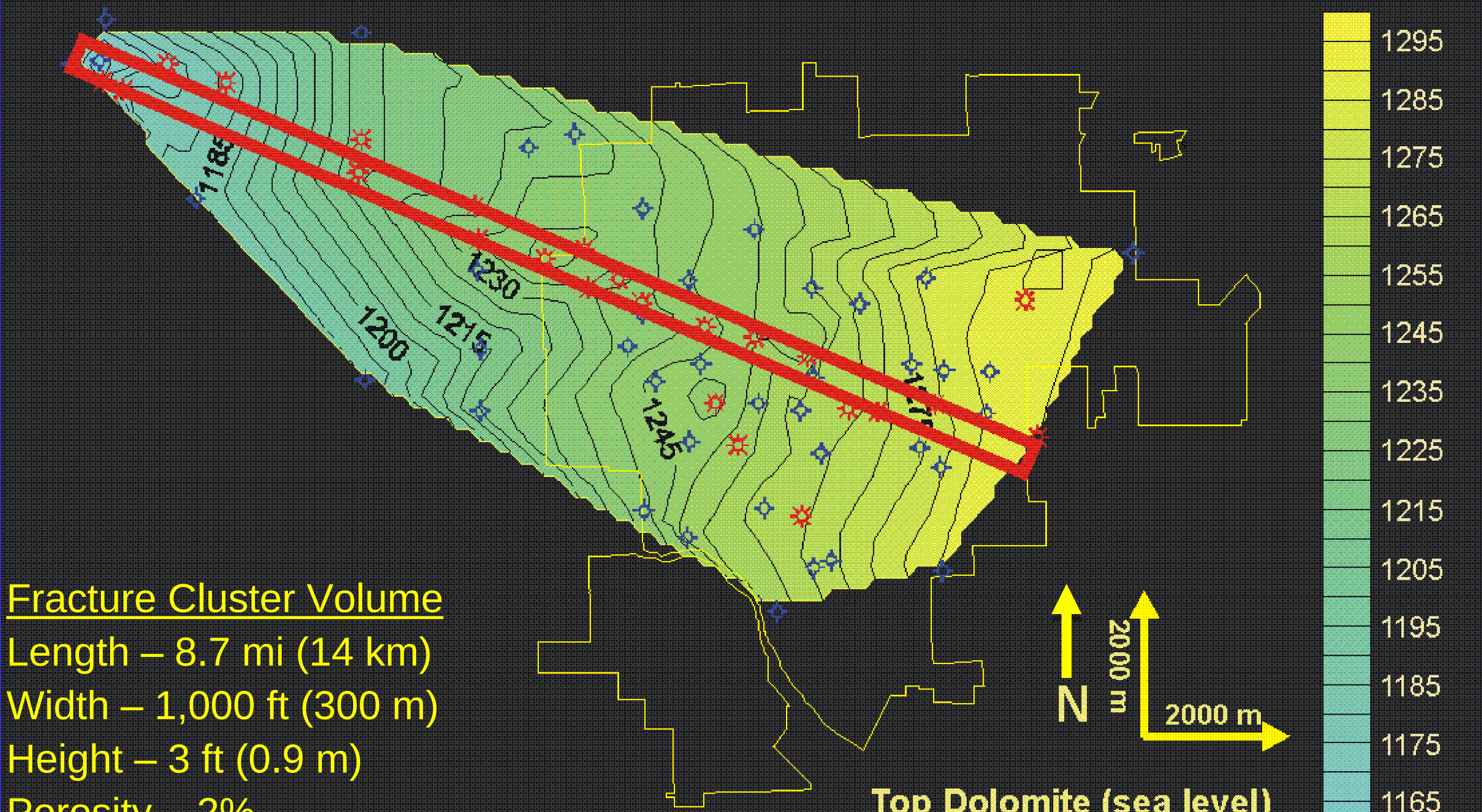
Basic Volumetrics



<u>Fracture Cluster Volume</u>

Length – 8.7 mi (14 km)

Width – 1,000 ft (300 m)

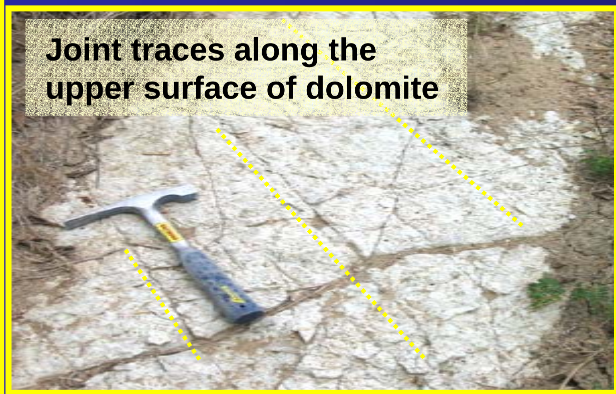
Height – 3 ft (0.9 m)

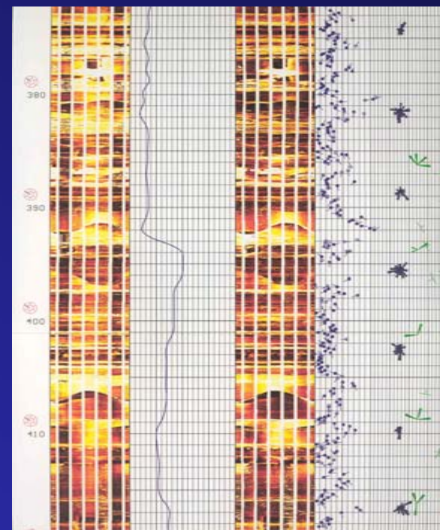
Porosity – 2%

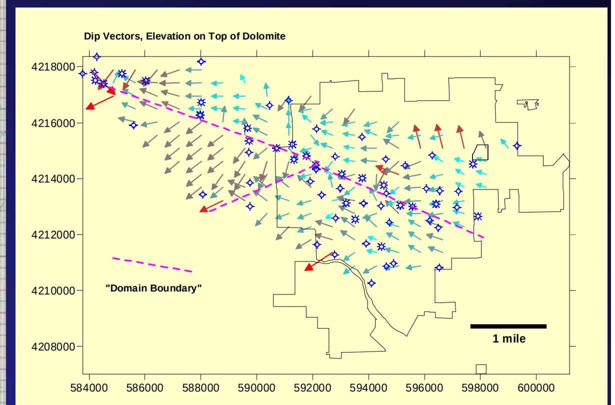
Fracture Volume = 2.8 Mcf (78,000 m^3)

Estimated Volume of Gas Released = 143 Mscf = 3.5 Mcf (at 600 psi, 54 ^oF)

Rough estimate of gas flow (cubic feet per day) associated with various fracture widths at various fracture widths







Well that intercepts fracture system could vent gas over several days.

Back of the envelope Flow Calculation →

Assumptions:

1) Continuous, 3-ft long, homogeneous fracture over entire 46,000 feet (8.7 mi)
2) 600 psi pressure maintained over entire length of fracture to venting location

q=6.323 kA(p1-p2)/uL	(liquid system or gas at mean pressure)				
		Linear	Radial		Fracture
		q (cf/D)	q (cf/D)	k (D)	width (um)
L=46,000 ft		13,425	1.11E+09	1	3.4
A=3,000 ft^2		134,249	1.11E+10	10	10.9
u= 0.018 cp		1,342,492	1.11E+11	100	34.4
k = darcies	★	13,424,920	1.11E+12	1,000	108.9
		134,249,203	1.11E+13	10,000	344.2

An alternative calculation for gas flow using an equation that incorporates gas compressibility resulting in an effective permeability of 3.2 darcies, a value that is easily obtainable in a fracture system. Results are similar to calculations presented in the previous slide that do not use compressibility.

Q = 0.003164*Tsc*Ac*K*(P1^2-P2^2)/(Psc*T*Z*L*mu)

K = Q*Psc*T*Z*L*mu/(.003164*Tsc*Ac*(P1^2-P2^2))

Volume leaked =	143,000,000	scf
Fraction of volume leaked along this system	1	
Time to surface =	90	day

Q =	1,588,889	scf/d	volume of gas/d
Tsc =	520	deg R	surface temperature
Ac =	3000	sq ft	cross section area of conduit
K =		md	average effective permeability of conduit
P1 =	600	psi	Pressure in reservoir (upstream)
P2 =	0	psi	Pressure at downstream end
Psc =	14.7	psi	atmospheric pressure
T =	535	deg R	average temperature of conduit/reservoir
Z =	0.882		gas compressibility factor
L =	45926	ft	length of conduit
mu =	0.01133	cp	gas viscosity

K =	**3227**	**md**
	3.2	**darcy**

ASSUMPTIONS:

Surface temp	60	F
Conduit temp	75	F
Ac assumption - Fracture dimension		
Effective width of conduit	1000	ft
Effective height of conduit	3	ft
Ac	3000	sq ft
P2 Calculation		
Height of water column in well blown in town		
Hydrostatic head =		
T assumption		
Height of leak =	500	
Temparature gradient		
Temperature of conduit =	75	
Z assumption		
Gas specific gravity	0.66	
Pseudocritical temperature	370	
Reservoir temp	75	
Pseudoreduced temp	1.4	
Pseudocritical pressure	670	
Reservoir pressure	600	
Pseudoreduced pressure	0.90	
Z	0.882	
L assumption		
Length of conduit	8.7	
Tortuosity	1	
L	45926.18	
Gas viscosity		
Gas gravity	0.66	
Atm temp	60	
Mu @ 1 atm	0.0103	
Mu ratio	1.1	
Mu @ res condts	0.01133	

Equation here as utilized in the published paper:

Watney, W.L., Nissen, S.E., Bhattacharya, S., and Young, D., 2003, Evaluation of the Role of Evaporite Karst in the Hutchinson, Kansas Gas Explosions, January 17 and 18, 2001, in Johnson, K. S.; and Neal, J. T., eds., Evaporite karst and engineering/environmental problems in the United States: Oklahoma Geological Survey Circular 109, p. 119-147.

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- Gas encountered in vent wells at depths ranging from 420 ft (Yaggy) to 240 ft below surface (eastern Hutch)
- Gas zone confined to 15-ft thick interval
  - three thin (2-3 ft) beds of dolomicrite
- Gas zone is located at the top of Upper Wellington Shale
- Vent wells closely follow crest of narrow, low-relief, asymmetric, northwesterly-plunging anticline
- Fractures/joints trending along crest of structure appear to be responsible for gas migration

Persistent Lineament in during deposition of Hutchinson Salt corresponding to Precambrian terrane boundary