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Oklahoma Geological Survey
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OKLAHOMA 3-D SEISMIC APPLICATIONS

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***Compiled by* Sue Britton Crites**

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The Oklahoma Geological Survey is chartered in the state's constitution and charged with investigating the land, water, mineral, and energy resources of the state, and disseminating the results of those investigations to promote the wise use of Oklahoma's natural resources consistent with sound environmental practices.

CONTENTS

PART I – INTRODUCTION TO 3–D SEISMIC TECHNIQUES

PART II – APPLICATIONS OF 3–D SEISMIC

Play 8 – Skinner Sand Play, Northwest Sooner Valley Field

Play 9 – Hartshorne Sand Channel Play, South Pine Hollow Field

Play 10 – Paleozoic Structural Play, Fitts Field

Play 11 – Spiro Sand and Arbuckle Dolomite Structural Play, Wilburton Field

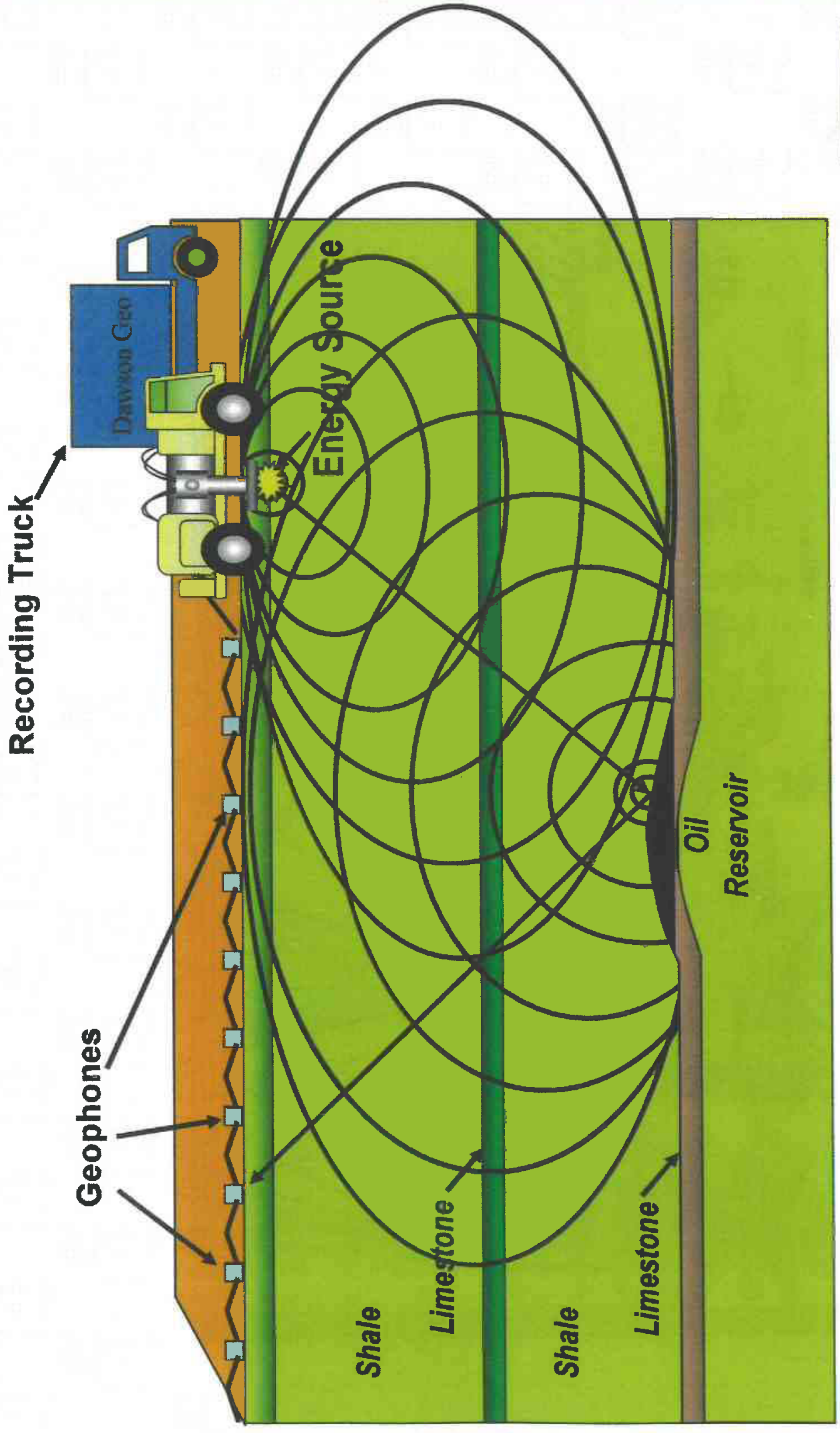
Play 12 – Ouachita Overthrust Play, Buffalo Mountain Field

Play 13 – Paleozoic Structural Play-Simpson Sand, West Whitebead Field

Play 14 – Paleozoic Structural Play, Cumberland Field

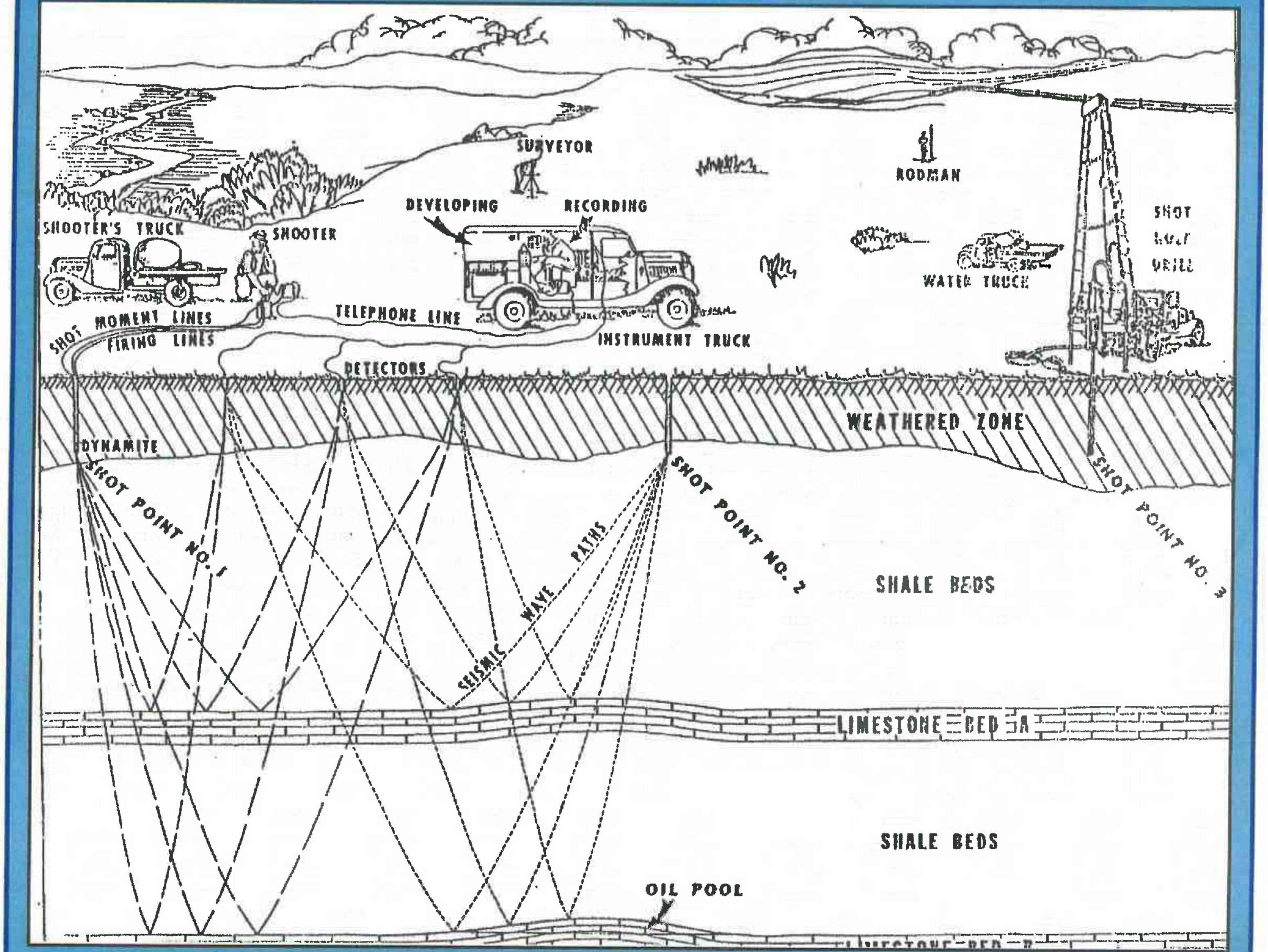
From Singlefold to 3D

Robert J. Springman



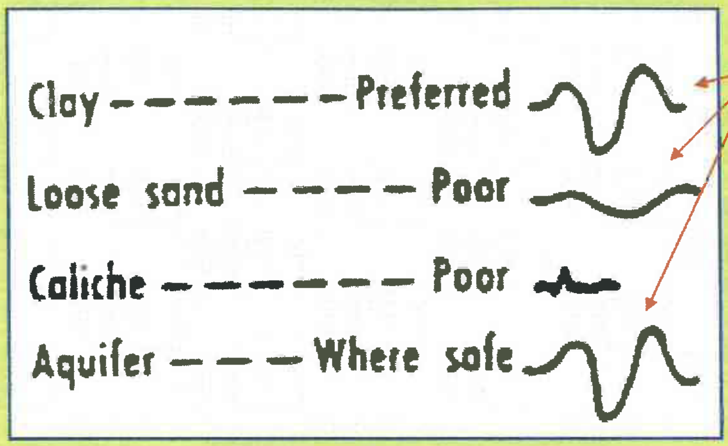
To understand what a seismic survey is and why we use them, we must first understand some of the basic principles of geophysics. Sound waves are generated on the ground and spread in the subsurface to reflect off of changing rock types. These reflected waves then travel back to the surface to be recorded by geophones placed in the ground.

1950's Seismic Recording Crew



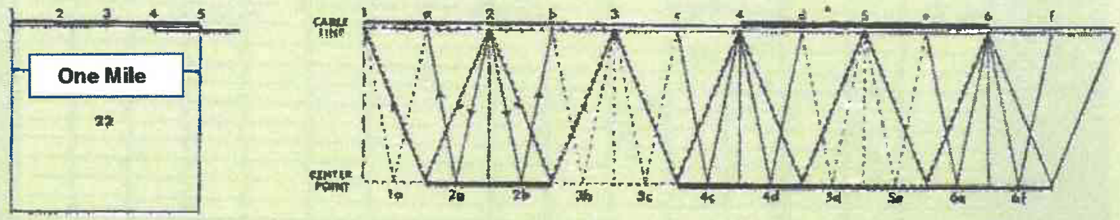
From Sheriff, Roberson, Hunt and Springman, 1983

Dynamite Charge Placement



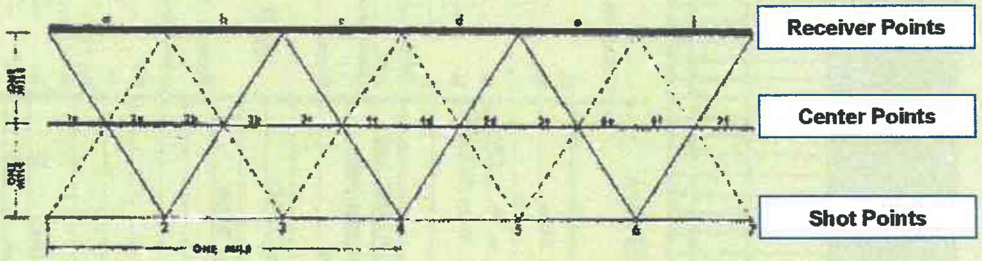
Input Wavelets

From Sheriff, Roberson, Hunt and Springman, 1983

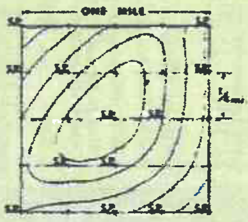


1935

CONTINUOUS CENTER POINT PROFILE METHOD



BROADSIDE SHOOTING PLAN VIEW



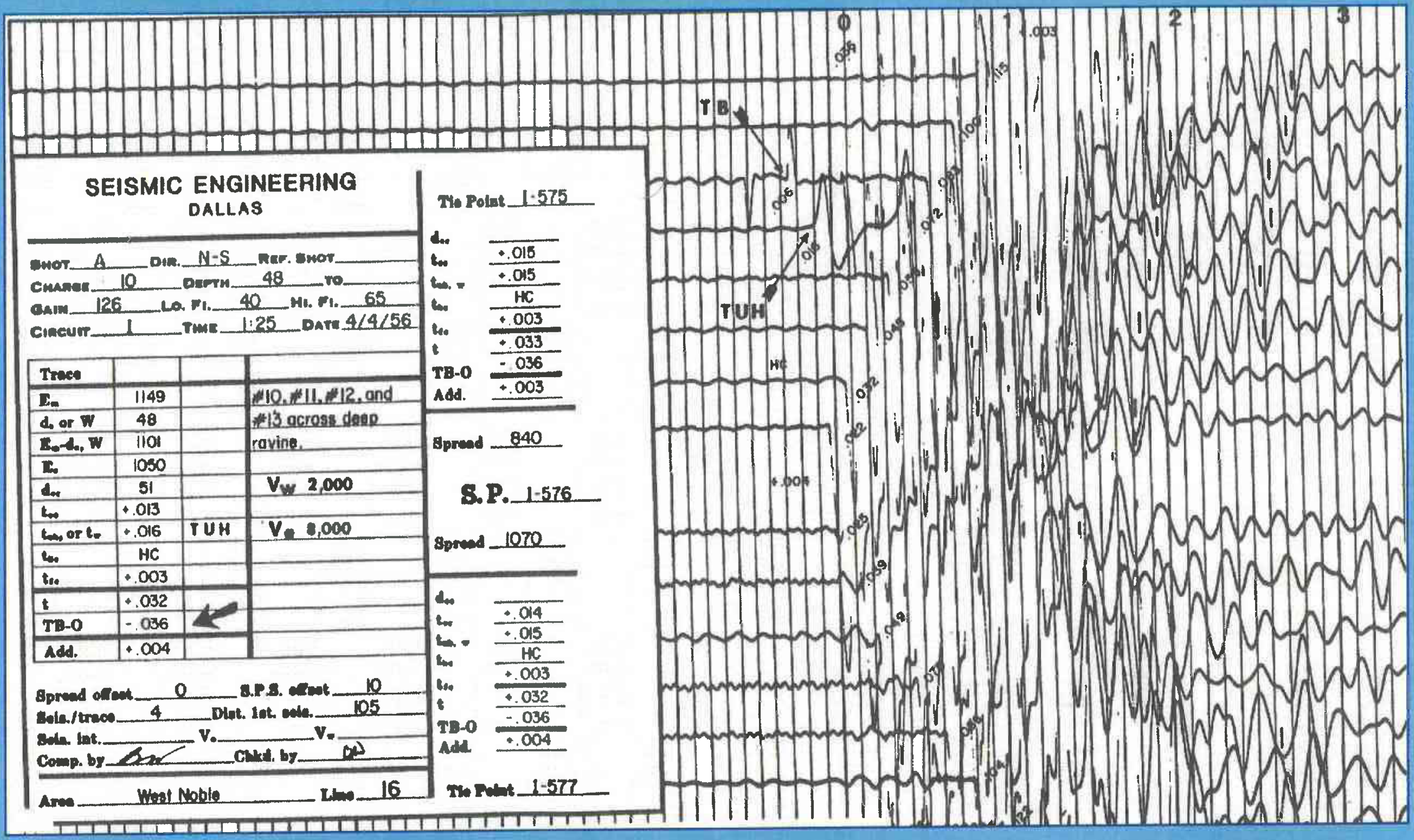
CONCENTRATED SHOOTING

For small anomalies. Orient cables any direction for equal surface elevation.

1950's 3D Solution

From Sheriff, Roberson, Hunt and Springman, 1983

Single fold Record 16 Trace Split spread



SEISMIC ENGINEERING
DALLAS

SHOT A DIR. N-S REF. SHOT
CHARGE 10 DEPTH 48 TO
GAIN 126 LO. FI. 40 HI. FI. 65
CIRCUIT 1 TIME 1:25 DATE 4/4/56

Trace			
E_m	1149		#10, #11, #12, and
d_s or W	48		#13 across deep
E_s-d_s, W	1101		ravine.
E_r	1050		
d_{ss}	51		V_W 2,000
t	+.013		
t, or t	+.016	TUH	V_B 8,000
t	HC		
t	+.003		
t	+.032		
TB-0	-.036		
Add.	+.004		

Spread offset 0 S.P.S. offset 10
Seis./trace 4 Dist. 1st. seis. 105
Seis. int. V. V.
Comp. by Bn Chkd. by
Area West Noble Line 16

Tie Point 1-575

d	
t	+.015
t	+.015
t	HC
t	+.003
t	+.033
TB-0	-.036
Add.	+.003

Spread 840

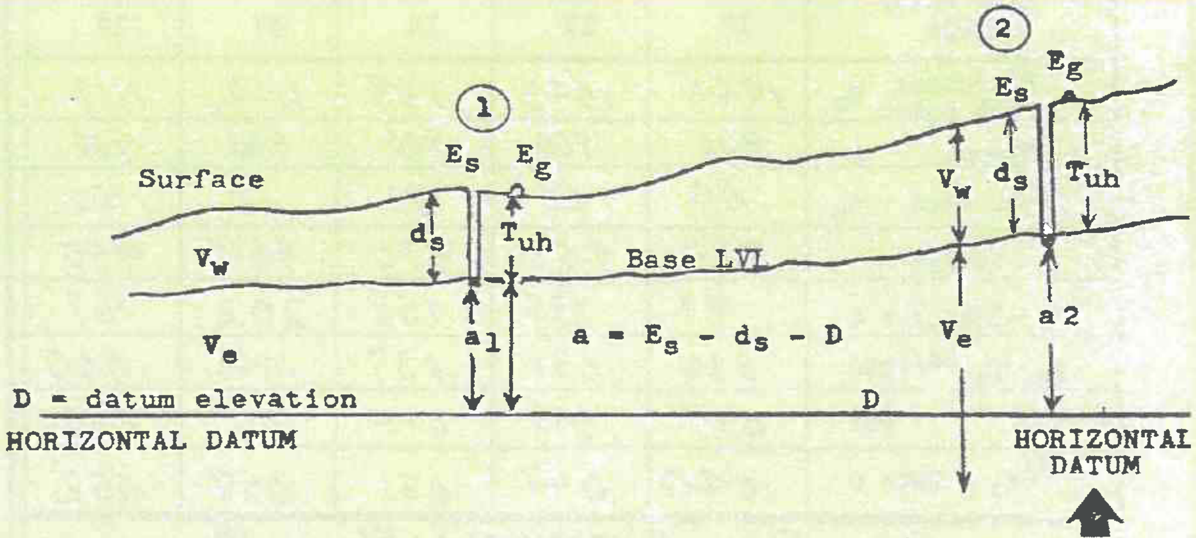
S. P. 1-576

Spread 1070

d	
t	+.014
t	+.015
t	HC
t	+.003
t	+.032
TB-0	-.036
Add.	+.004

Tie Point 1-577

From Sheriff, Roberson, Hunt and Springman, 1983



$$\text{Time from shot to Datum} = \frac{E_s - d_s - D}{V_e} = \frac{a}{V_e}$$

$$\text{Time from near phone to Datum } (E_s = E_g) = \frac{a}{V_e} + T_{uh}$$

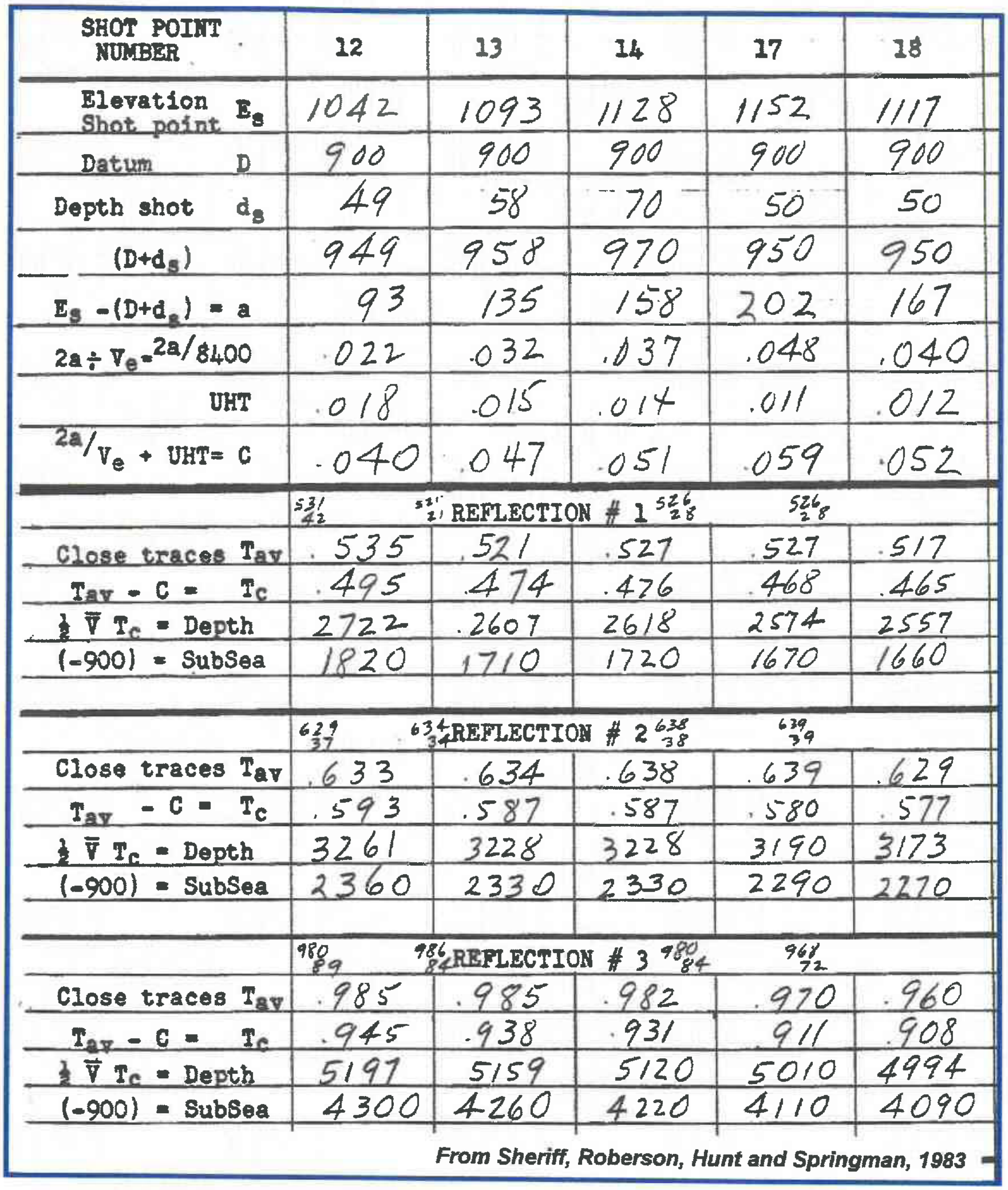
$$\text{Total time consumed above Datum} = \text{"C"} = \frac{2a}{V_e} + T_{uh}$$

$$C = \left[\frac{2(E_s - d_s - D)}{V_e}\right] + T_{uh}$$

$$T_c = T_{obs} - C$$

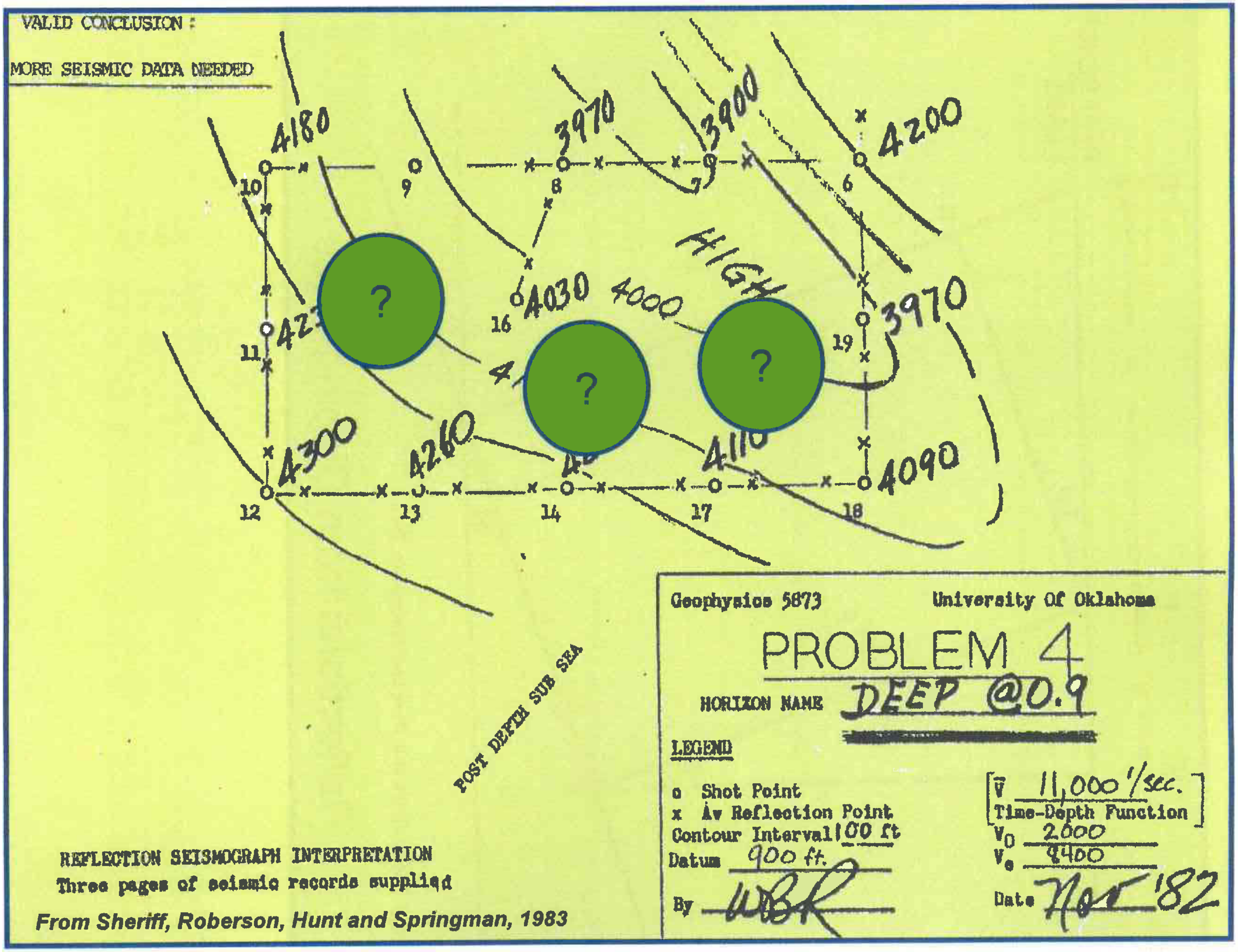
$$\text{DEPTH} = \tfrac{1}{2}\, V\, T_c$$

From Sheriff, Roberson, Hunt and Springman, 1983



SHOT POINT NUMBER	12	13	14	17	18
Elevation Shot point E_s	1042	1093	1128	1152	1117
Datum D	900	900	900	900	900
Depth shot d_s	49	58	70	50	50
$(D+d_s)$	949	958	970	950	950
$E_s - (D+d_s) = a$	93	135	158	202	167
$2a \div V_e = 2a/8400$	.022	.032	.037	.048	.040
UHT	.018	.015	.014	.011	.012
$2a/V_e + \text{UHT} = C$	.040	.047	.051	.059	.052
	531 42	521 21 REFLECTION # 1	526 28	526 28	
Close traces T_{av}	.535	.521	.527	.527	.517
$T_{av} - C = T_c$	.495	.474	.476	.468	.465
$\frac{1}{2}\bar{V}T_c$ = Depth	2722	.2607	2618	2574	2557
(-900) = SubSea	1820	1710	1720	1670	1660
	629 37	634 34 REFLECTION # 2	638 38	639 39	
Close traces T_{av}	.633	.634	.638	.639	.629
$T_{av} - C = T_c$	.593	.587	.587	.580	.577
$\frac{1}{2}\bar{V}T_c$ = Depth	3261	3228	3228	3190	3173
(-900) = SubSea	2360	2330	2330	2290	2270
	980 89	986 84 REFLECTION # 3	980 84	968 72	
Close traces T_{av}	.985	.985	.982	.970	.960
$T_{av} - C = T_c$	.945	.938	.931	.911	.908
$\frac{1}{2}\bar{V}T_c$ = Depth	5197	5159	5120	5010	4994
(-900) = SubSea	4300	4260	4220	4110	4090

From Sheriff, Roberson, Hunt and Springman, 1983



Geophysics 5873 University Of Oklahoma

PROBLEM 4

HORIZON NAME DEEP @0.9

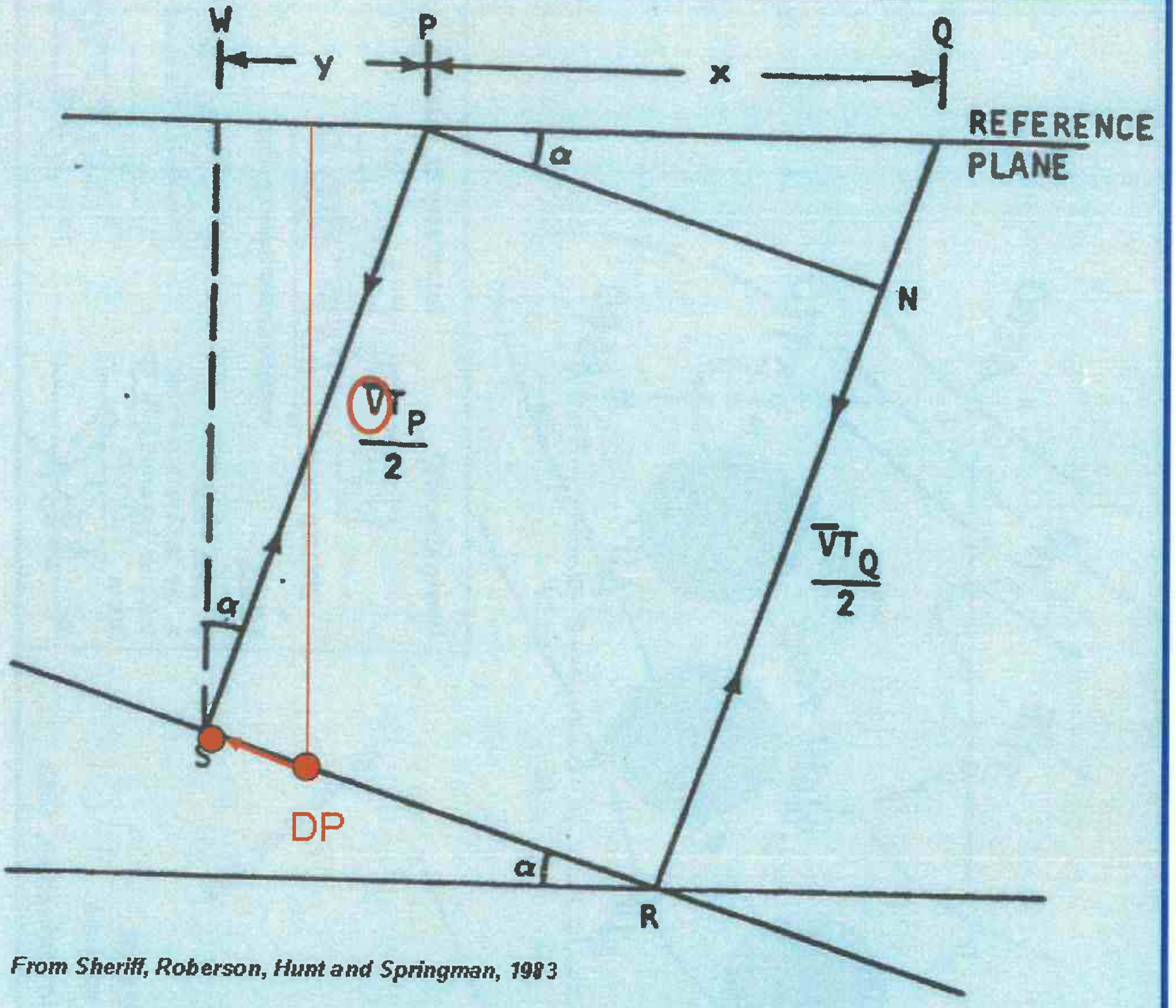
LEGEND

o Shot Point
x Av Reflection Point
Contour Interval 100 ft
Datum 900 ft.
By WBR

[$\bar{V}$ 11,000 '/sec.
Time-Depth Function]
V_0 2000
V_e 9400
Date Nov '82

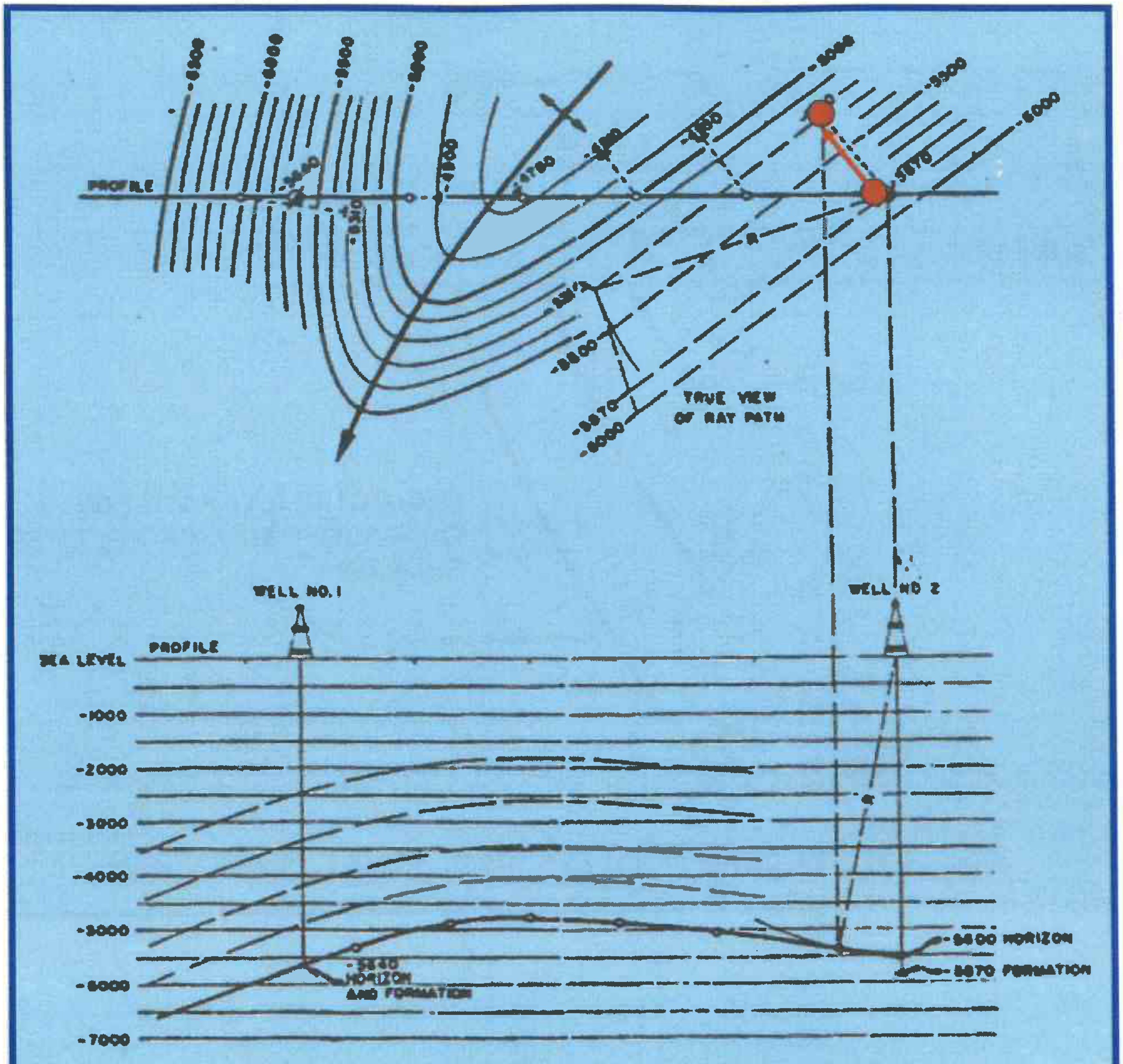
REFLECTION SEISMOGRAPH INTERPRETATION
Three pages of seismic records supplied

From Sheriff, Roberson, Hunt and Springman, 1983

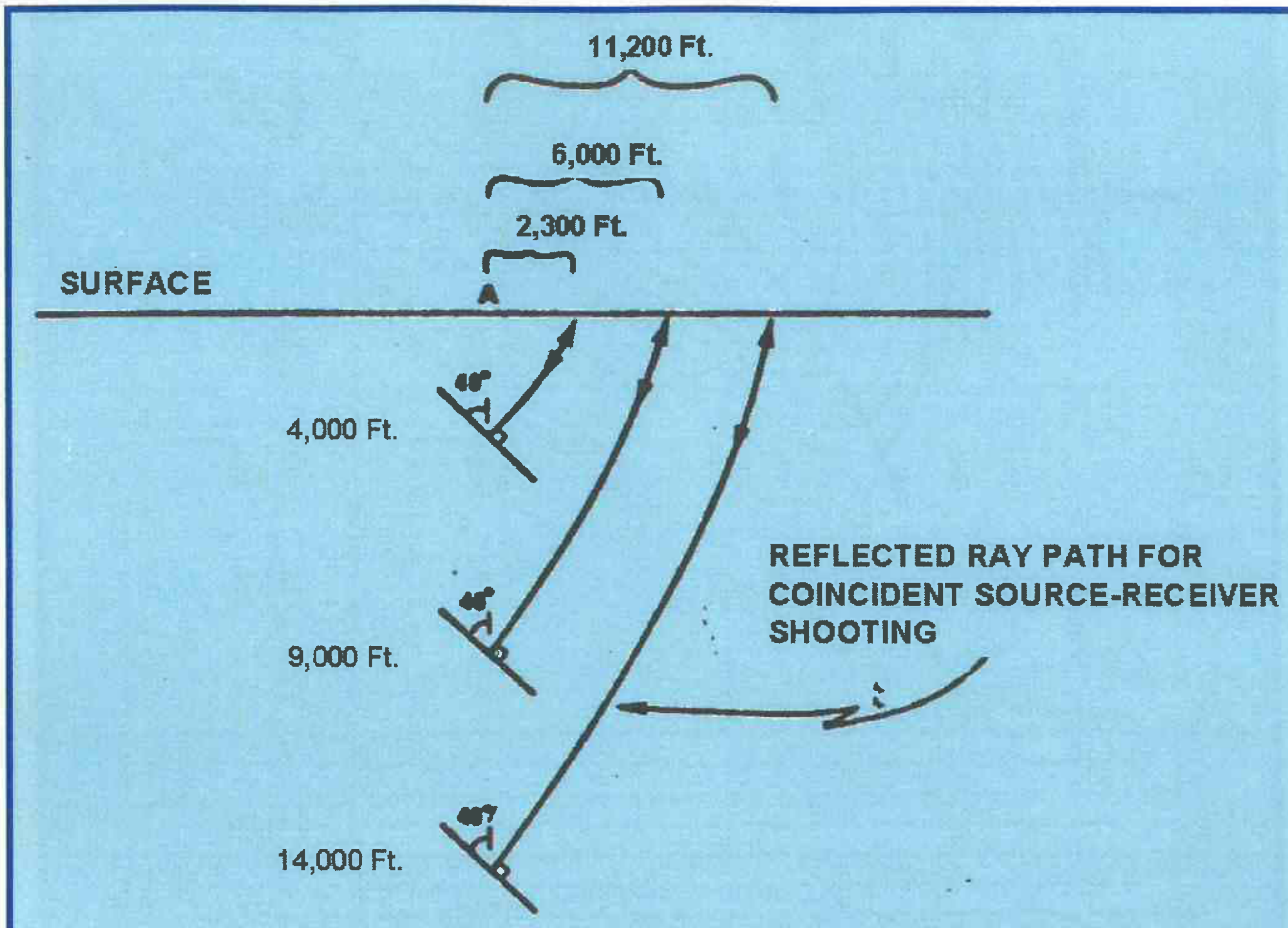


From Sheriff, Roberson, Hunt and Springman, 1983

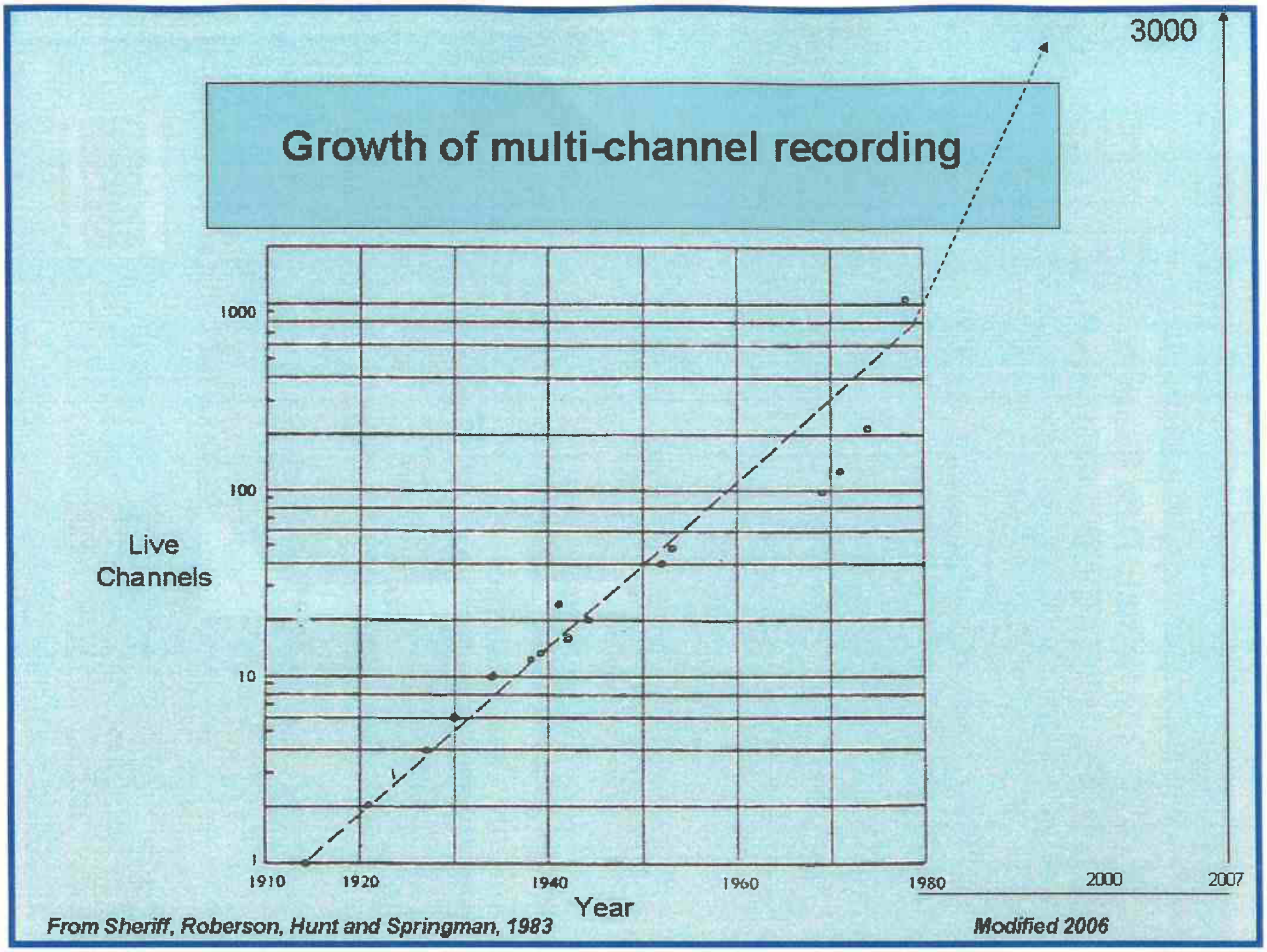
Reflections from Dipping Beds



Migrating Strike Reflectors from John Gates



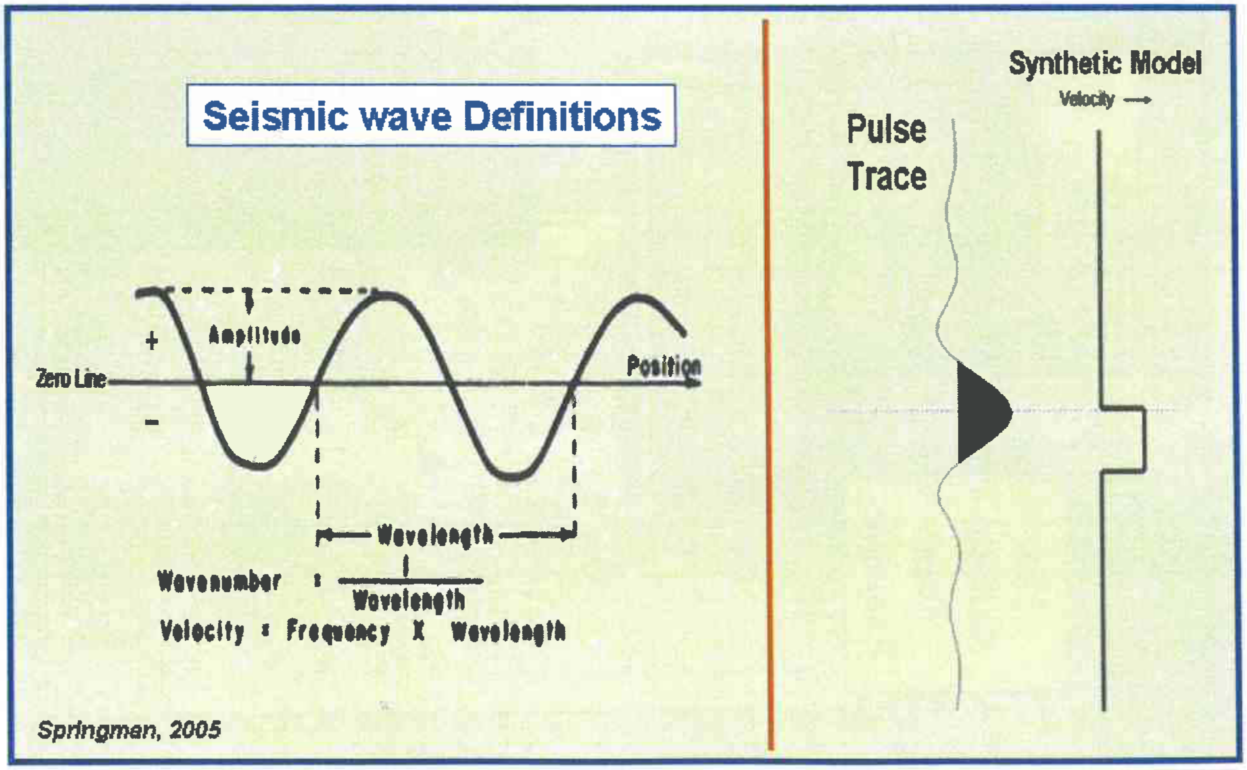
Migration Window from Ray Path Model After French



Growth of multi-channel recording

From Sheriff, Roberson, Hunt and Springman, 1983

Modified 2006

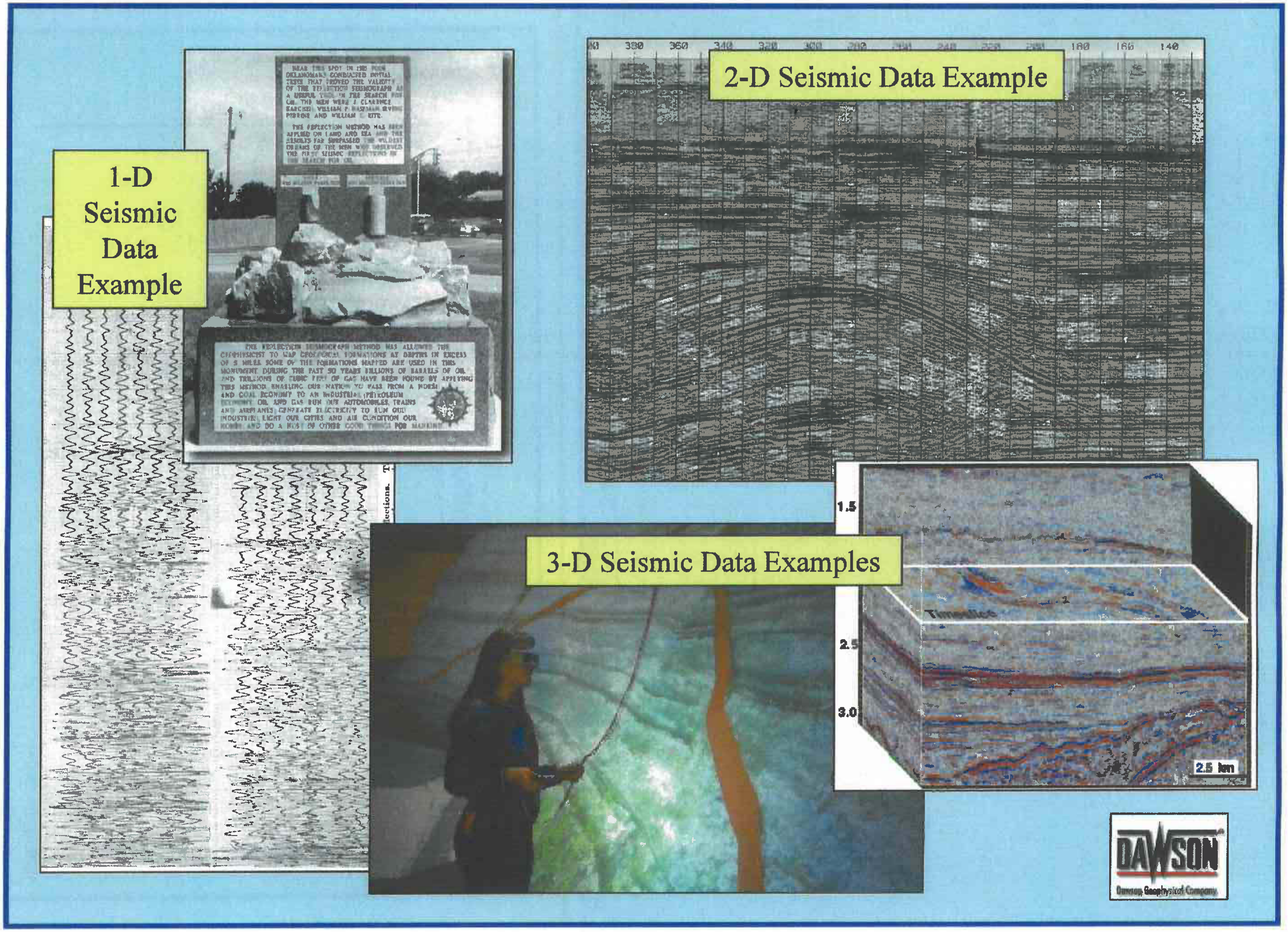


Seismic wave Definitions

$$\text{Wavenumber} = \frac{1}{\text{Wavelength}}$$

Velocity = Frequency X Wavelength

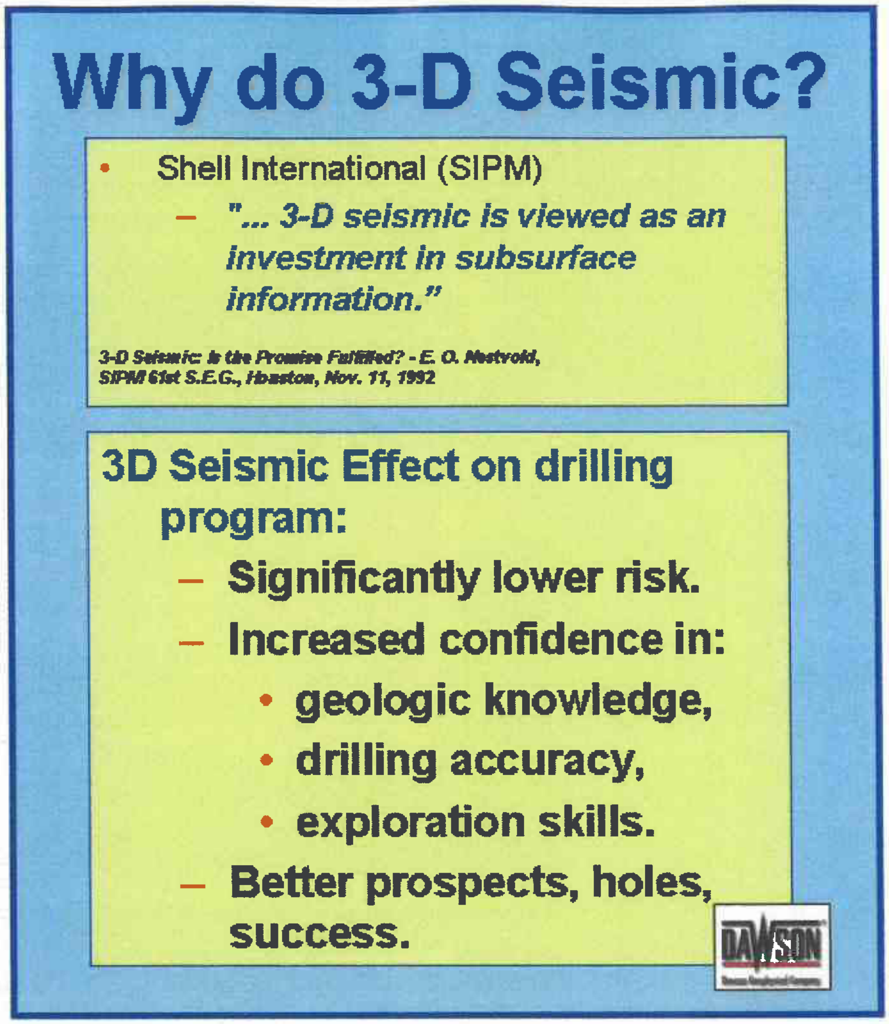
Springman, 2005



1-D Seismic Data Example

2-D Seismic Data Example

3-D Seismic Data Examples



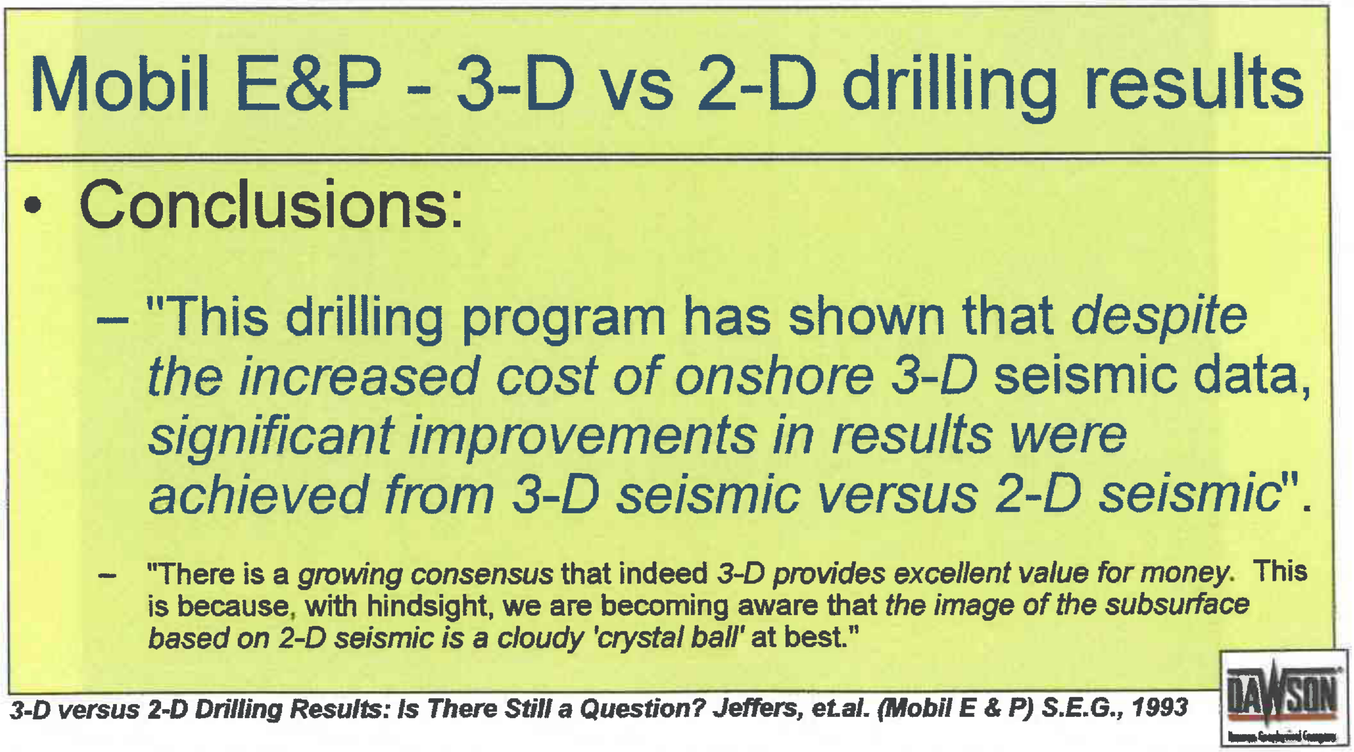
Why do 3-D Seismic?

- Shell International (SIPM)
  - *"... 3-D seismic is viewed as an investment in subsurface information."*

3-D Seismic: Is the Promise Fulfilled? - E. O. Nestvold, SIPM 61st S.E.G., Houston, Nov. 11, 1992

3D Seismic Effect on drilling program:

- **Significantly lower risk.**
- **Increased confidence in:**
  - **geologic knowledge,**
  - **drilling accuracy,**
  - **exploration skills.**
- **Better prospects, holes, success.**



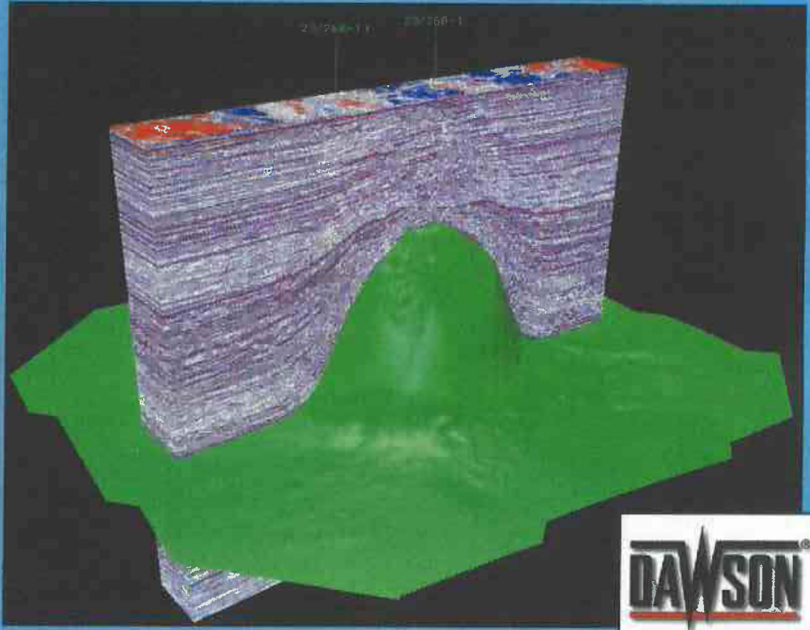
Mobil E&P - 3-D vs 2-D drilling results

- Conclusions:
  - "This drilling program has shown that *despite the increased cost of onshore 3-D* seismic data, *significant improvements in results were achieved from 3-D seismic versus 2-D seismic*".
  - "There is a *growing consensus* that indeed *3-D provides excellent value for money*. This is because, with hindsight, we are becoming aware that *the image of the subsurface based on 2-D seismic is a cloudy 'crystal ball'* at best."

3-D versus 2-D Drilling Results: Is There Still a Question? Jeffers, et.al. (Mobil E & P) S.E.G., 1993

SOUND/ACOUSTICS

With technology today, would you have surgery without a sonogram ? The 3D seismic data uses the same laws of physics.



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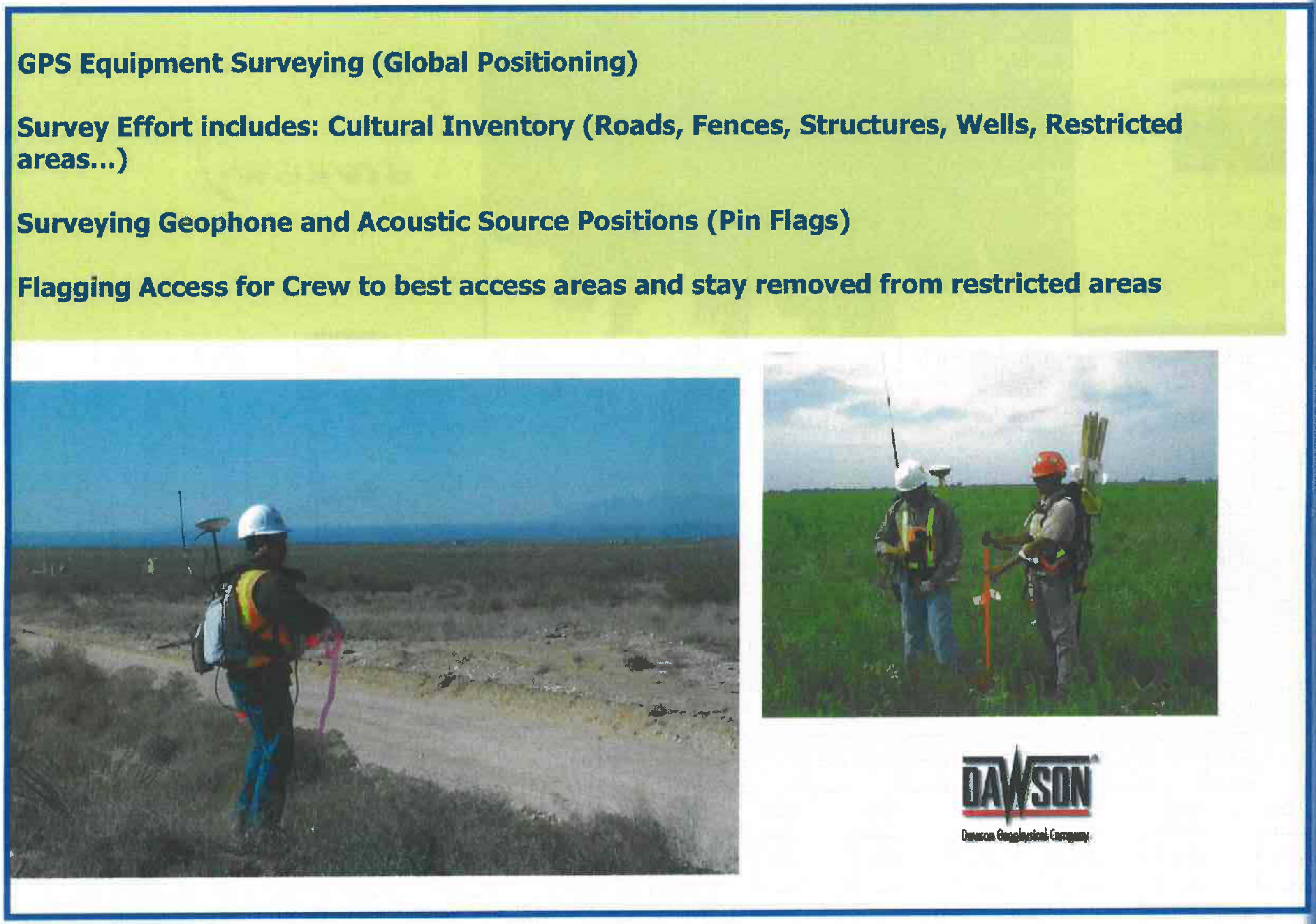
NOTES

Seismic Acquisition and Obsticles to Overcome with Design Options

Kevin Werth



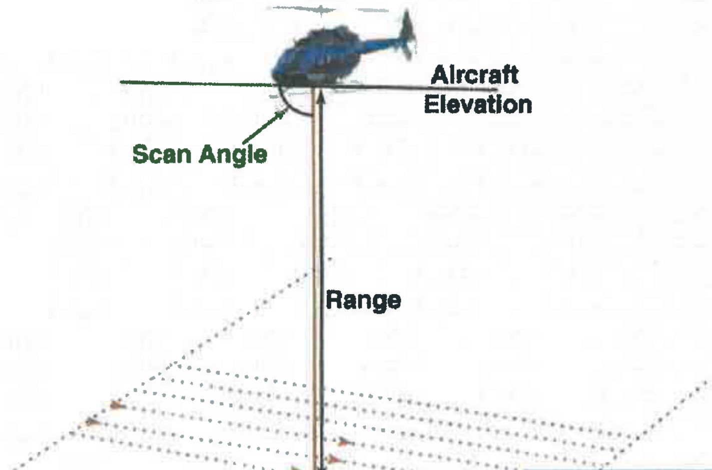
GPS Equipment Surveying (Global Positioning)

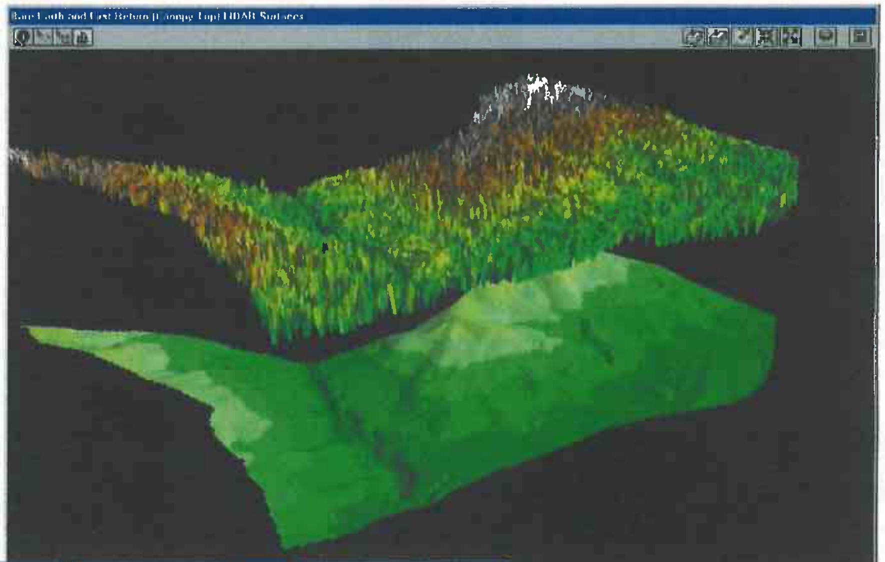
Survey Effort includes: Cultural Inventory (Roads, Fences, Structures, Wells, Restricted areas...)

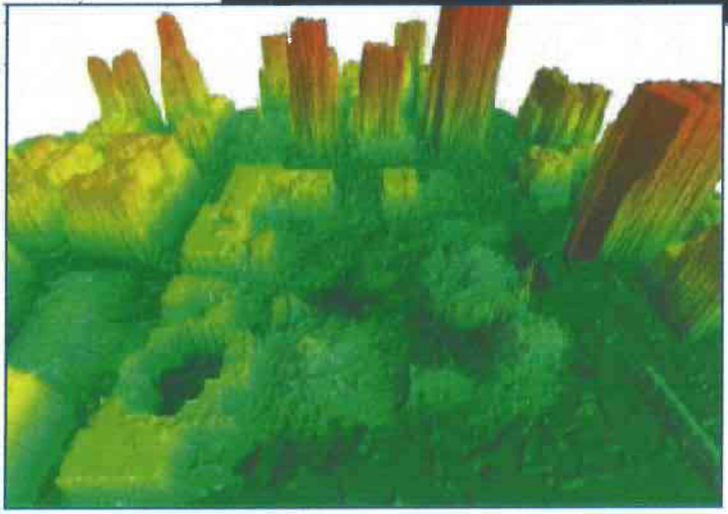
Surveying Geophone and Acoustic Source Positions (Pin Flags)

Flagging Access for Crew to best access areas and stay removed from restricted areas

Light Detection and Reflection. A laser pulse is emitted from the source. Energy is returned back from surface & time interval is recorded. Laser range is computed by multiplying the time interval by speed of light.







MOSAIC MAPPING SYSTEMS INC

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SEISMIC ACOUSTIC SOURCES

1. Explosives
2. Vibroseis Trucks
3. Air Gun (marine or lake acquisition)

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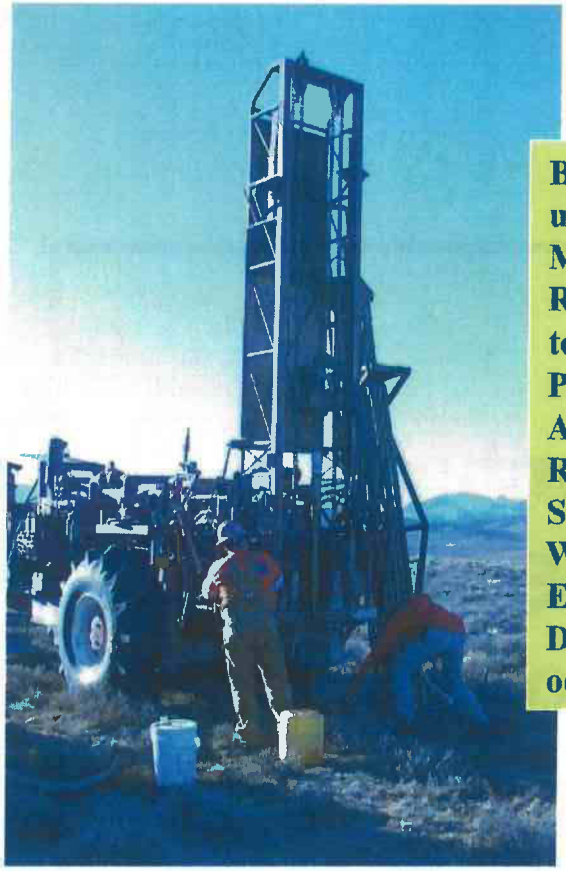
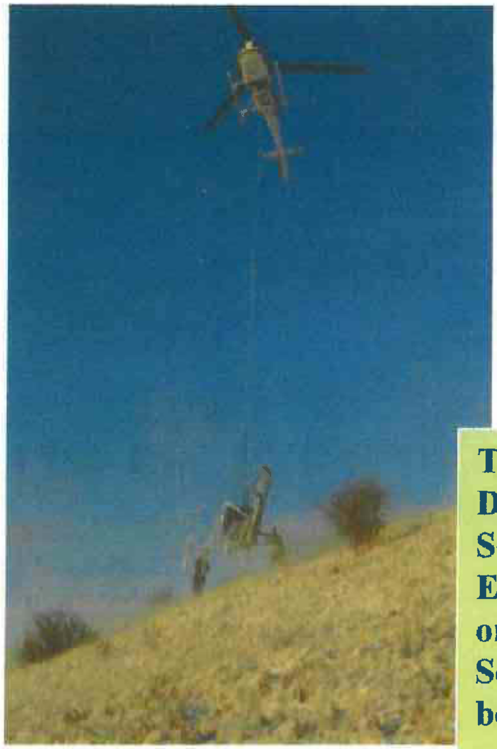


Buggy Drills are used to Maneuver the Rugged Terrain to Drill Source Points Where Access is not Restricted by Stipulations or When Minimal Environmental Damage will occur.



This Heli-Portable Drill Unit allow Source Points in Extremely Rugged or Environmentally Sensitive Areas to be Drilled for the operation

Examples of a Dynamite Acoustic Sleeve, Hole Anchor, Hole Plug and Cap Leads.

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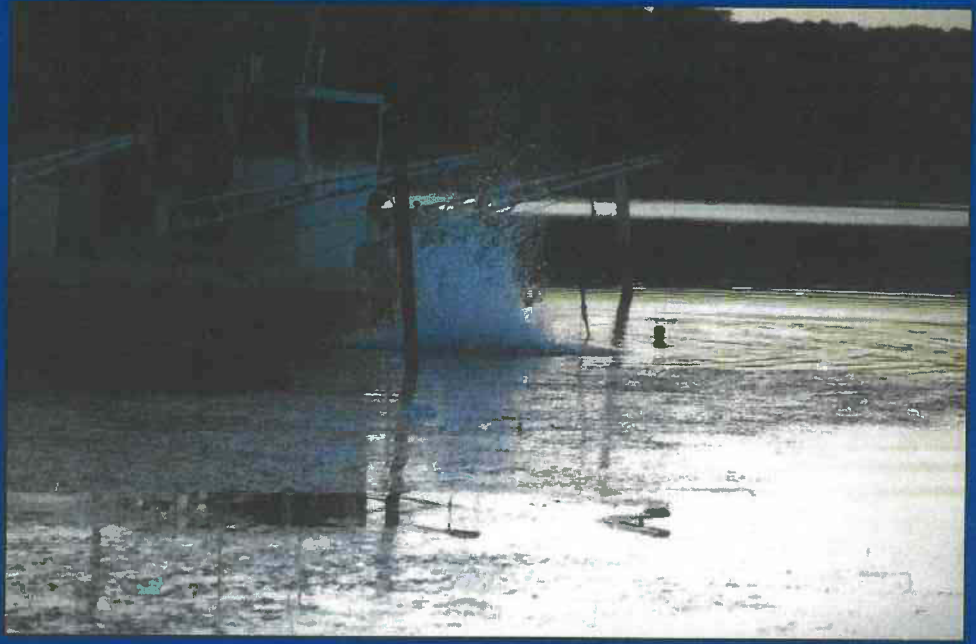
This is an Articulated Mertz 26 with "Terra Tires" Vibroseis Buggy. These units weigh 62,000 pounds. All of the diesel engines in the rear of the Buggy operate the small pad in below and center of the machine to place sound waves at various frequency into the ground. The terra tires will displace the weight of the vehicle to 18 pounds per square inch.

The Air Gun Source is used on Oklahoma Lakes to generate the Acoustic sounds in water. The boat is equipped with canisters of air that "pop" the water. The oxygenated water will not harm fish.



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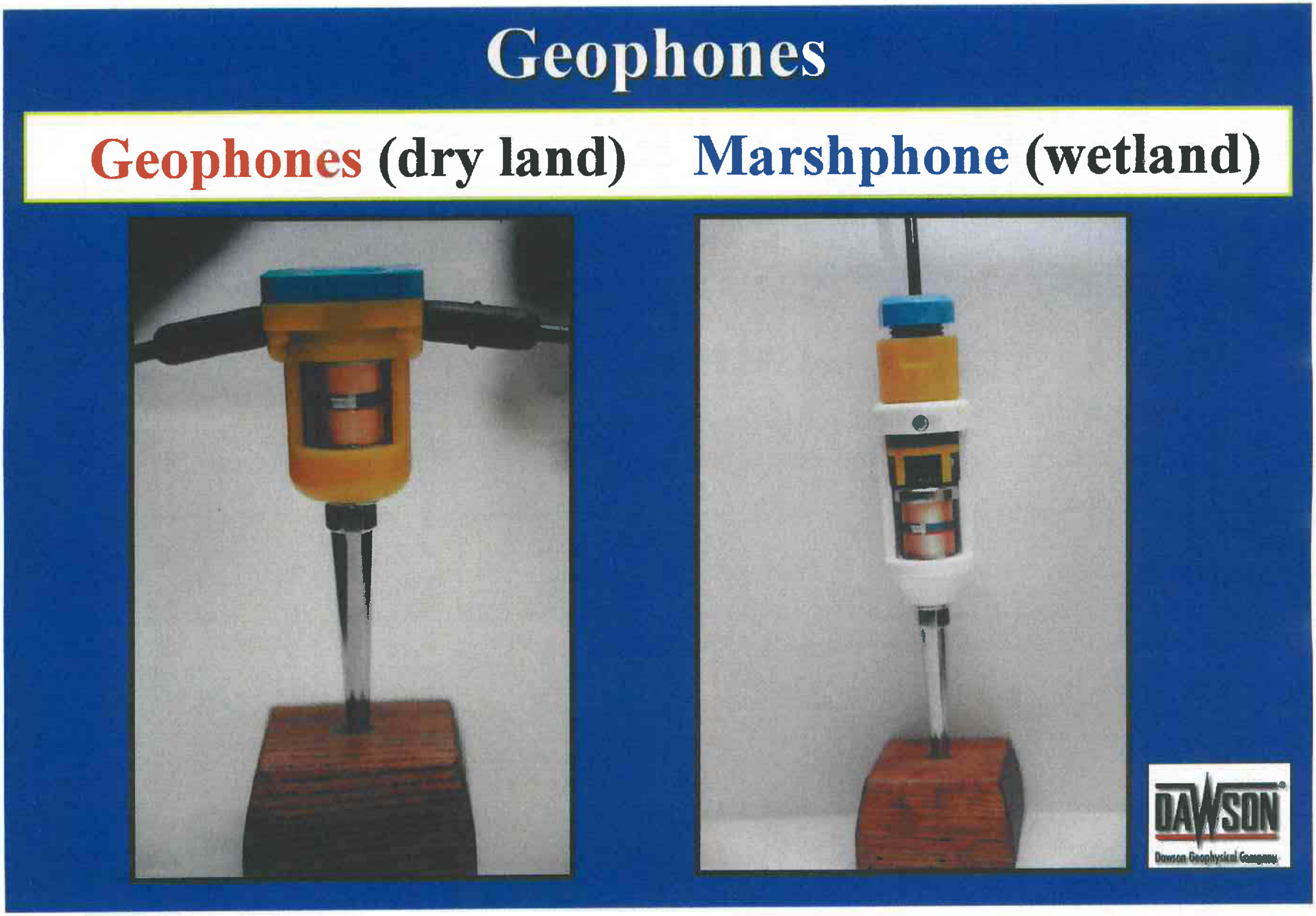
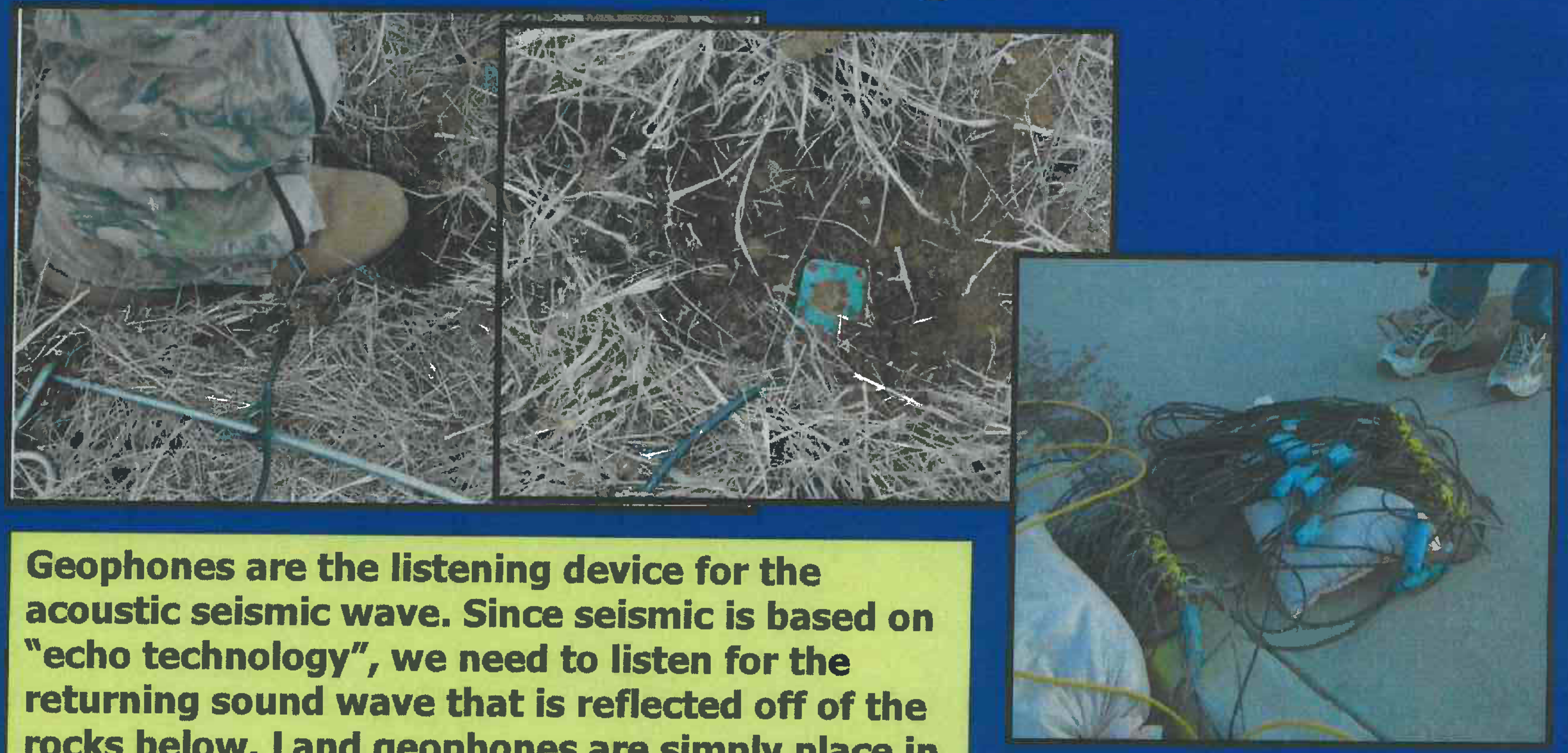


Geophones

Geophones (dry land) **Marshphone (wetland)**

Planting Geophones



Geophones are the listening device for the acoustic seismic wave. Since seismic is based on "echo technology", we need to listen for the returning sound wave that is reflected off of the rocks below. Land geophones are simply place in the ground and stepped on so that the spike sets the geophone in the dirt.

In Urban settings, the geophone is placed in sand bags on the street or sidewalk.

Moving all of this equipment may be done by Trucks, 4 wheeled "mules" or simply walking the equipment in if needed.

The amount of equipment for a modern seismic crew can be staggering. Most equipment is moved from project site to project site by Semi Trucks. Today's crews have the need for 30,000 geophones, equal amount of cable, 8-10 Vibroseis vehicles and 60-100 people to operate the project.

The Recorder is "The Heart Of The Operation". Inside this vehicle, electronic, computer and diagnostic equipment QC recording equipment in the field, start the acoustic sources and record seismic data from the thousands of geophones and cables placed on the ground over many square miles.

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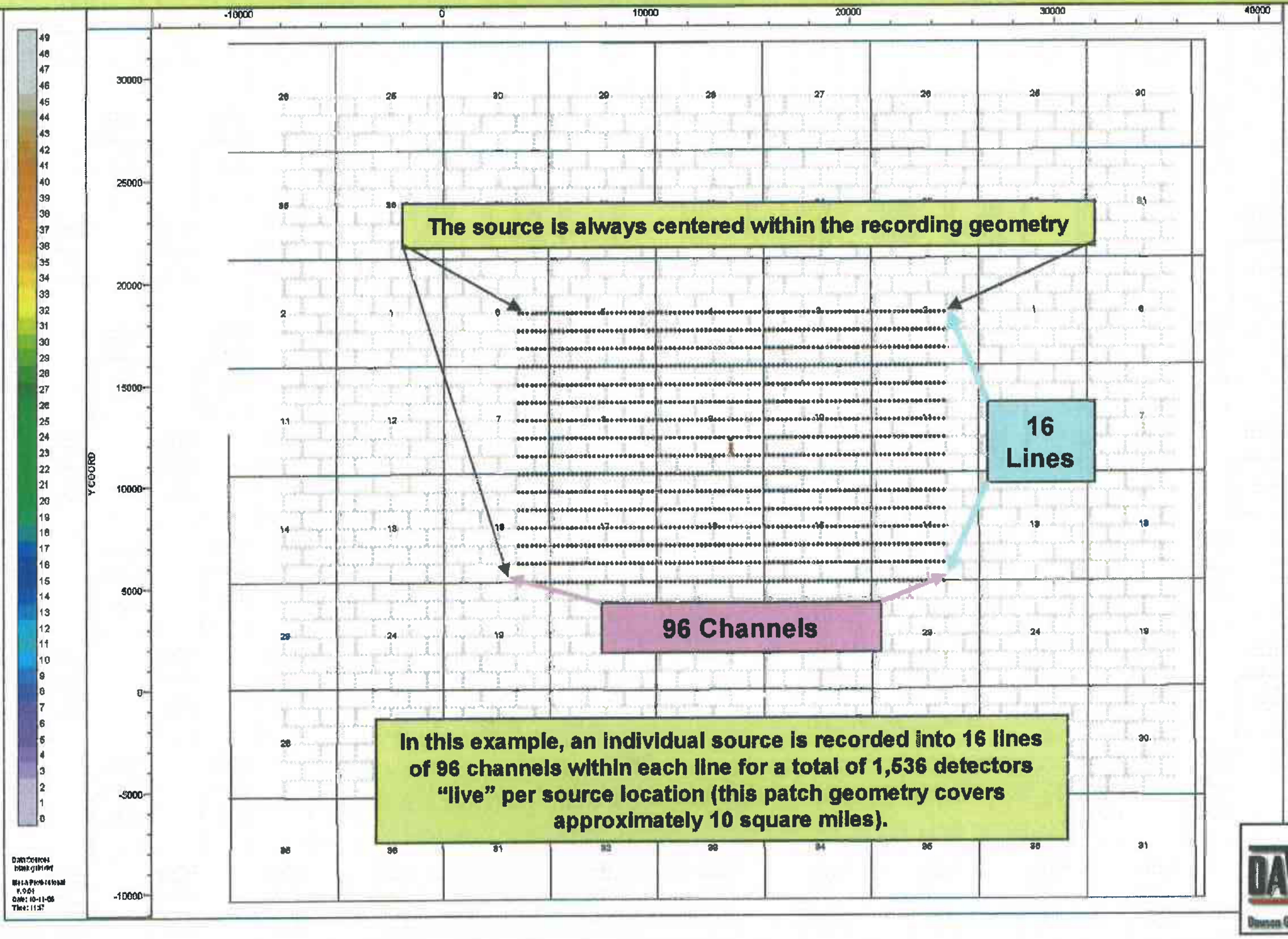
The *Recording Geometry* is the Macro-Building Block of the 3D Survey. It is responsible for the information or "DNA" that goes into the Micro-Building Block, which is the bin or cell. The Macro Building Block is responsible for Offset, azimuth and fold/statistical attributes and is sized by the Geophysicist's depth of objective (Deep Objective=Large Recording Geometry, Shallow Objective=Small Recording Geometry).

DESIGN ASPECT OF INTRO TO 3D SEISMIC



The source is always centered within the recording geometry

16 Lines

96 Channels

In this example, an individual source is recorded into 16 lines of 96 channels within each line for a total of 1,536 detectors "live" per source location (this patch geometry covers approximately 10 square miles).

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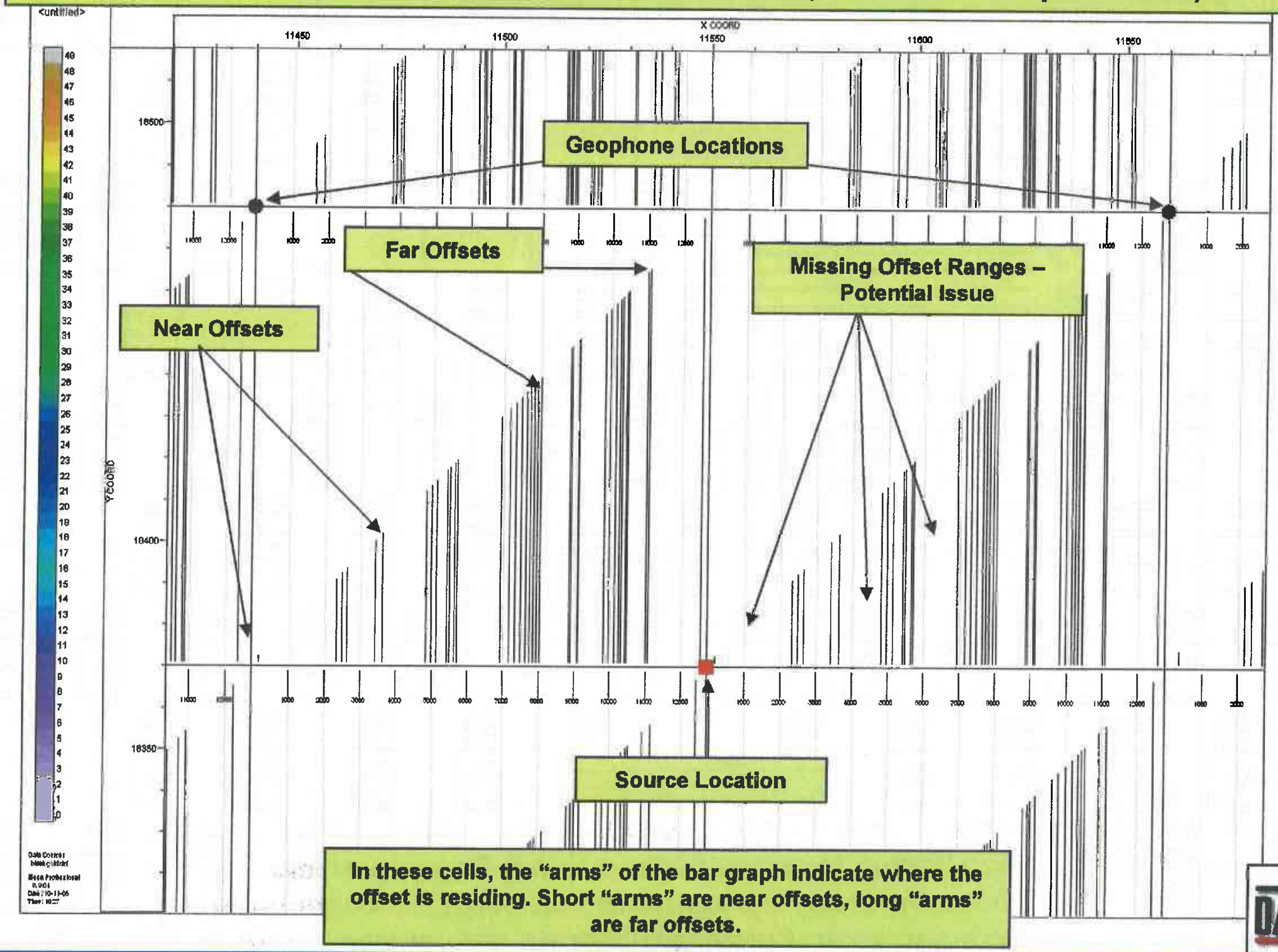
The *Recording Geometry* will also generate OFFSET information that will populate the BIN or CELL. Offset information is defined by distances that traces travel from source to detector. A good cell will have many offsets from near to far and the number of unique offsets will be defined by fold or trace count (48 Fold=48 unique offsets).



Geophone Locations

Far Offsets

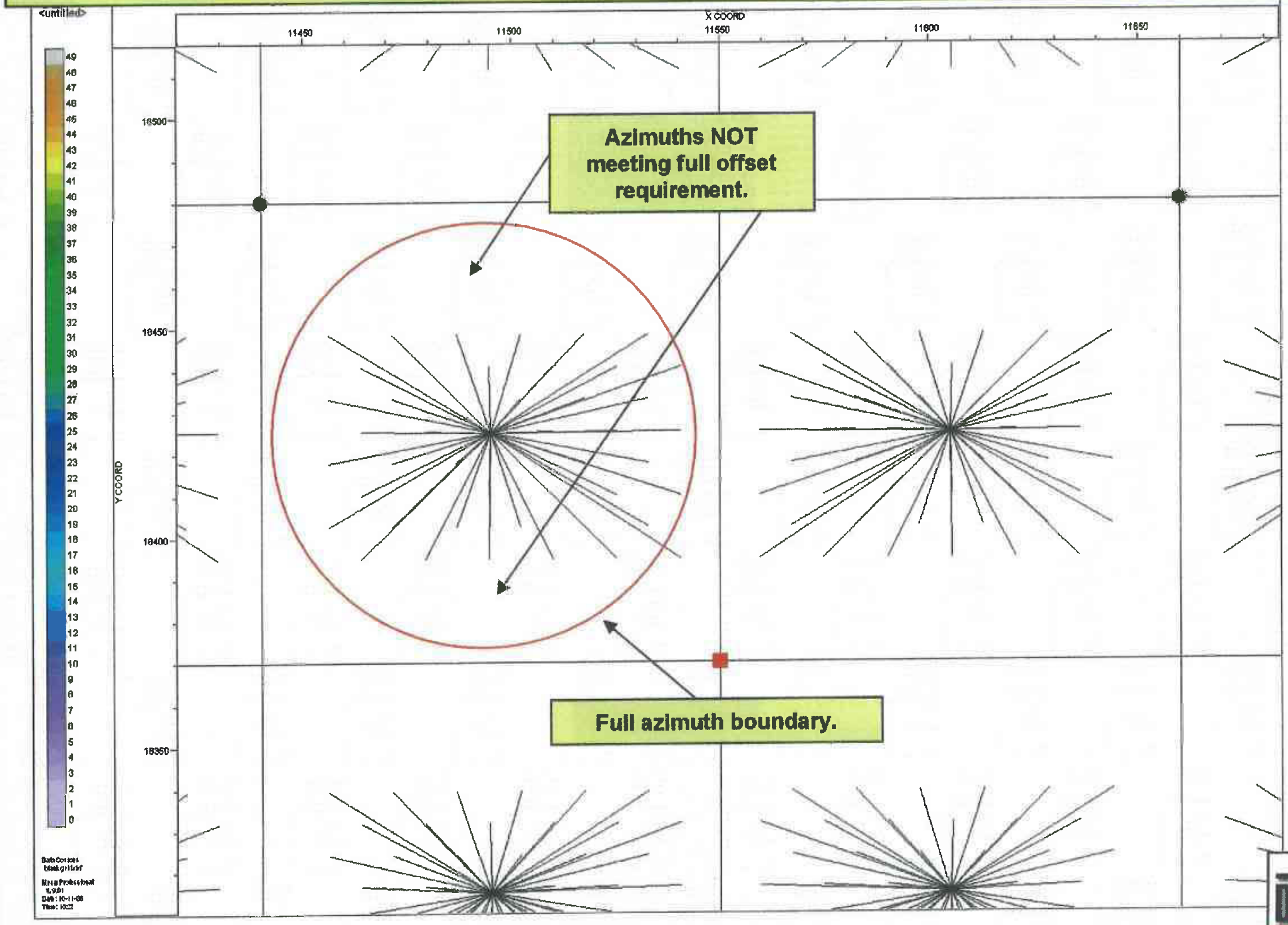
Missing Offset Ranges – Potential Issue

Near Offsets

Source Location

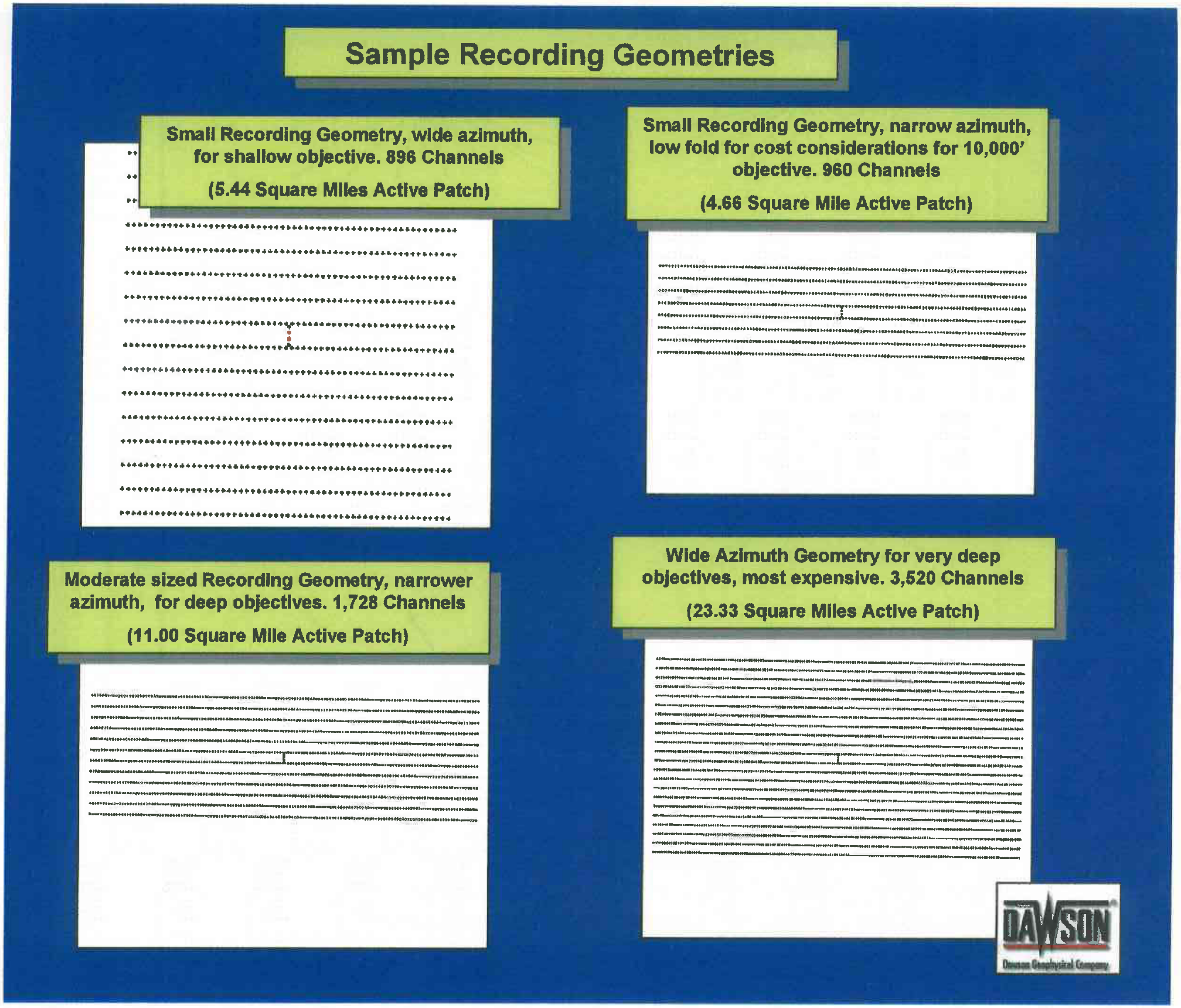
In these cells, the "arms" of the bar graph indicate where the offset is residing. Short "arms" are near offsets, long "arms" are far offsets.

The *Recording Geometry* will also generate AZIMUTH information that will populate the BIN or CELL. Azimuth information is defined by direction that traces travel from. Some designs demand wide azimuth or all directions for an offset limit (Fracture Detection) while many more are narrower azimuth where azimuth may not be an issue.



Azimuths NOT meeting full offset requirement.

Full azimuth boundary.



Sample Recording Geometries

Small Recording Geometry, wide azimuth, for shallow objective. 896 Channels

(5.44 Square Miles Active Patch)

Small Recording Geometry, narrow azimuth, low fold for cost considerations for 10,000' objective. 960 Channels

(4.66 Square Mile Active Patch)

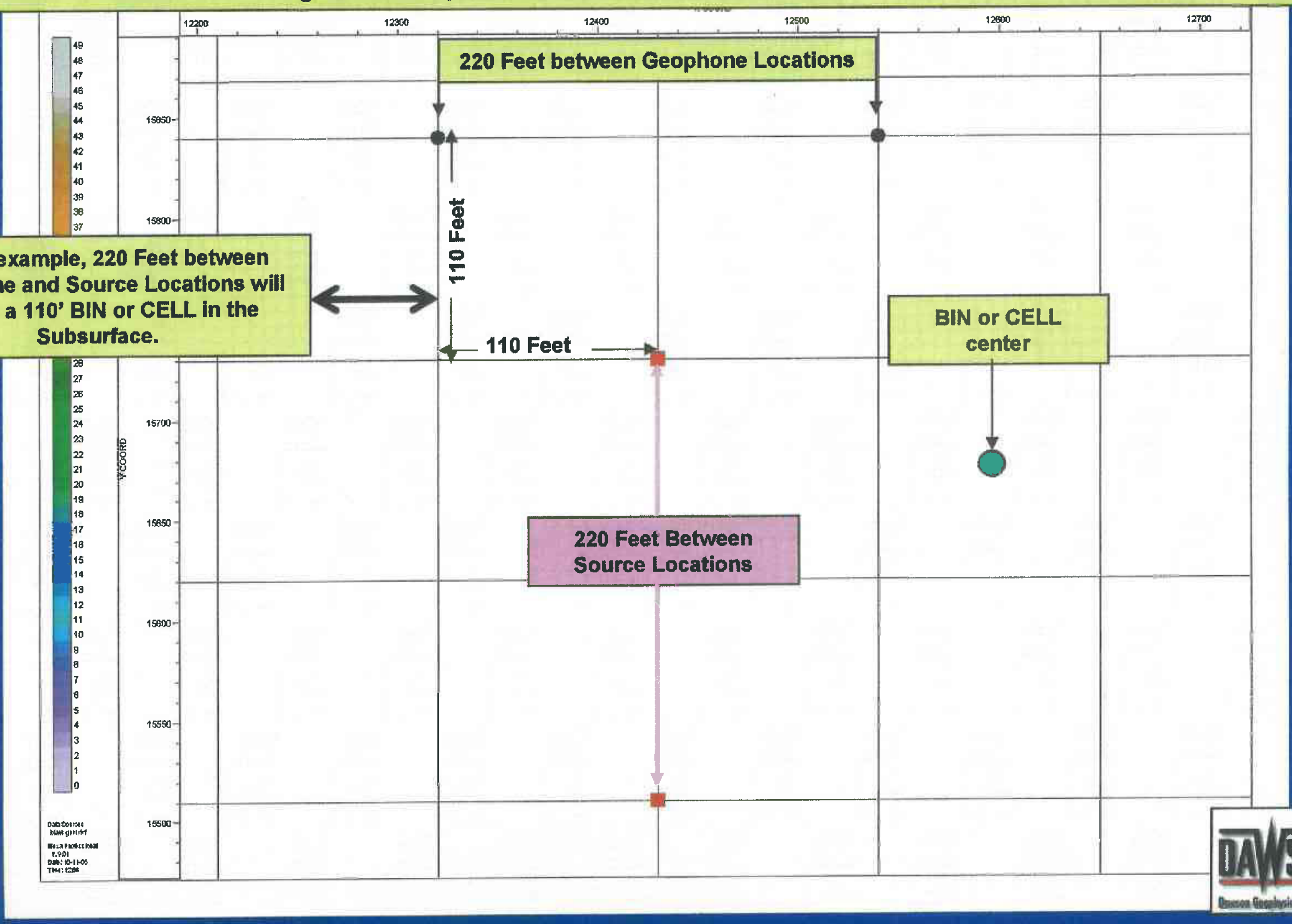
Moderate sized Recording Geometry, narrower azimuth, for deep objectives. 1,728 Channels

(11.00 Square Mile Active Patch)

Wide Azimuth Geometry for very deep objectives, most expensive. 3,520 Channels

(23.33 Square Miles Active Patch)

The *CELL or BIN* is the Micro-Building Block of the 3D Survey. It is responsible for receiving the information from the various Recording Geometries and focusing in the data to a very specific area in the subsurface and in the CELL or BIN center. The size of a BIN or CELL is determined by the intervals between Sources and Detectors. The required Geophysical size of the CELL or BIN is determined by either the complexity of the subsurface structure (anticlines thrusts or faults) or the need to image a very subtle event in great detail (ancient river beds, sand bodies or rock fracture orientation).



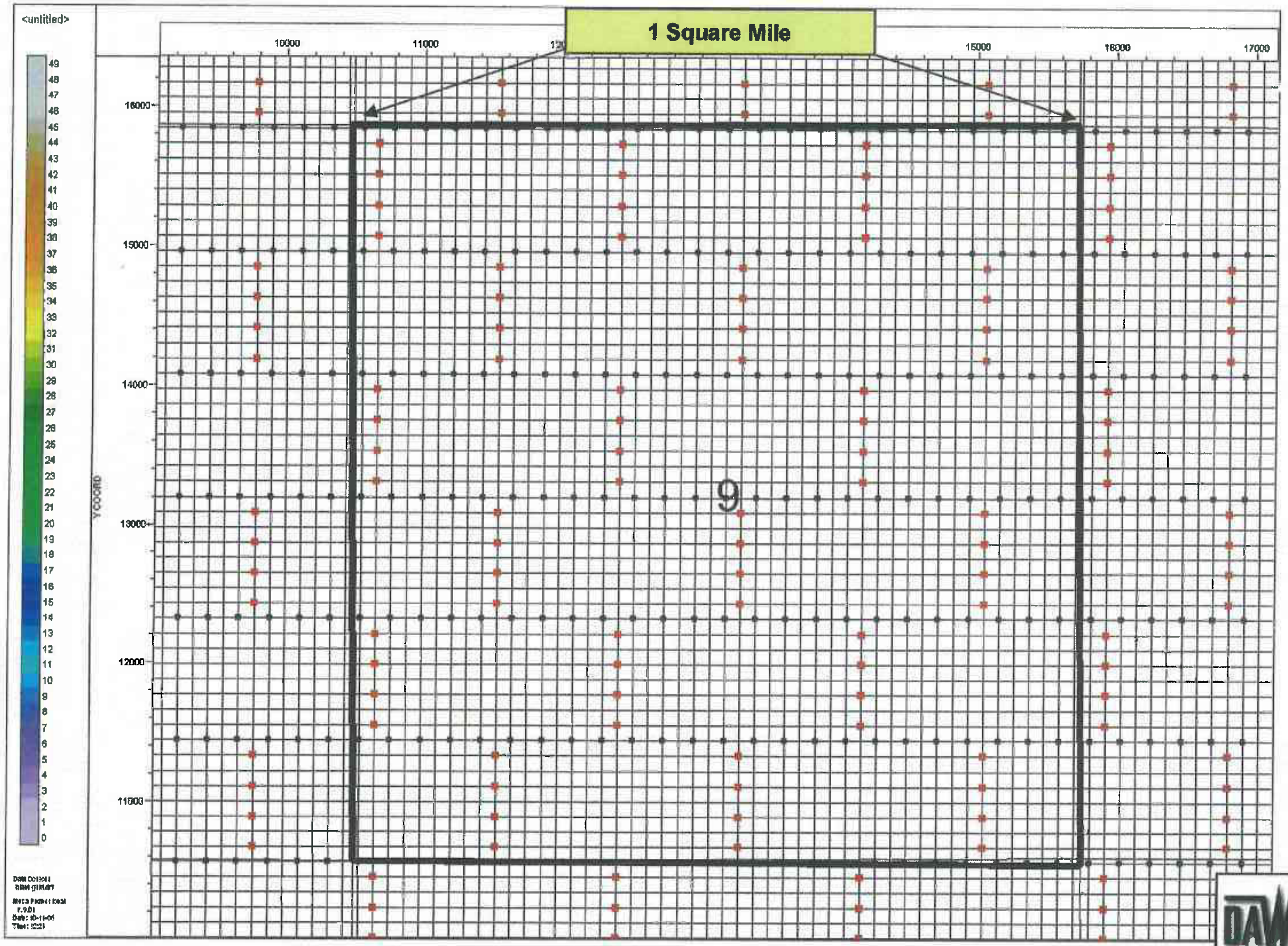
220 Feet between Geophone Locations

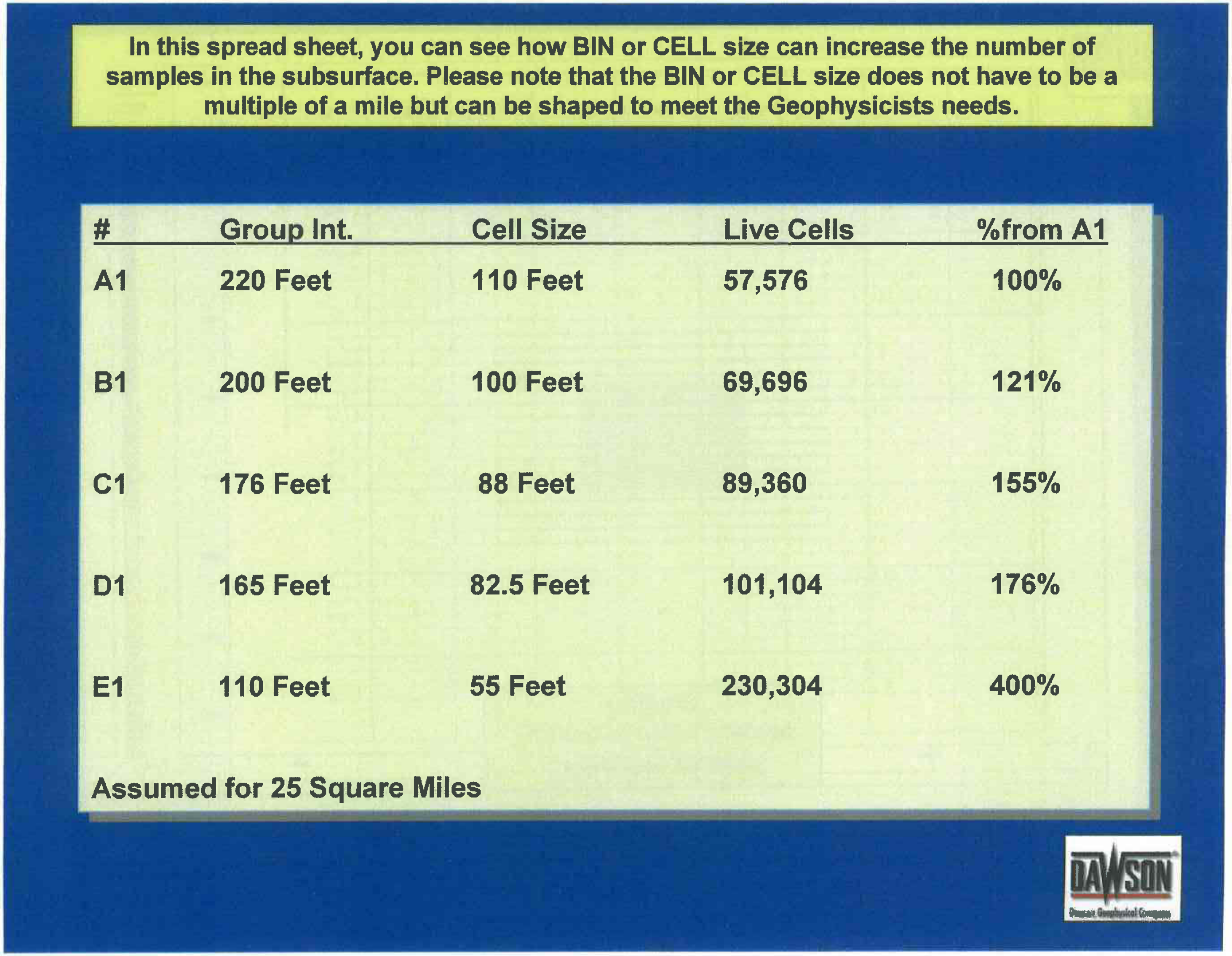
In this example, 220 Feet between Geophone and Source Locations will create a 110' BIN or CELL in the Subsurface.

BIN or CELL center

220 Feet Between Source Locations

The area defined by the Black Line is a single Square Mile and is showing the BINS or CELLS present within that square mile. BINS or CELLS that 110' X 110' will populate a square mile with 2,304 total subsurface locations. A design that has 55' X 55' BINS or CELLS would have 9,216 in the same square mile.



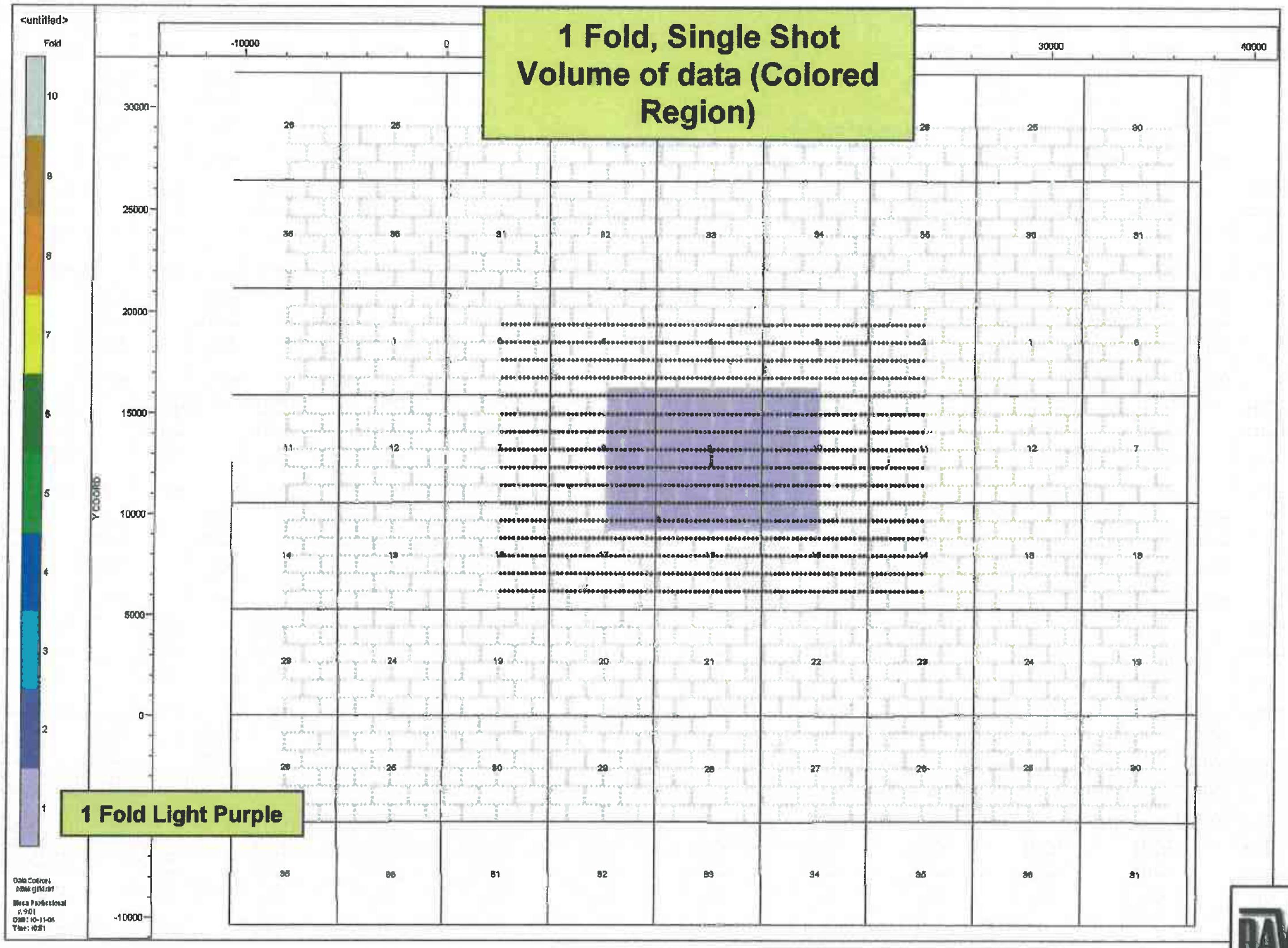


In this spread sheet, you can see how BIN or CELL size can increase the number of samples in the subsurface. Please note that the BIN or CELL size does not have to be a multiple of a mile but can be shaped to meet the Geophysicists needs.

#	Group Int.	Cell Size	Live Cells	%from A1
A1	220 Feet	110 Feet	57,576	100%
B1	200 Feet	100 Feet	69,696	121%
C1	176 Feet	88 Feet	89,360	155%
D1	165 Feet	82.5 Feet	101,104	176%
E1	110 Feet	55 Feet	230,304	400%

Assumed for 25 Square Miles

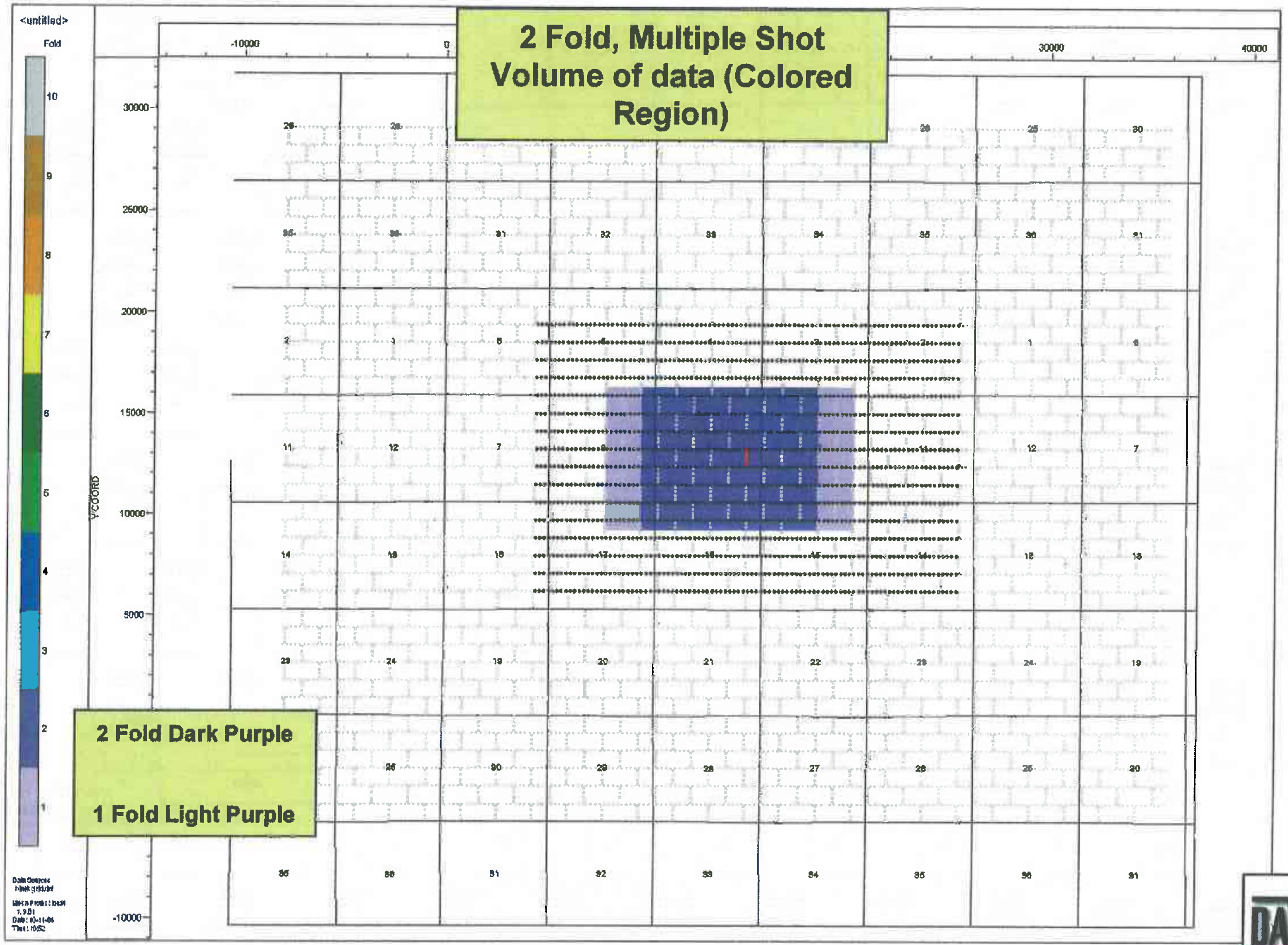
This is how fold or traces build a data volume in 3D data sets. The process starts with one group of sources for single fold data and as additional sources are acquired, the data volume expands and statistically gets stronger up to 48 fold, in this example



1 Fold, Single Shot Volume of data (Colored Region)

1 Fold Light Purple

This is how fold or traces build a data volume in 3D data sets. The process starts with one group of sources for single fold data and as additional sources are acquired, the data volume expands and statistically gets stronger up to 48 fold, in this example

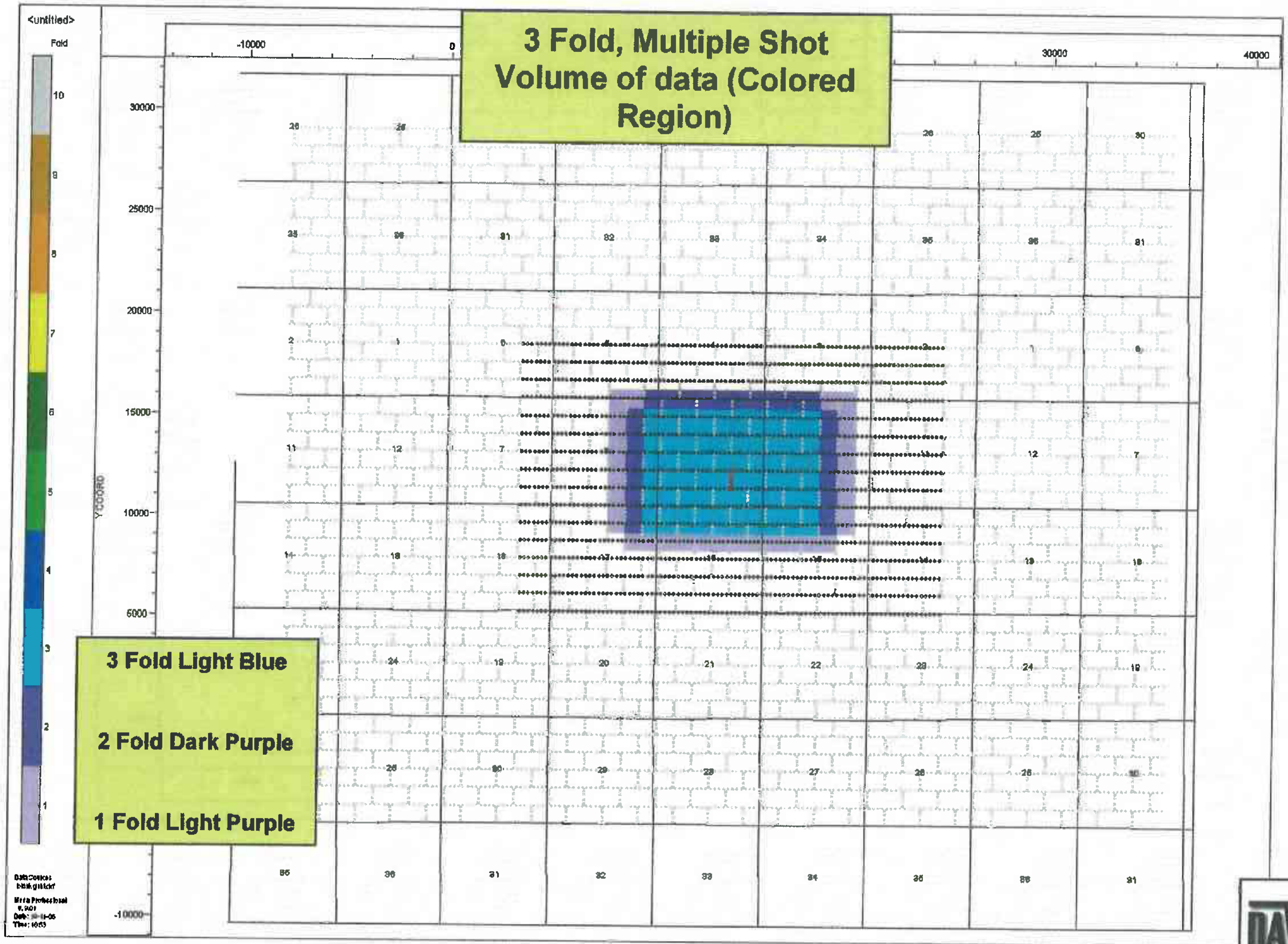


2 Fold, Multiple Shot Volume of data (Colored Region)

2 Fold Dark Purple

1 Fold Light Purple

This is how fold or traces build a data volume in 3D data sets. The process starts with one group of sources for single fold data and as additional sources are acquired, the data volume expands and statistically gets stronger up to 48 fold, in this example



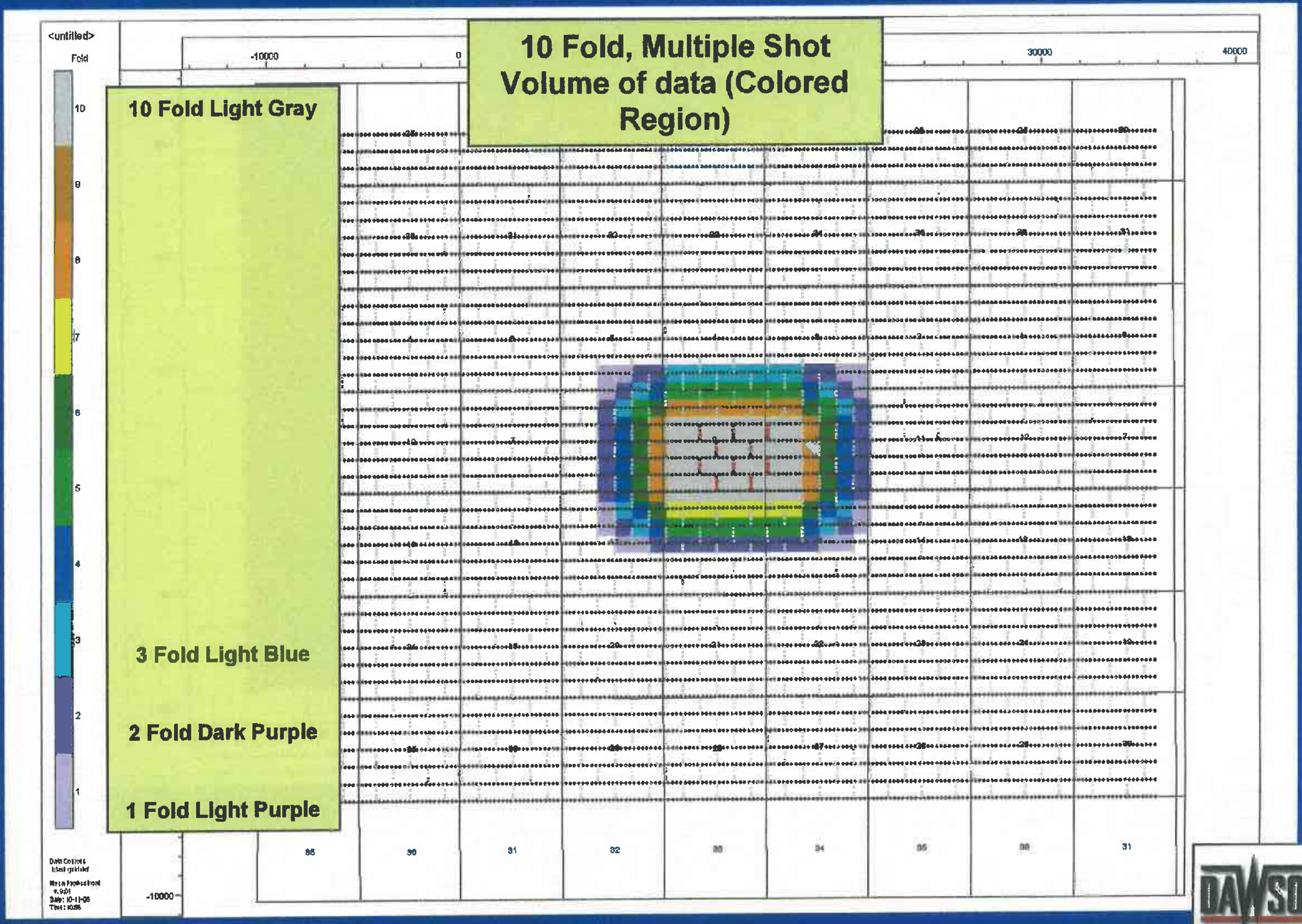
3 Fold, Multiple Shot Volume of data (Colored Region)

3 Fold Light Blue

2 Fold Dark Purple

1 Fold Light Purple

This is how fold or traces build a data volume in 3D data sets. The process starts with one group of sources for single fold data and as additional sources are acquired, the data volume expands and statistically gets stronger up to 48 fold, in this example



10 Fold, Multiple Shot Volume of data (Colored Region)

10 Fold Light Gray

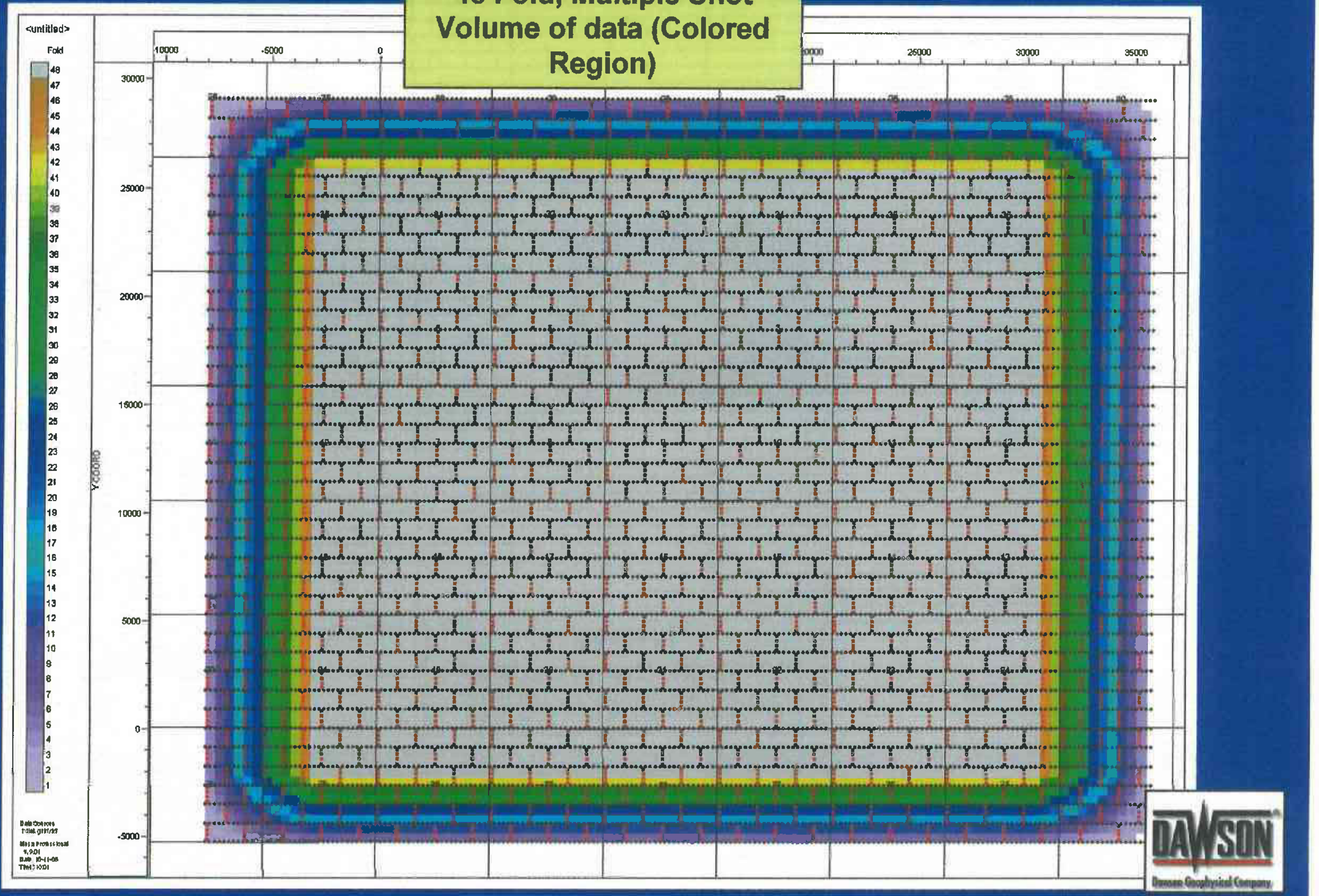
3 Fold Light Blue

2 Fold Dark Purple

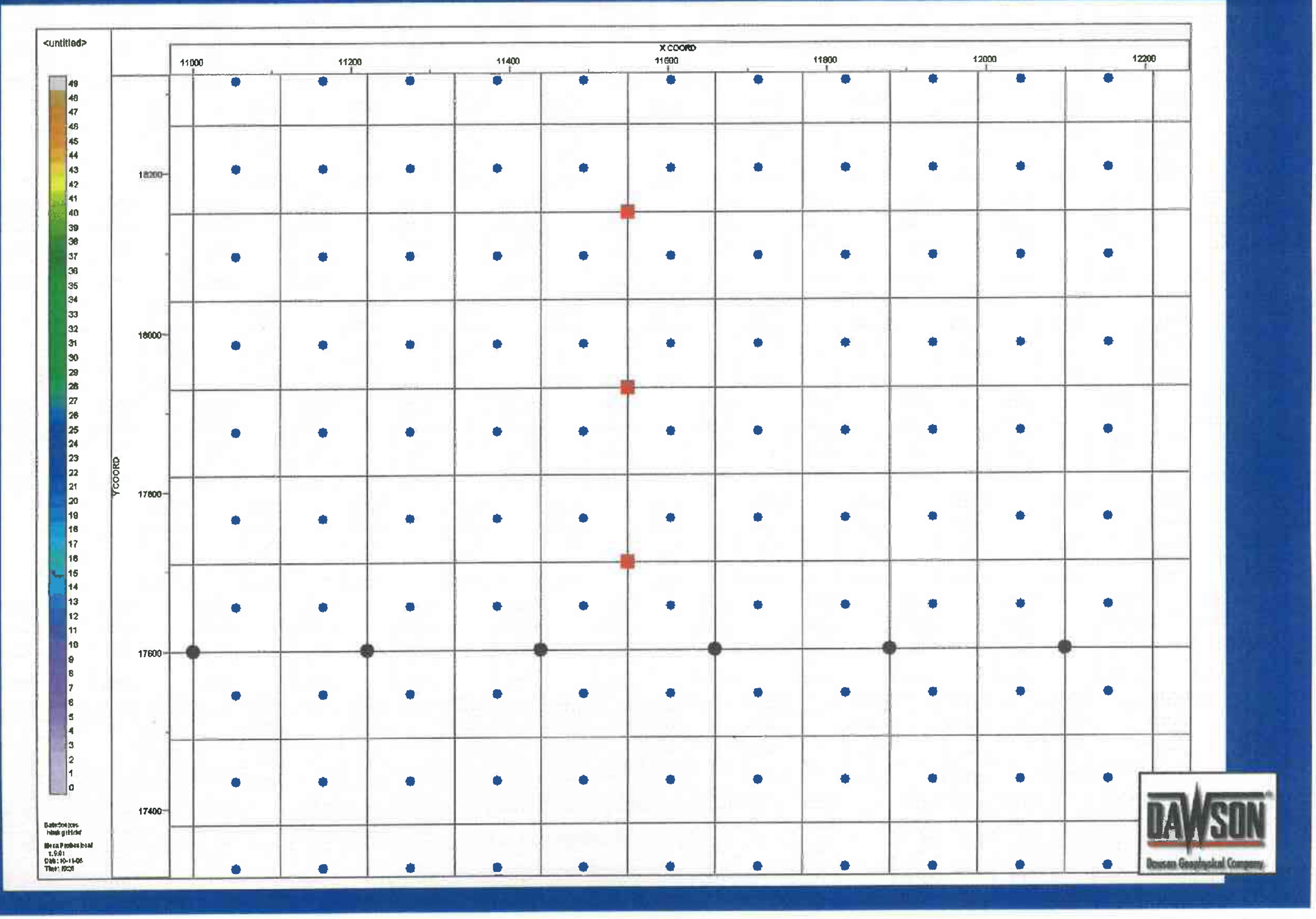
1 Fold Light Purple

This is how fold or traces build a data volume in 3D data sets. The process starts with one group of sources for single fold data and as additional sources are acquired, the data volume expands and statistically gets stronger up to 48 fold, in this example

48 Fold, Multiple Shot Volume of data (Colored Region)



The 3D Geophysical Designer tries to place all data in the center of the Cell or Bin. However, forces such as structures, bodies of water, pipelines, water wells and others will move trace centers in a random manner. It is our job to be sure we "contain" the traces in the best possible manner in order to full fill the Cell or Bin attributes.



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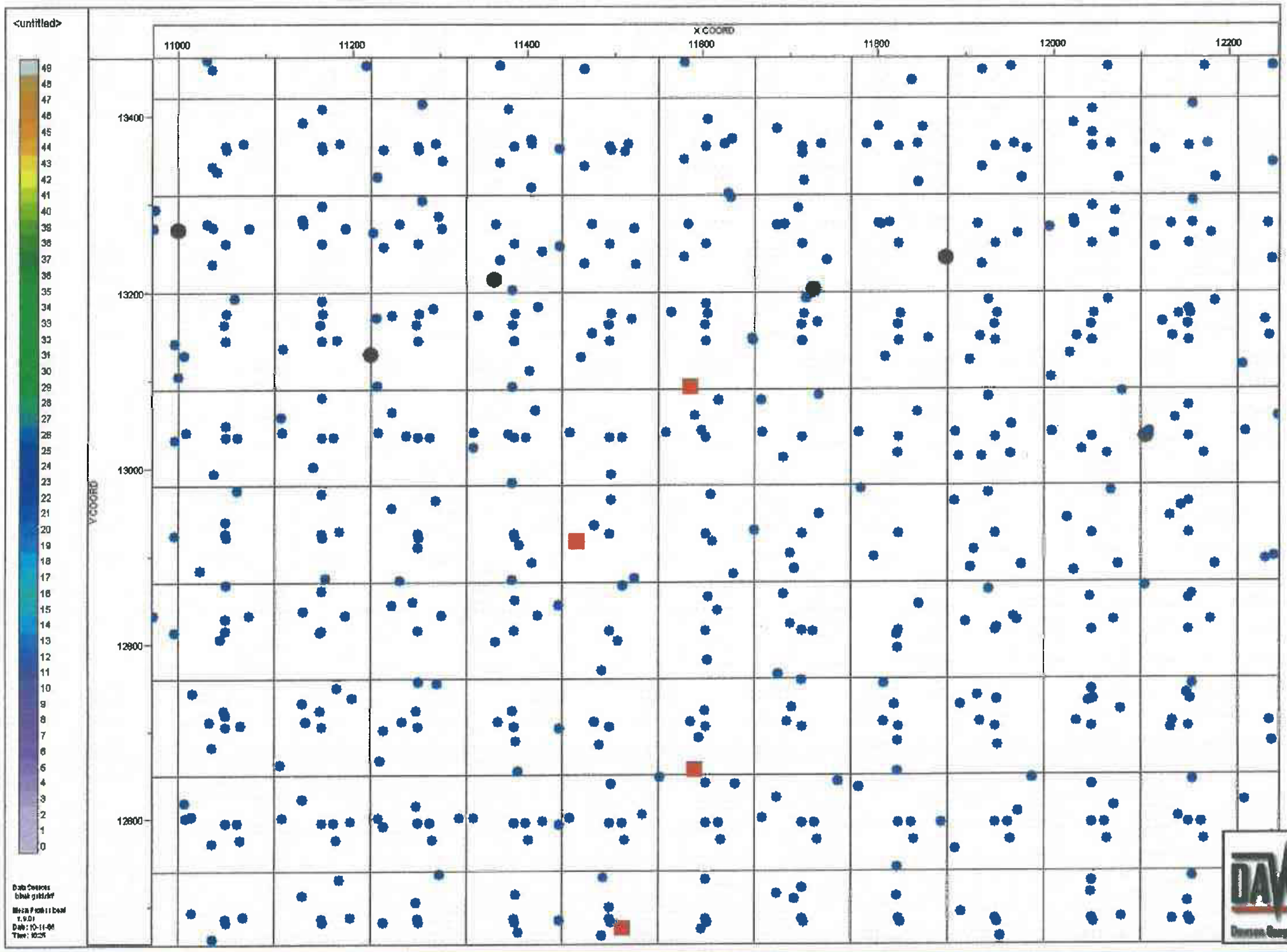
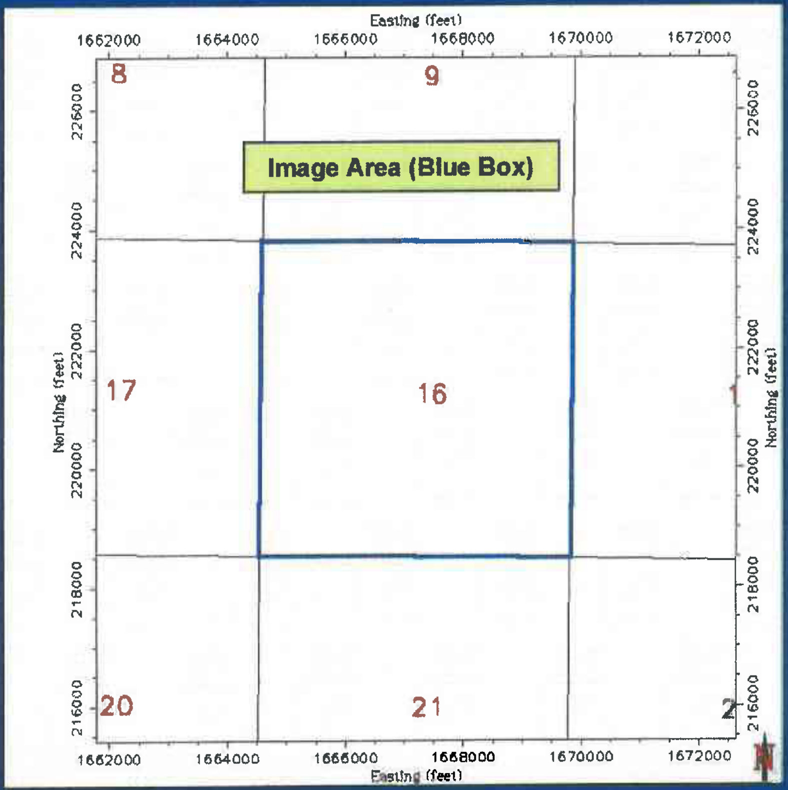
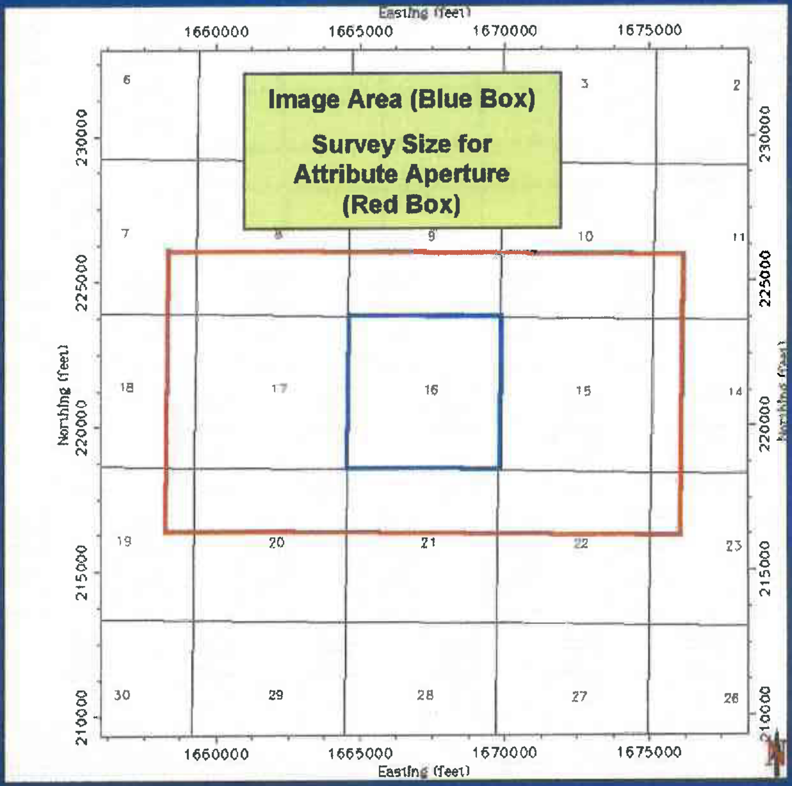
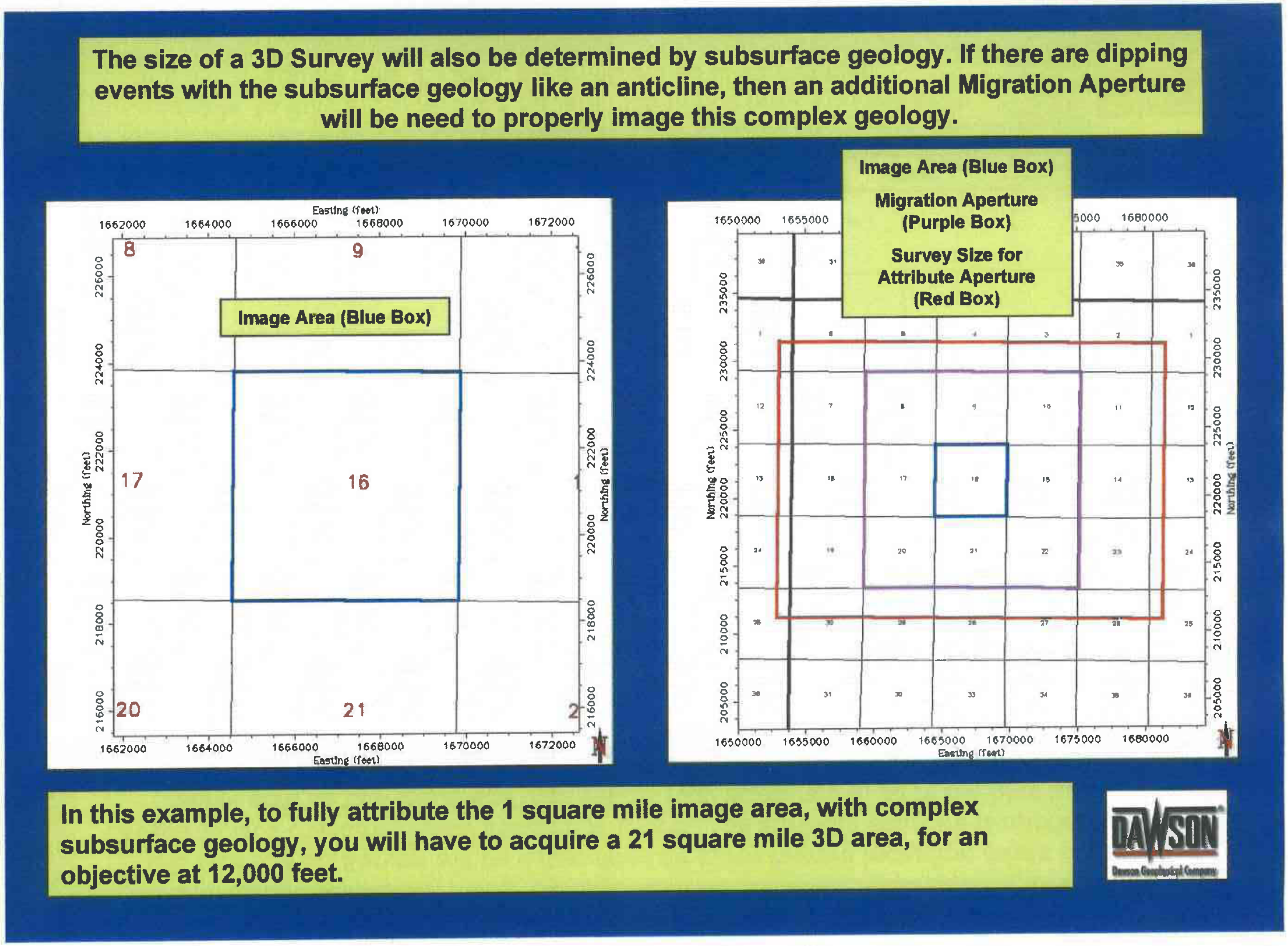


The size of a 3D Survey will be determined by many factors including depth of the Geophysicist's objective, lease position and cost. The attribute aperture is applied to the image area so that the image area will be fully attributed in all of the blue box.





In this example, to fully attribute the 1 square mile image area, you will have to acquire a 6.75 square mile 3D area, for an objective at 12,000 feet.



The size of a 3D Survey will also be determined by subsurface geology. If there are dipping events with the subsurface geology like an anticline, then an additional Migration Aperture will be need to properly image this complex geology.

Image Area (Blue Box)

Image Area (Blue Box)

Migration Aperture (Purple Box)

Survey Size for Attribute Aperture (Red Box)

In this example, to fully attribute the 1 square mile image area, with complex subsurface geology, you will have to acquire a 21 square mile 3D area, for an objective at 12,000 feet.

NOTES

NOTES

Basic Processing Concepts for Surface Seismic Data

Raymon Brown

Reflection seismic processing consists of basic steps that are used to make the data easier to interpret. This brief note introduces some of the basic aspects of processing seismic reflection data.

Geometry-Definitions

Geometry refers to the arrangement of the source (s) and the receiver (s). If all of the receivers are located to one side of the receiver, this type of shooting geometry is referred to as ***"end on".*** "Split spread" recording is often used in onshore 2D onshore exploration as shown in **Figure 1**. Often when shooting 3D seismic data, the source and receivers are laid out in patterns that optimize the way sound waves hit the reflectors being studied. For 3D seismic on land, we need a picture of the topography as well as the recording geometry as shown in **Figure 2**. A group of traces plotted or processed together are called a ***"gather".*** In other words ***a gather*** represents a collection of recorded traces. If all the traces that were recorded by a single source are used together, these traces are referred to as ***a common source gather*** or a ***common shot gather*** (**Figure 3**). When data are recorded in the field, the common source or shot gather describes all of the traces that are recorded for a single shot. If all the traces that have a common midpoint between their sources and receivers are plotted together, this type of gather is referred to as ***a common midpoint gather*** (**Figure 4**). In many circumstances, especially for 3D shooting, the idea of a point is too restrictive for practical purposes. In this case a larger region where mid points may fall is used. These regions are called ***stacking bins*** (**Figure 5**). Even though the ***stacking bins*** represent approximately the same midpoint, the ideas for stacking with bins rather than exact midpoints assume that the traces act associated with a bin can be treated as if they have the same midpoint. It is not exactly a correct idea but using bins works in practice. When you make the bins too big, you lose the ability to see the smaller aspects of the geology. So keep your bins as small as possible.

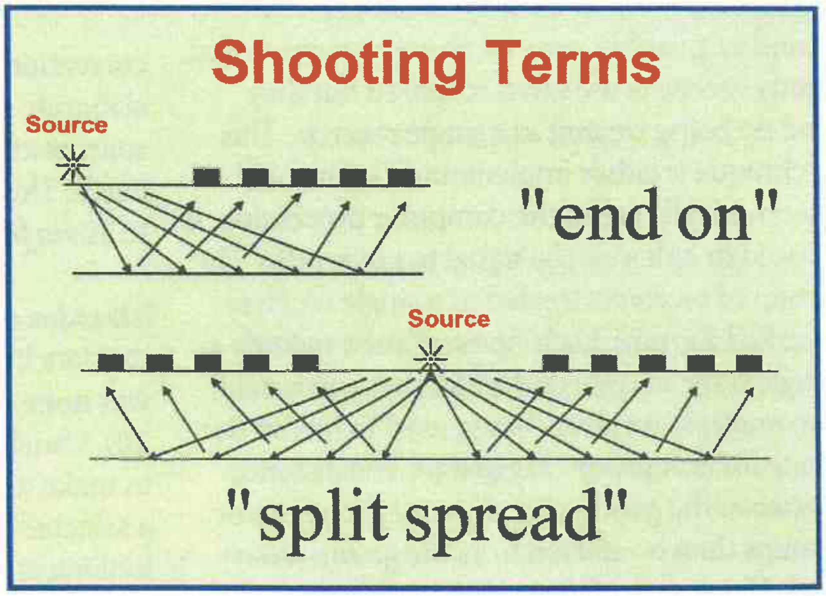


Figure 1. Schematic of two ways to shoot seismic data.

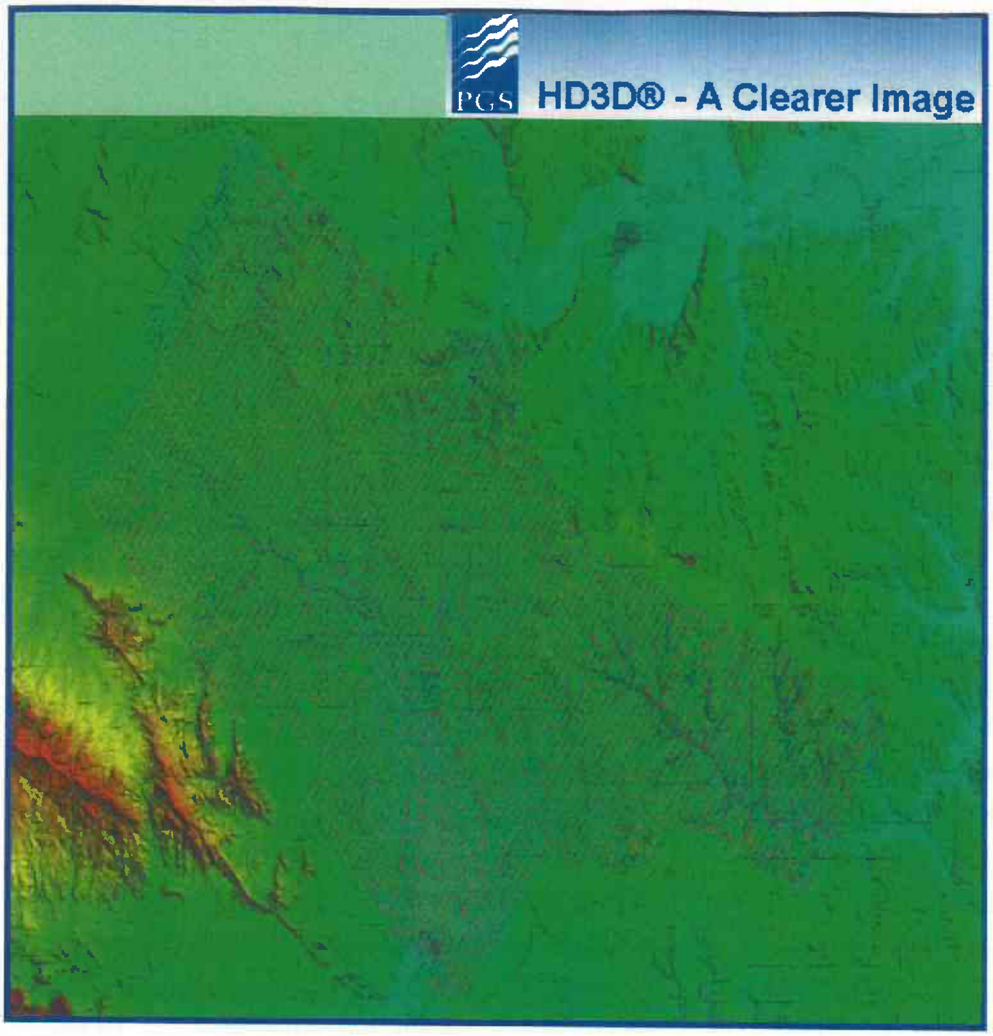


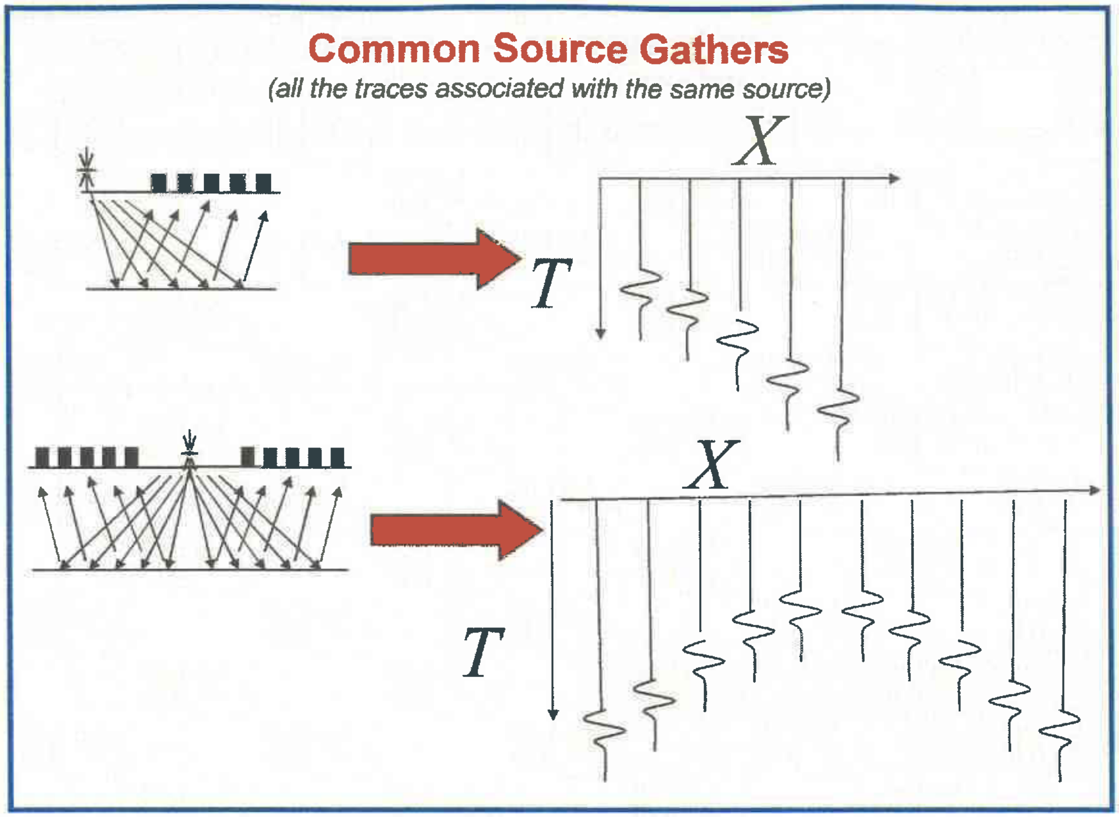
Figure 2. Topographic map of survey area with survey outline.

Another possible surprise to newcomers is that many receivers are often recorded but they end up being treated as a single receiver. This technique is either implemented in the field electronically are in the computer processing. It is used to enhance the signal to noise ratio. The group of receivers treated as a single receiver is called a group. Each ***"group"*** then records a single trace in spite of the fact that you would see multiple receivers being used to record the trace for that group (**Figure 6**). The distance between the geometric center of the arrays or groups then is referred to as the ***group interval***. The distance between source positions is called the ***source interval***. Group interval and source interval influence the resolution of a seismic survey.

Datum/ Statics

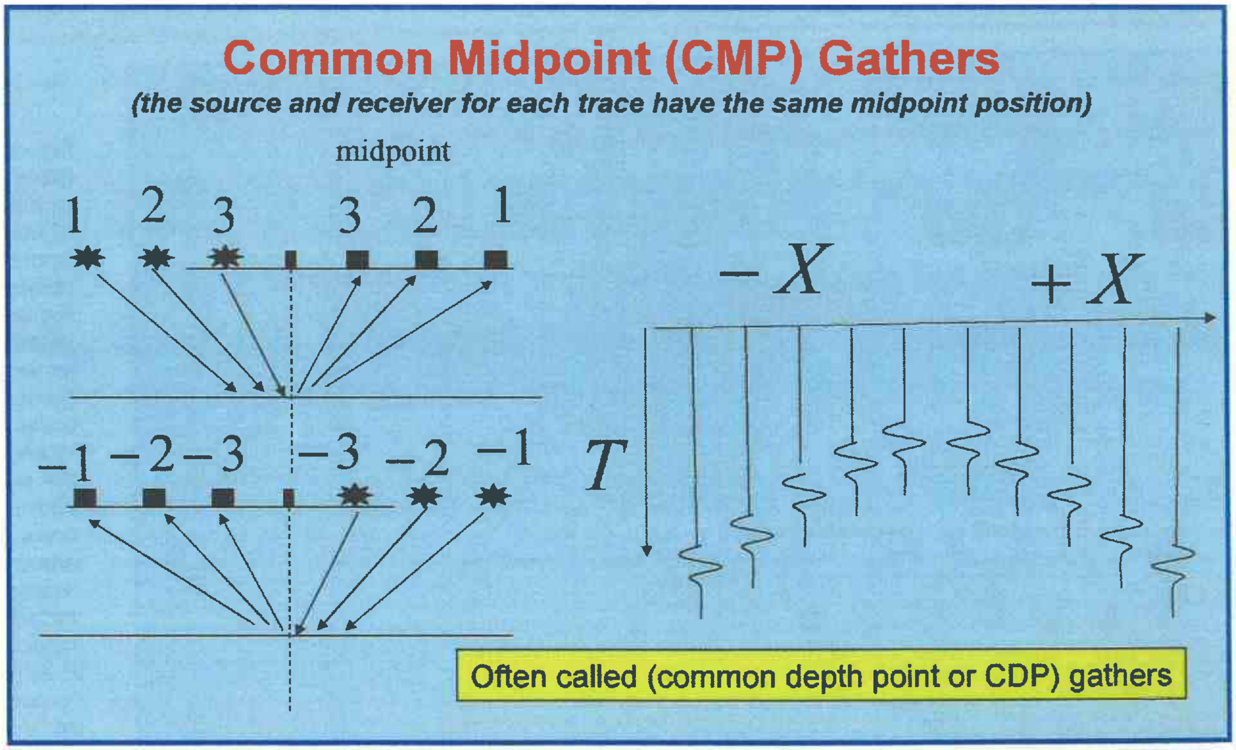
If you add a constant time to a seismic trace, the correction to the trace is a static one. In other words, imagine that we want to shift a seismic trace by 2 seconds. The basic idea of a ***static shift*** is to shift the whole trace by 2 seconds. Simple static corrections take a single measurement and estimate the static correction. One approach to estimating the static correction is to use signals refracted near the surface. This approach to measuring the static correction is called ***refraction statics***. A more elaborate static correction accounts for all the sources and receivers at a single location of the Earth. This type of static correction is referred to as ***surface consistent statics***.

This idea of static shifting is used to improve the data by making it appear that the recording was done over a smooth surface (**Figures 7-10**). Usually this static shifting is accomplished to make it appear the data was recorded from a selected elevation called a ***datum***. When looking at seismic data, is a good thing to know which datum is being used for that set of seismic data.


Common Source Gathers

(all the traces associated with the same source)

Figure 3. When a group of traces that were associated with the same source is viewed, the group of traces is referred to as a common source gather.


Common Midpoint (CMP) Gathers

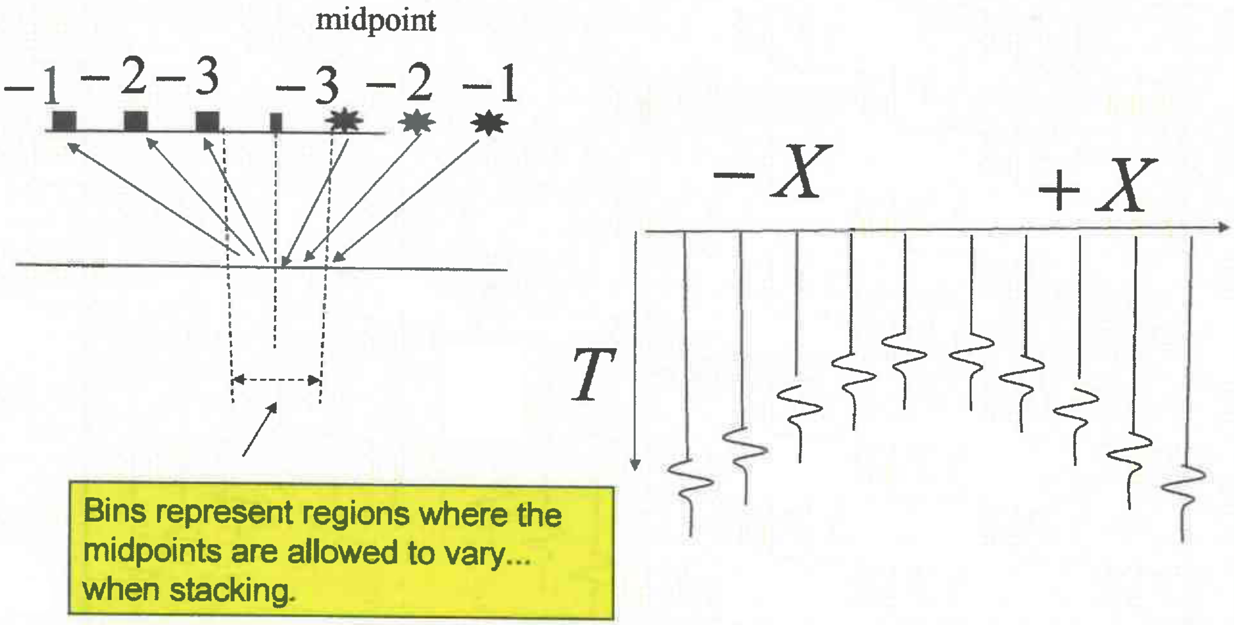
(the source and receiver for each trace have the same midpoint position)

Often called (common depth point or CDP) gathers

Figure 4. When the source and receiver positions for a group of traces all have the same midpoint, the group of traces is referred to as a common midpoint gather. When the layers of rock are horizontal, the term common depth point gather is used.

Stacking Bins....are used to approximate Midpoint (CMP) Gathers

In otherwords.......the source-receiver pairs may not have exactly the same midpoint......but close enough......to use for stacking purposes.



Bins represent regions where the midpoints are allowed to vary... when stacking.

Figure 5. Stacking Bins. Rather than a common depth point.....or a common mid point .....Stacking is often applied to traces that do not have exactly the same midpoint .....but close enough.....for the stacking idea to still work. The range of variation for the midpints is called a bin....or a stacking bin. Bins represent a line in 2D shooting and an area for 3D shooting.

Groups....or Arrays

Many signals averaged to get a single trace....

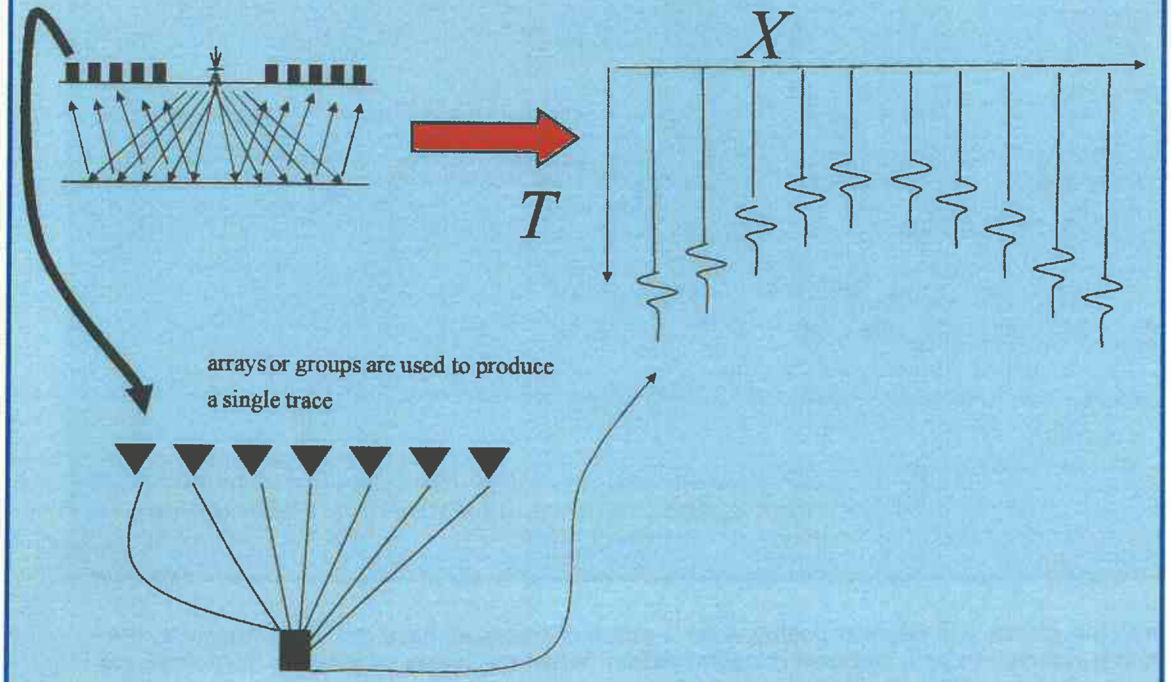


Figure 6. Often the signals of many single receivers are added together in some manner in order to strengthen the signal above the noise. The group of receivers added together is called a "group" or an "array".

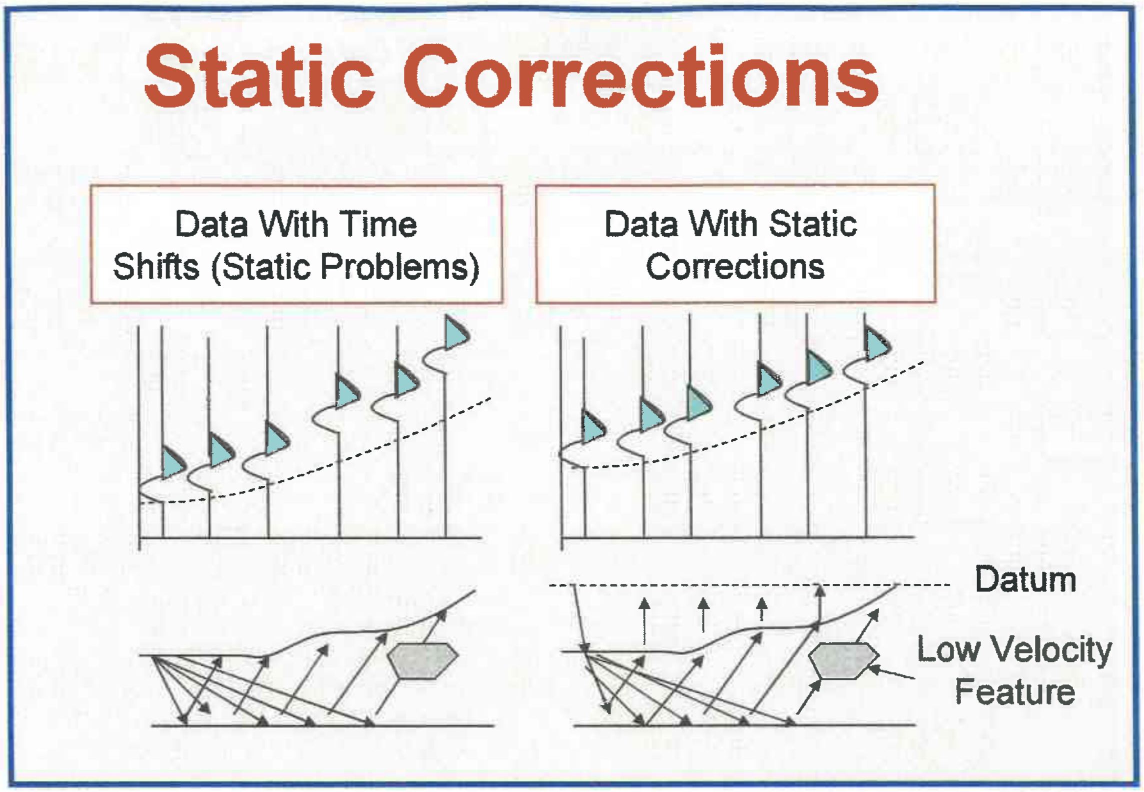


Figure 7. Irregular surfaces and geology can cause problems with interpreting the seismic data. One easy solution is to add a static correction that makes the data look as if it was recorded from a smooth surface (called a datum).

Deconvolution

Seismic sources come in a variety of types and sizes. They all create basic waveforms that differ. Consider the way a person says “hello.” Different people say the word “hello” in such a way that you can distinguish the difference. The waveforms on seismic data are often shaped into a more desirable shape for interpretation. The processing that revises the shape of the source wavelet is called ***deconvolution***. See the example in **Figure 11**.

Noise Attenuation and Filtering

Noise attenuation is often possible with simple filtering. There are many types of filters that act to reduce the noise compared to the signal. The basic idea is to emphasize the signal at the expense of the noise. There are times when noise attenuation is very difficult. When this happens, the seismic image can be very difficult to interpret. One common way is to filter according to the dip of the noise as seen on the seismic section. In other words, the noise (often the ground roll or the direct arrival) has a distinct dip on the seismic gathers from the reflected signals that are to be emphasized. Geophysicists refer to this type of filtering as F-K filtering, but it is just as easy to think of it as dip filtering (**Figures 12-15**). Geophysicists think of F-K filtering as working in the frequency (F) and space (K) domains simultaneously. Sometimes the filtering is required only in the frequency domain (F). For example, if you happen to be shooting near some power lines, your data may be very noisy with 60 cycle noise. Simple frequency filtering is great for this type of noise (**Figures 16 and 17**).

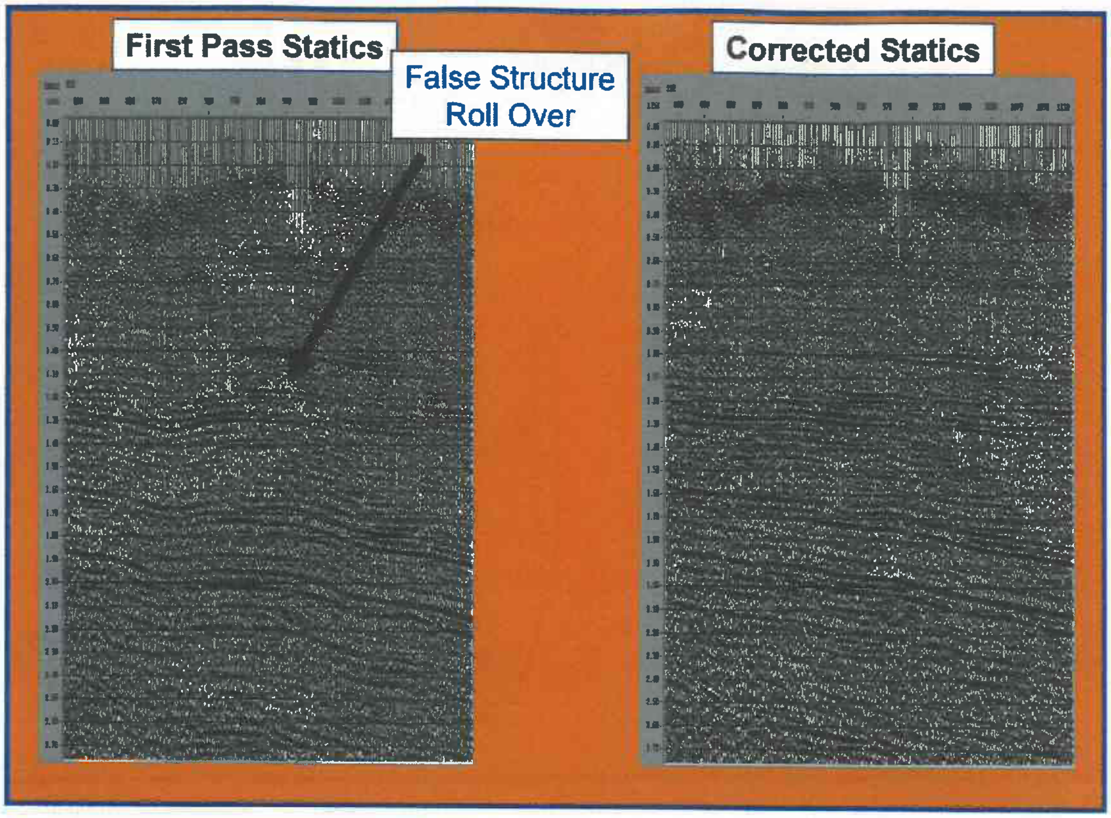


Figure 8. Static problems can cause the creation of artificial structure. The figure on the left still exhibited false structure after the first pass of static corrections. The corrected statics figure on the right shows a smoother structure.

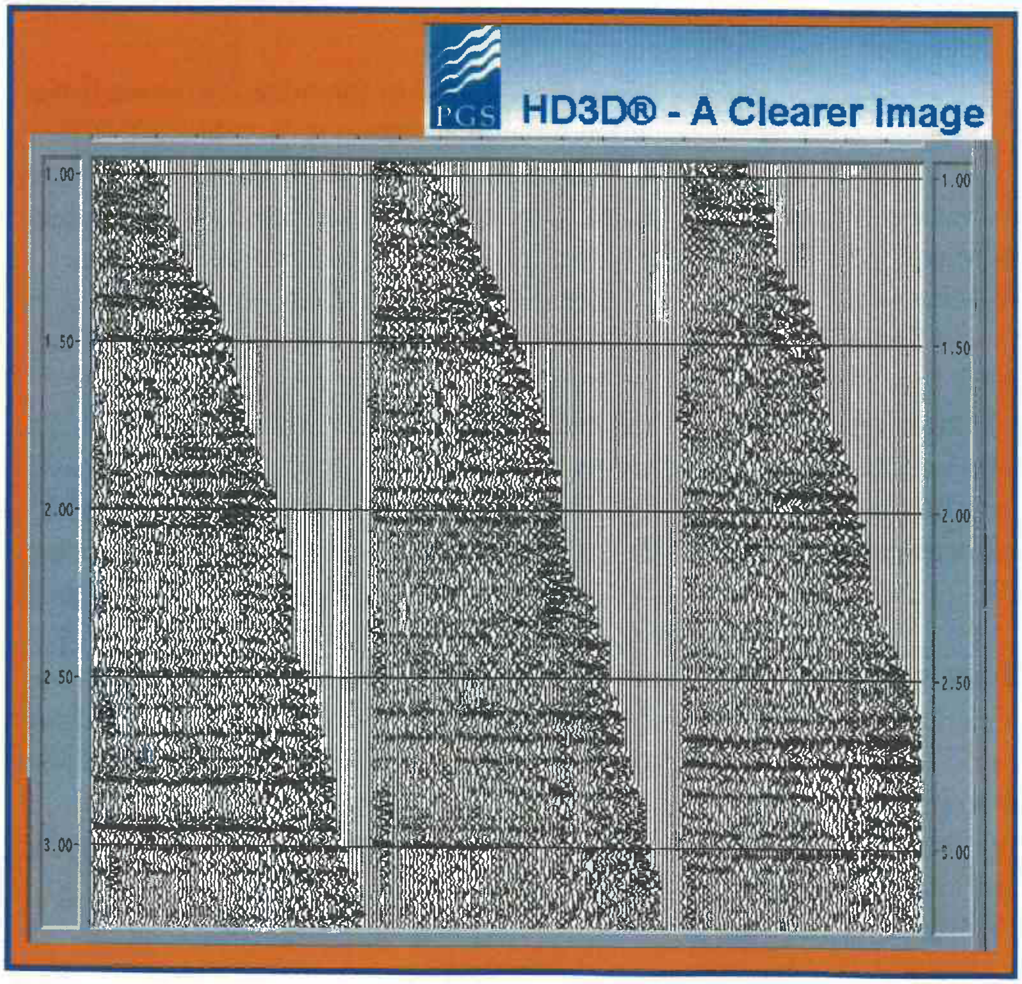


Figure 9. CDP gathers without surface consistent statics.

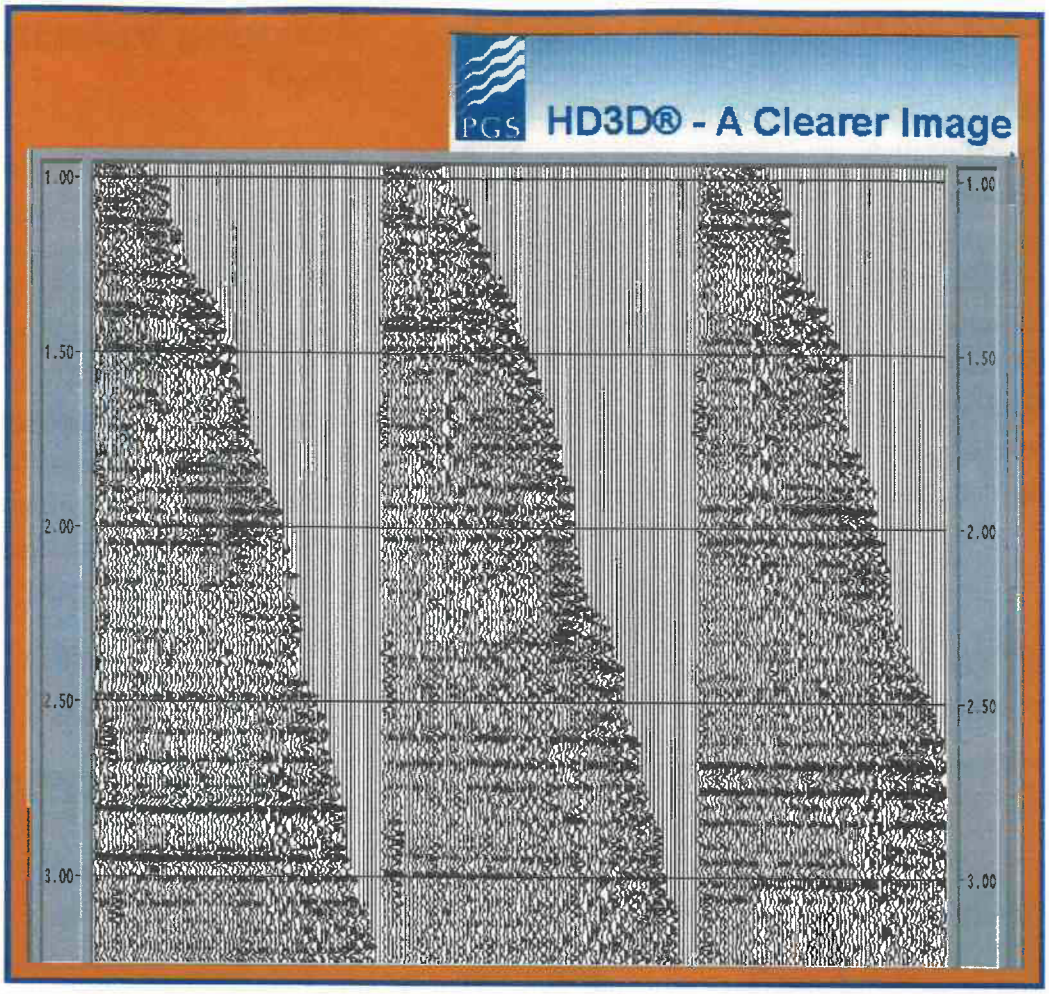


Figure 10. CDP gathers with surface consistent statics.

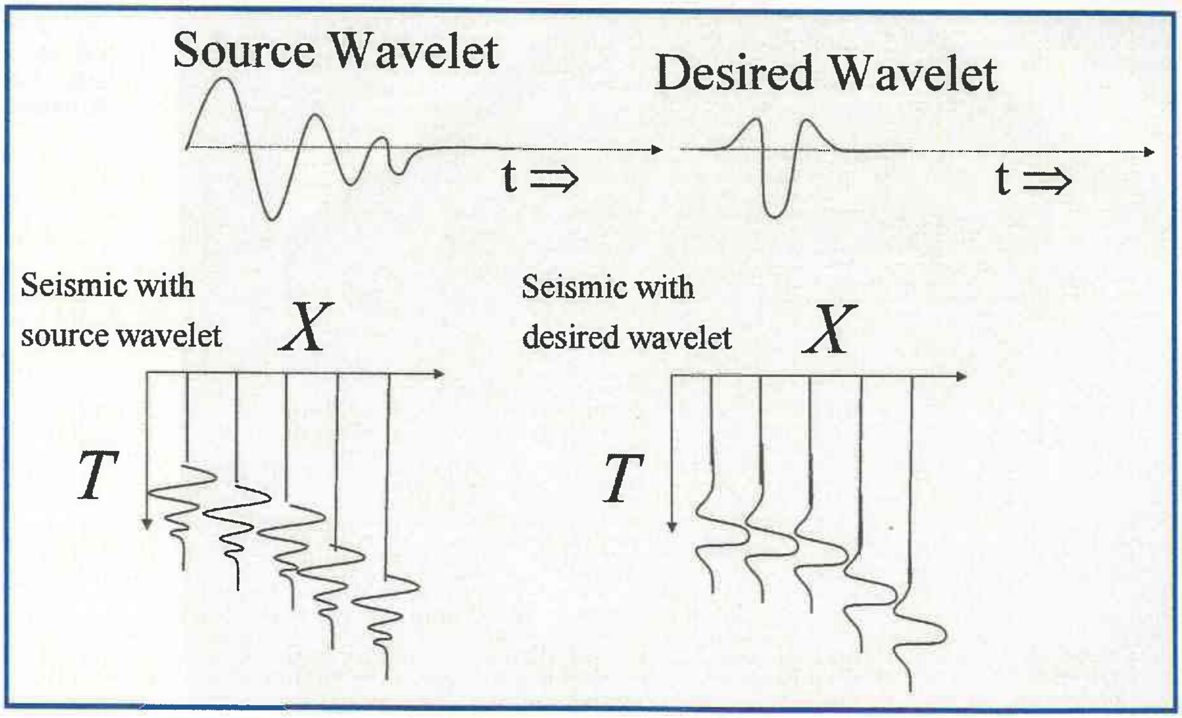


Figure 11. Deconvolution-Changing the shape of the wavelet on the data.

CDP Sort

When a common midpoint gather lies over a horizontally layered Earth, all of the reflections observed on the ***common midpoint (CMP)*** gather took place at a ***common depth point (CDP)*** as shown in **Figure 18**. In the 1950's it became convenient to sort the seismic traces into a common depth point gather (***"CDP Sort"***). In general, ***CMP sort*** is the more general term when the Earth is not a horizontally layered medium.

Stacking Velocity Analysis, NMO

When sound waves are reflected from a single reflector and observed on a CMP gather, they appear to take longer to arrive as the source-receiver distance (X) increases (**Figure 19**). This increase in reflector traveltime is called Normal Moveout (NMO). The NMO can be mimicked using a simple equation and the NMO can be eliminated by determining the velocity in the simple equation and correcting the traveltime equation for each offset. The process of eliminating the NMO is called ***NMO***

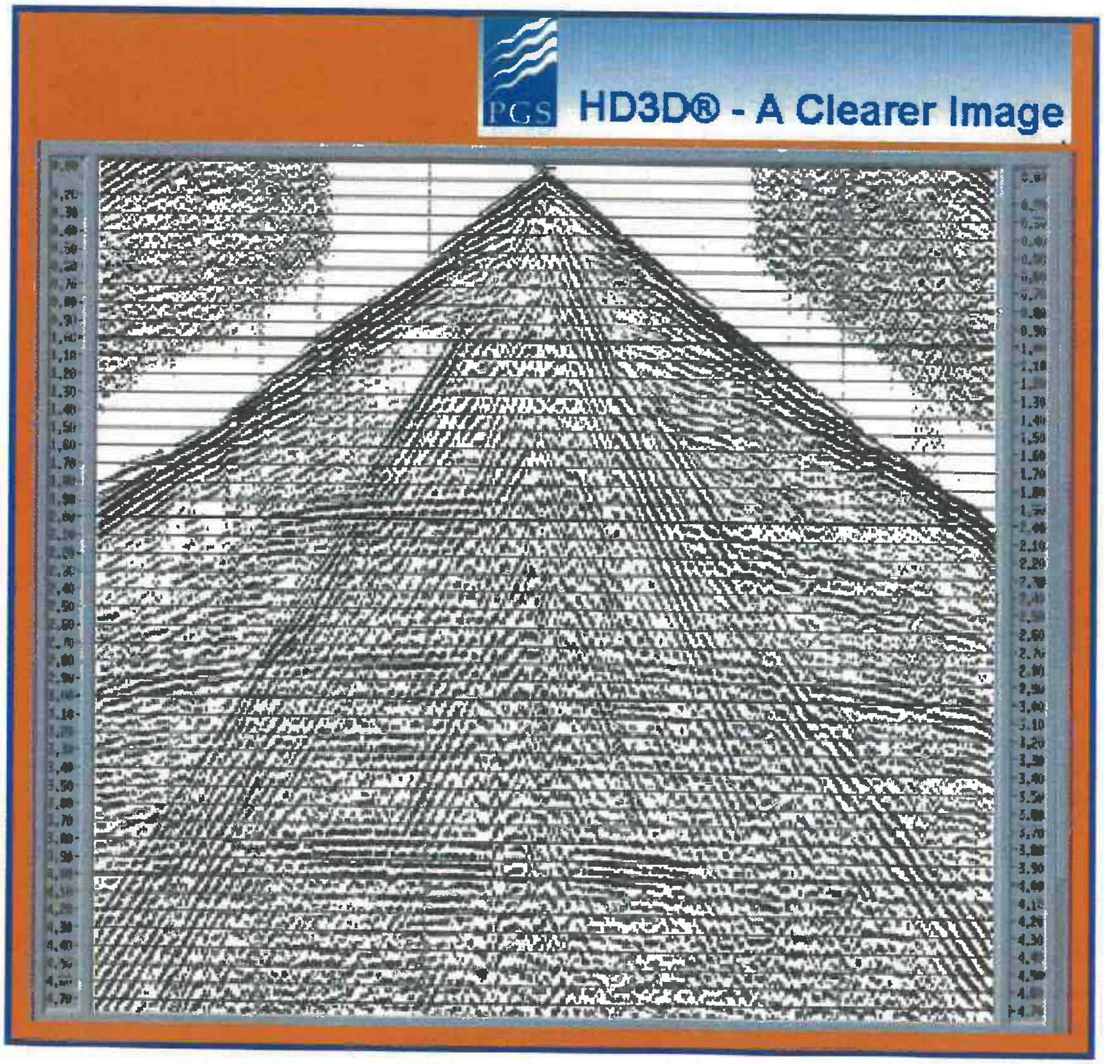


Figure 12. Shot gather with coherent noise, before FK filtering.

correction. The velocity in the equation is not a velocity in the normal sense of the word. It is called the ***stacking velocity*** because it is the velocity in the equation that flattens the seismic data for processing purposes. Do not confuse the stacking velocity with a real velocity inside the Earth. The computer simply tries different stacking velocities as shown in **Figure 18** until the stacking velocity in the simple equation shown in **Figure 19** gives the desired result (flattens the events). One way to approach this problem is to simply have the computer try a range of stacking of constant stacking velocities (in other words, the whole gather is moveout corrected with the same stacking velocity) and viewing the results of constant velocity stacks (**Figure 20**). These constant velocity stacks give the seismic processor a direct view of the gathers and allows a visual interpretation of which stacking velocities do the best job of flattening the events. Another approach is to use the computer to estimate the best flattening through a term called the semblance. The highest semblance value is used to pick the stacking velocity in this case (**Figure 21**).

Once the NMO has been estimated via the stacking velocities, the computer uses the stacking velocities to correct the CDP gathers so that the reflections appear flat on the gath-

Figure 13. Shot gather after FK filtering.

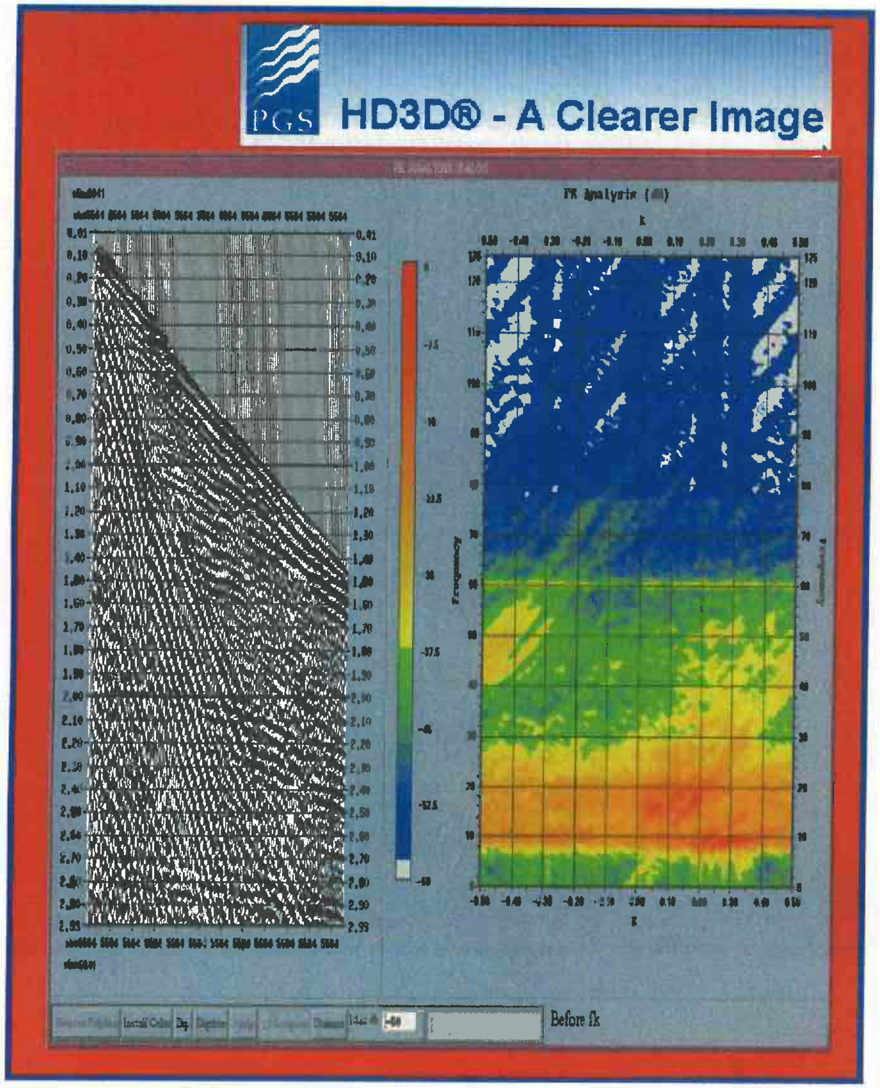


Figure 14. FK spectrum of shot gather before FK filtering.

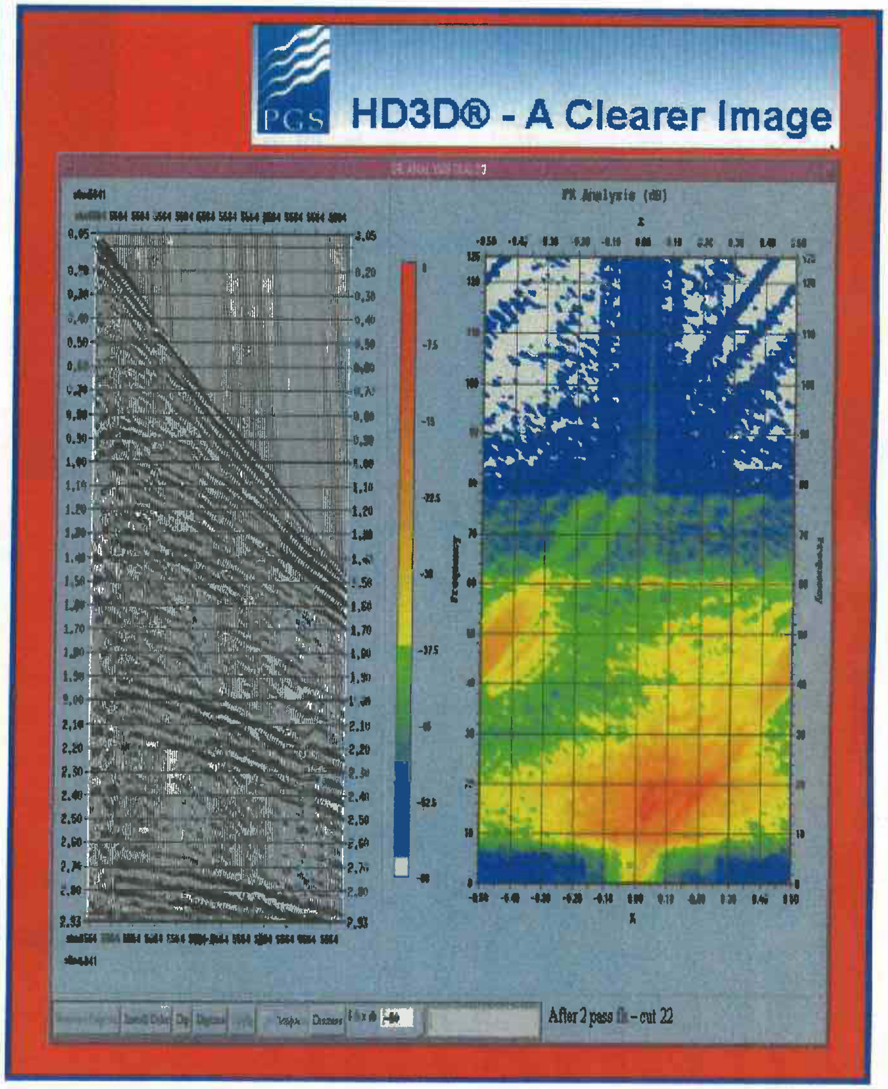
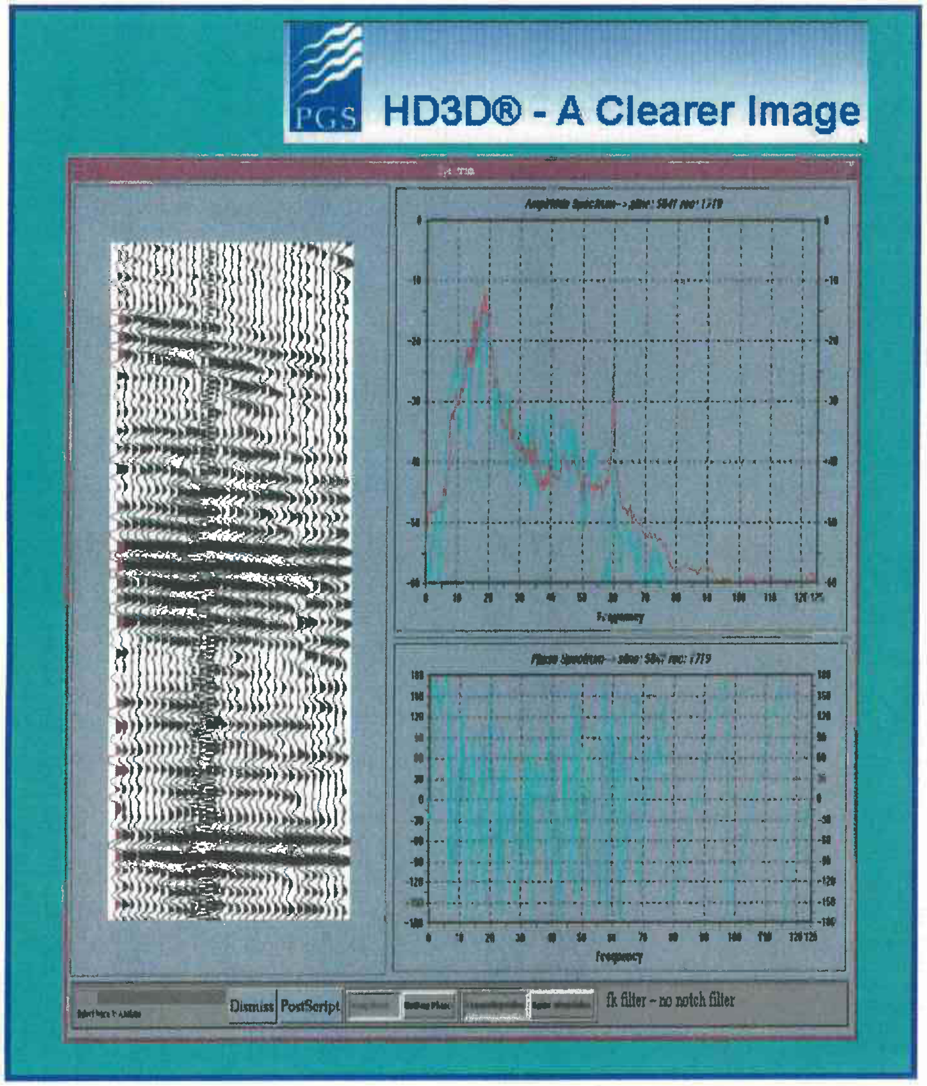
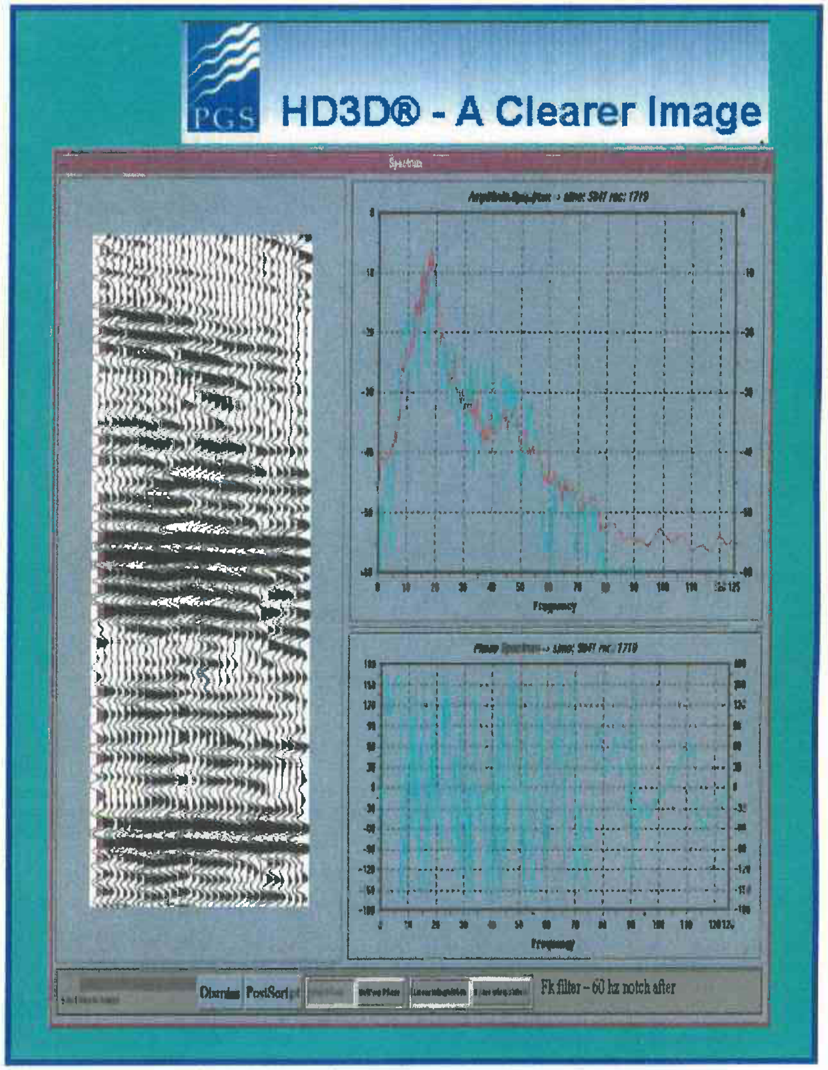


Figure 15. FK spectrum of shot gather after FK filtering.



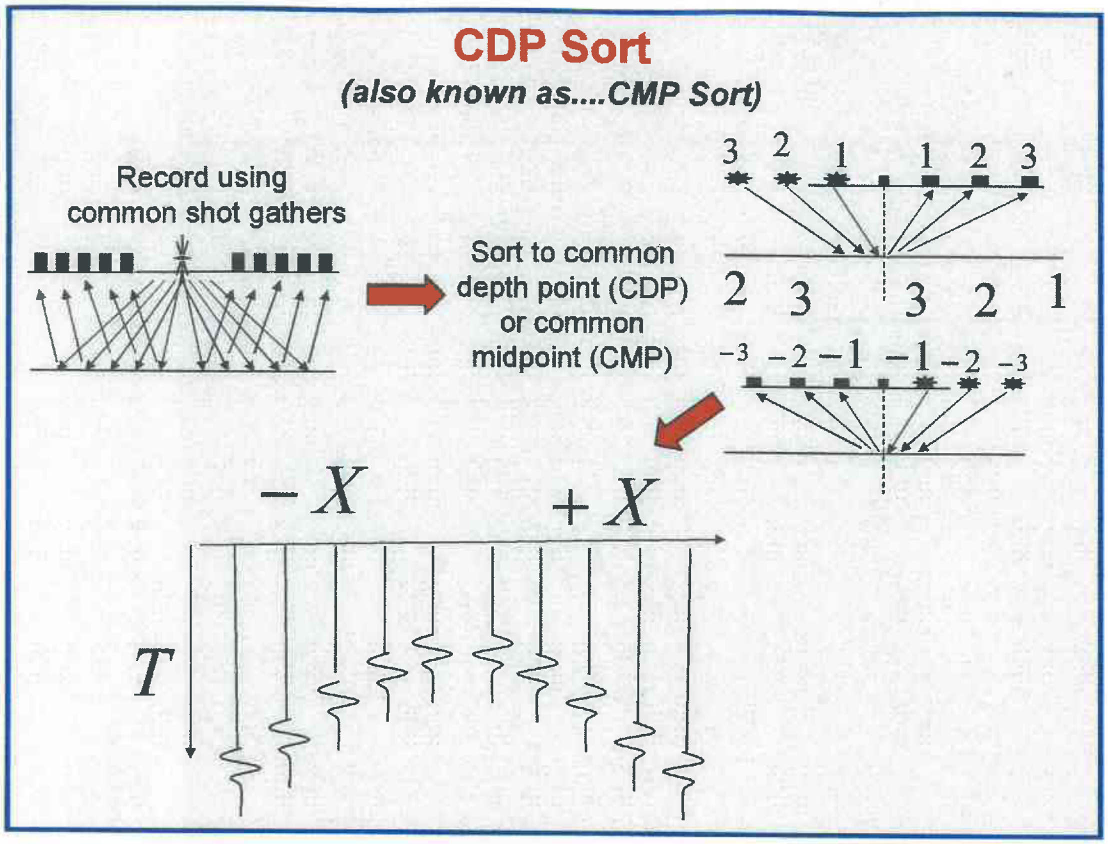
HD3D® - A Clearer Image

Figure 16. A close up of a shot gather showing the 60 Hz noise.



HD3D® - A Clearer Image

Figure 17. A close up of a shot gather with the 60 Hz noise notched.



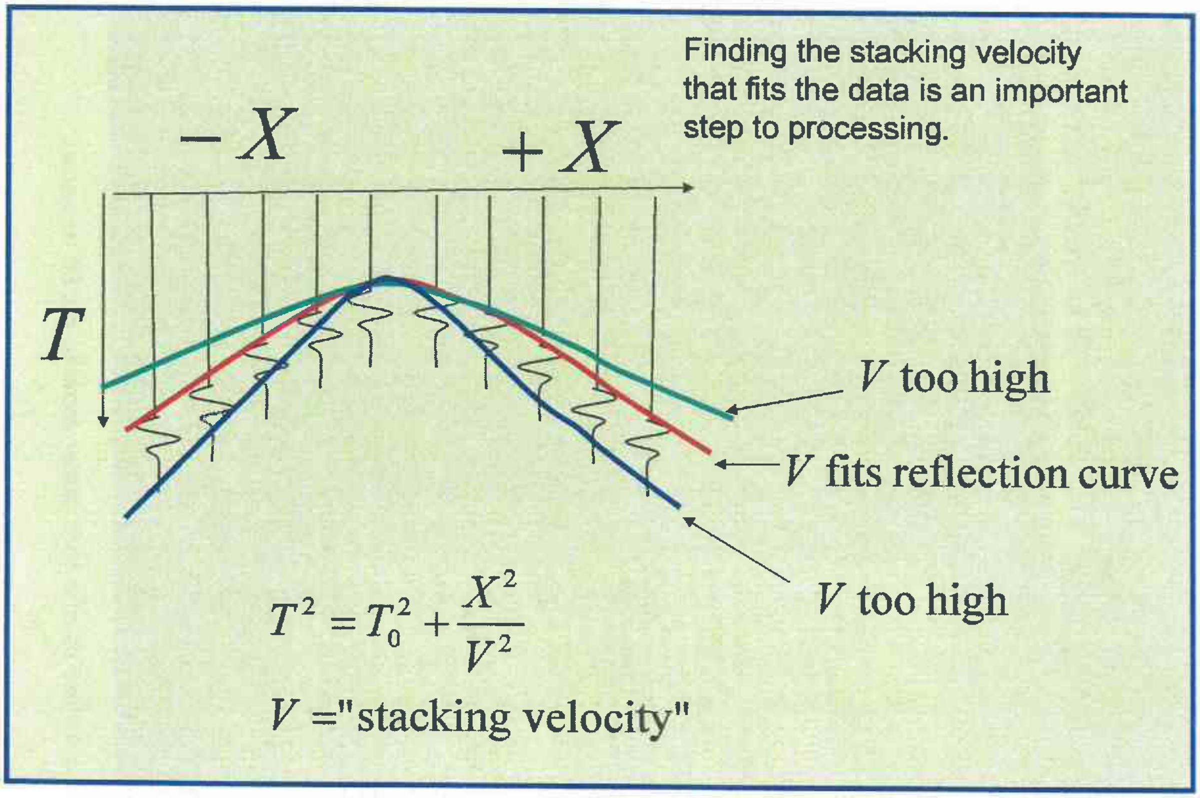
CDP Sort

(also known as....CMP Sort)

Record using common shot gathers

Sort to common depth point (CDP) or common midpoint (CMP)

Figure 18. A common depth point sort is one in which each trace represents a reflection at the same common depth point.



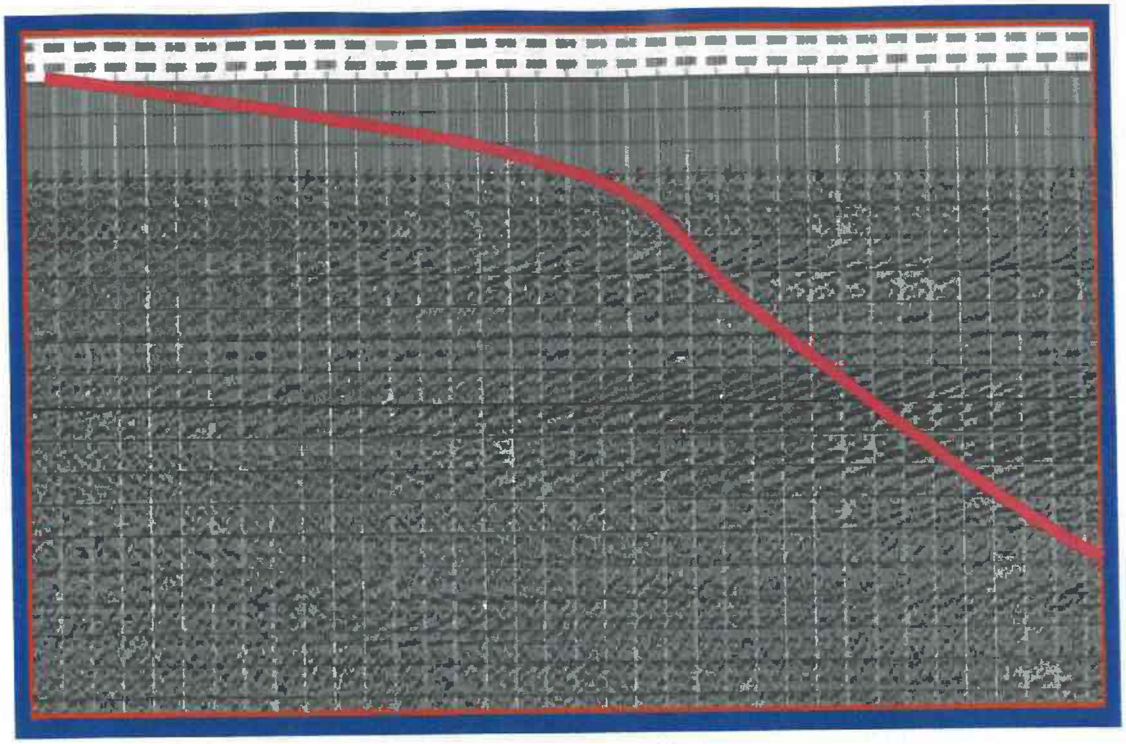
Finding the stacking velocity that fits the data is an important step to processing.

$$T^2 = T_0^2 + \frac{X^2}{V^2}$$

V ="stacking velocity"

Figure 19. Stacking Velocity Analysis. In order to match the moveout on the CMP Gathers, the "stacking" velocity in the simple equation shown has to fit the data.

Figure 20. Constant Velocity Stack. The stacking velocity interpreter can draw his pick of the stacking velocities for a series of reflectors at different depths..... giving him a continuous curve of stacking velocity versus zero offset two-way travel time.



ers. **Figure 22** illustrates a CDP gather in which a single reflector has NMO. The first step to stacking this gather is to correct the NMO. **Figure 23** illustrates the gather in Figure 22 after NMO correction has been implemented via the computer. The basic idea for this approach is to signal processing is to get multiple copies of the same signal aligned and then to average them to increase the signal to noise. You would be surprised how different the signal might look before and after this averaging. There are times when you cannot see the signal at all before the traces are averaged (or "stacked"). The number of traces averaged together is called the fold of the data. Stacking then represents a reduction of the number of traces as shown in **Figure 24**. **Figure 24** illustrates that six fold data represents 6 traces as a single trace. If you happen to be looking at a stacked seismic section described as 200 fold data, each trace viewed on this section is the result of averaging 200 traces. This is quite a reduction from the original data recorded in the field!

Final Stack

When the data has been CMP sorted, the stacking velocities determined, and NMO corrections applied, the data is "stacked" or averaged as discussed earlier. Repeating the earlier discussion, the reason for this averaging is an increase in the signal to noise ratio. Stacking simulates having a source and receiver at the same position on the surface of the Earth (called a zero offset reflection experiment). Here the term "zero offset" refers to the distance between the source and the receiver. Stacking creates a single trace that represents the signal that would be recorded by a zero offset reflection experiment conducted at a CMP point on the surface. The reflection time of a wavelet on a stacked section is the time that it takes to travel from the source on the surface to the reflector and back to a receiver at the same location (remember the zero offset condition). The plotting of a single stacked trace is plotted

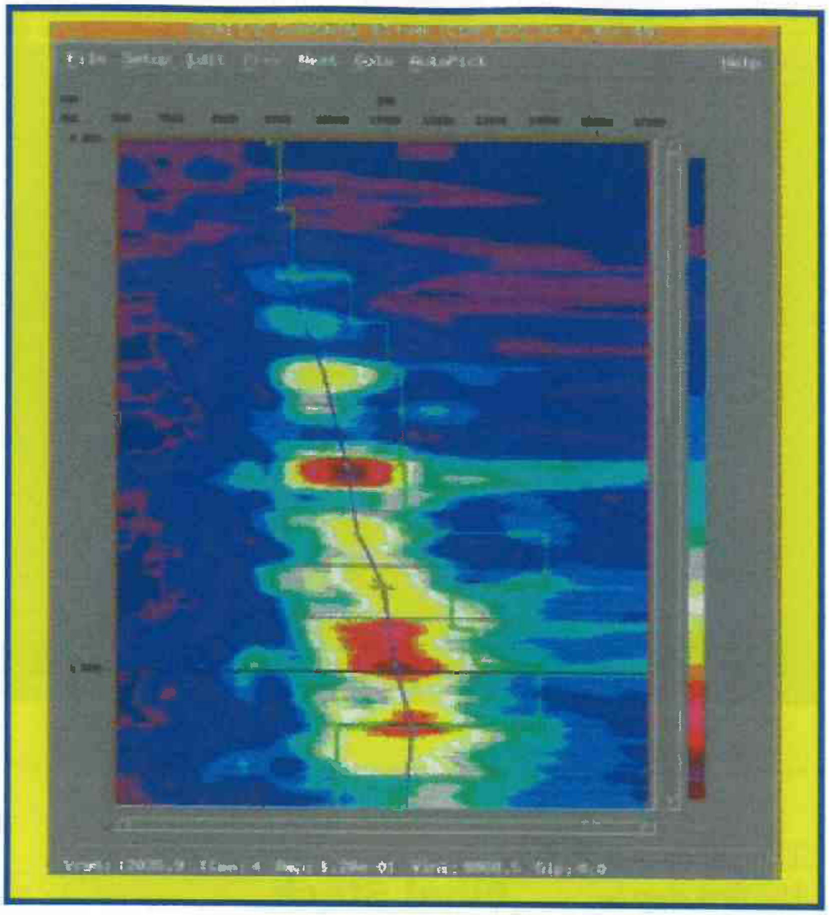
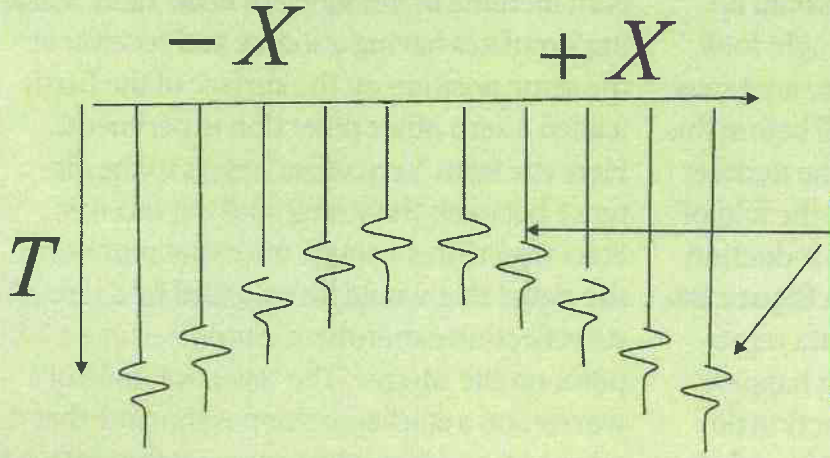


Figure 21. Semblance Plot. The computer does a lot of work to produce a semblance plot where the peaks are used to estimate the velocity at each two way traveltime.

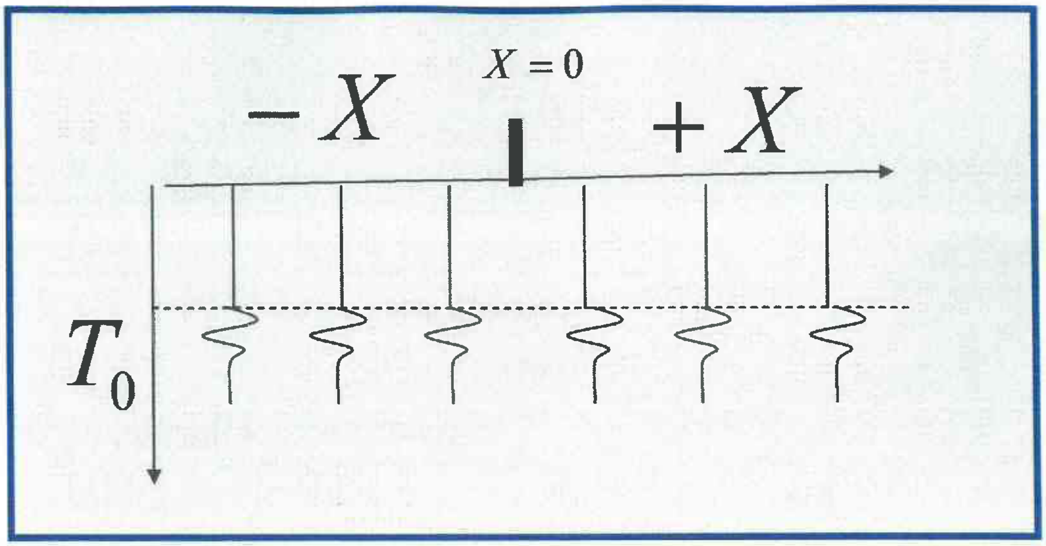
Normal Moveout (NMO)



Normal moveout is the increase in time that occurs as the source-receiver offset increases.

Figure 22. Normal Moveout (NMO). NMO is used to describe the increase in traveltime as the offset (X) increases on a CMP gather. If we have picked the correct stacking velocity for the above event, we could flatten the events by correcting the times in the above CDP Gather. This act of flattening the events by correcting the times in a CDP gather is called "NMO correction".

Figure 23. NMO Corrected Gather (flattened). When the stacking velocities are determined, NMO correction is used to flatten the reflection event. The justification for this flattening is to add multiple copies of the same signal, getting a better estimate of the signal. A lot of the noise is canceled when the traces are added like this.



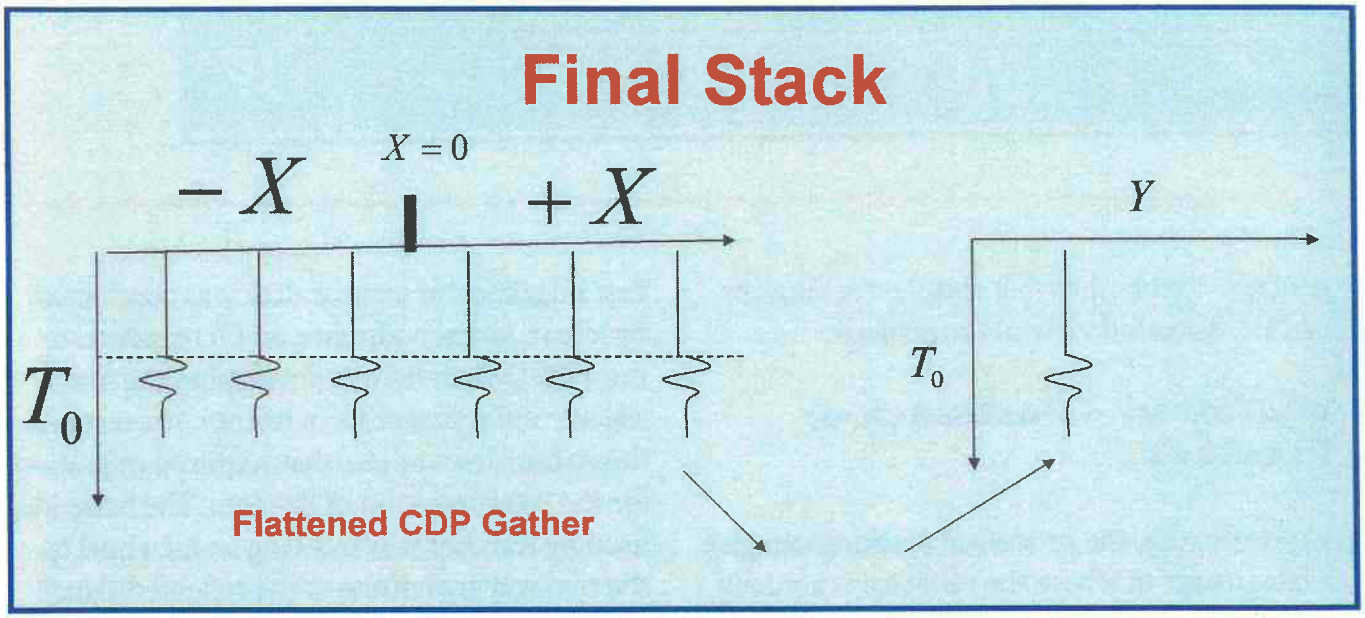


Figure 24. Average these traces together to get a final stacked trace with midpoint position Y. The number of traces in the CDP (more correctly the CMP) is called the fold. Repeating the process for each midpoint position gives the final stack.

in the vertical direction. This is a big assumption on the part of stacking. When a series of the stacked traces are plotted next to one another, the viewer gets an image of the cross section of the Earth. The imaging due to stacking works fine if the reflectors are horizontal and boring (not much in the way of interesting geology) as shown at the top of **Figure 25**. However, when there is structure or diffractions due to faulting, stacking gives a false image of the subsurface as shown in **Figure 25**. If the seismic data that is being viewed has simply been stacked, then the interpretation of that image has to correct for these artifacts of stacking. The final stack or stacked section is the result of any processing leading up to a stacked view of the

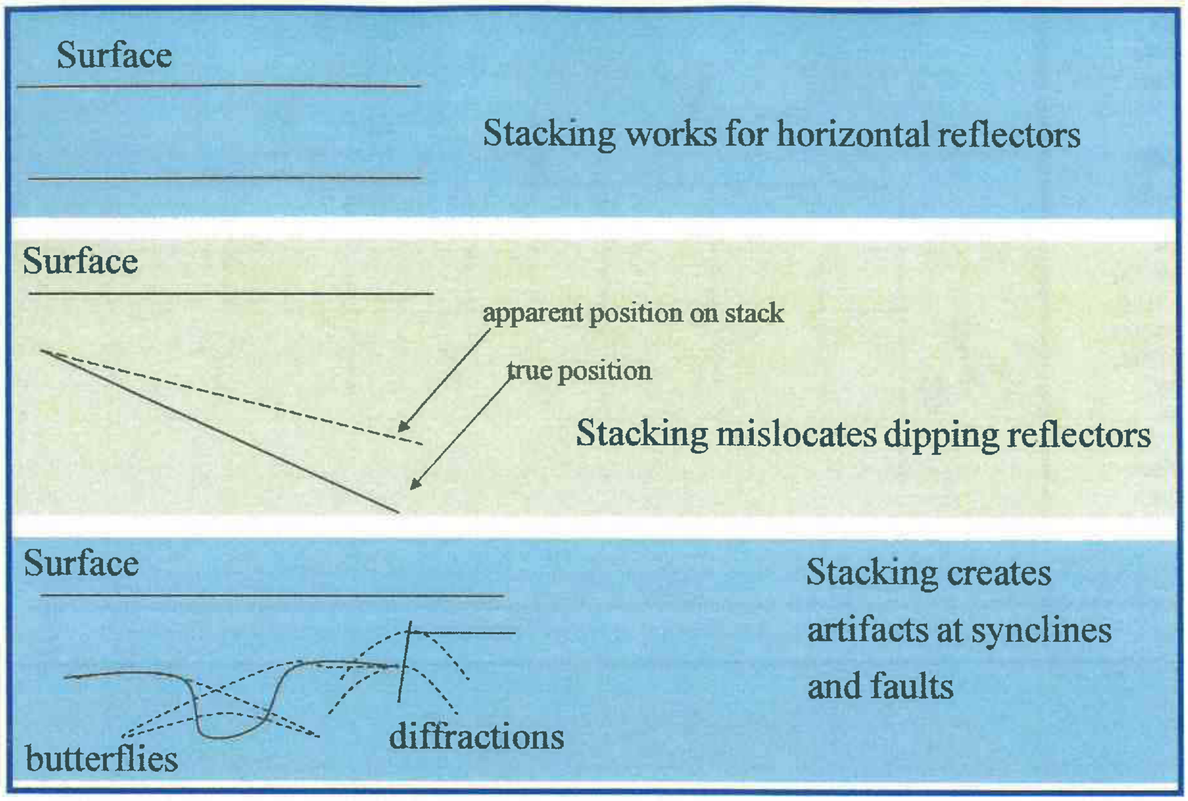


Figure 25. Stacked data can cause problems with the interpretation.

geology. Remember that simple stacking can cause a distorted view of the geology.

Migration – Poststack or Prestack

Unfortunately, the process of stacking can give a false image of where the reflector is actually located. This results from the process of always plotting the stacked traces in a vertical sense when in fact the signal could have arrived from a dipping reflector (**Figure 26**). So stacking works fine for a horizontally layered Earth, but has problems with dipping beds, curved beds, velocity variations and other details that do not exactly meet the rather ideal circumstances for stacking data shown in the bottom of **Figure 25**.

The cure for the misrepresentation of reflector position is called ***migration***. Surprisingly, the first migration of seismic data was conducted by John Clarence Karcher, an OU gradute, in the 1920's when he was developing the first seismic reflection crew in history. His test near the Arbuckles was one that required migration for the interpretation of the data. The basic idea used by Karcher was to swing an arc equal to the two way traveltime of the reflected signal. Since his recording was very close to zero offset (the same as modern day stacking), he was conducting the first migration in history. Today computers migrate by swinging arcs in very much the same manner used by Karcher (only faster) as shown in **Figure 26**.

There are many types and names for the migration algorithms offered by processing contractors. If you want to save money, it is cheaper to apply migration to stacked data. In this case the migration is referred to as ***poststack migration***. The more expensive form of migration is

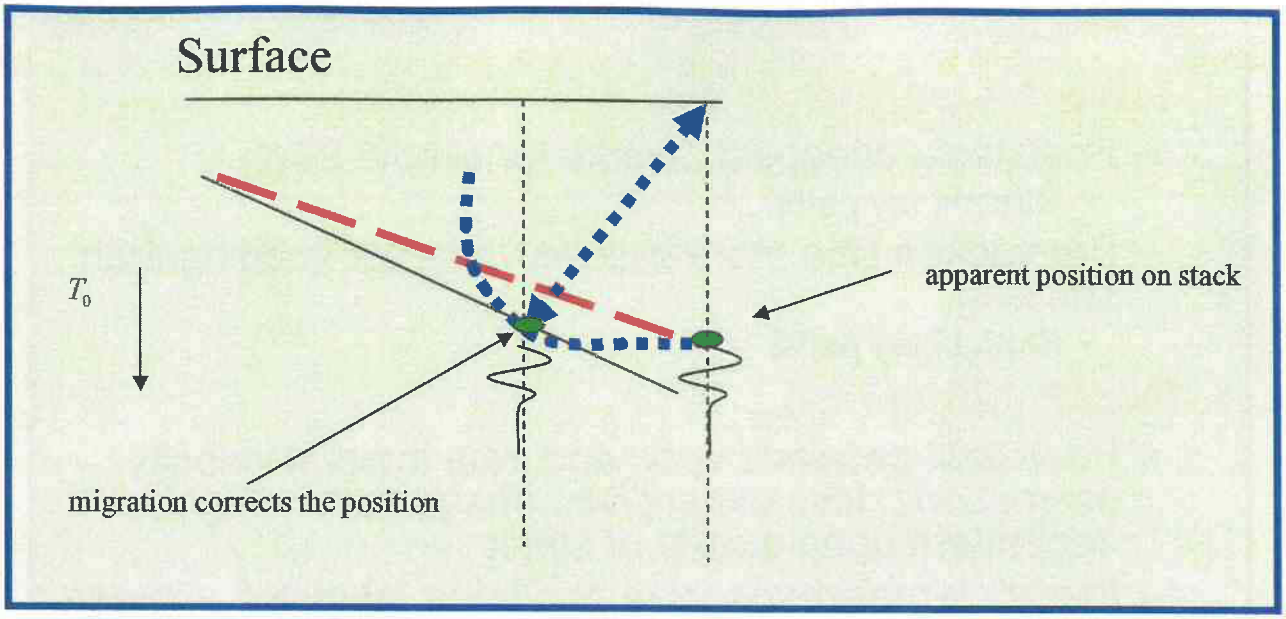


Figure 26. Migration attempts to correct for the problems with simple stacking. If you swing an arc with a radius equal to the two-way traveltime, the arc goes through the apparent position of the reflector on the stack and the actual position of the reflector. This basic idea of migration was first utilized by John Clarence Karcher in the 1920's when he developed the reflection seismic method. Today computers swing the arcs and the process is called migration.

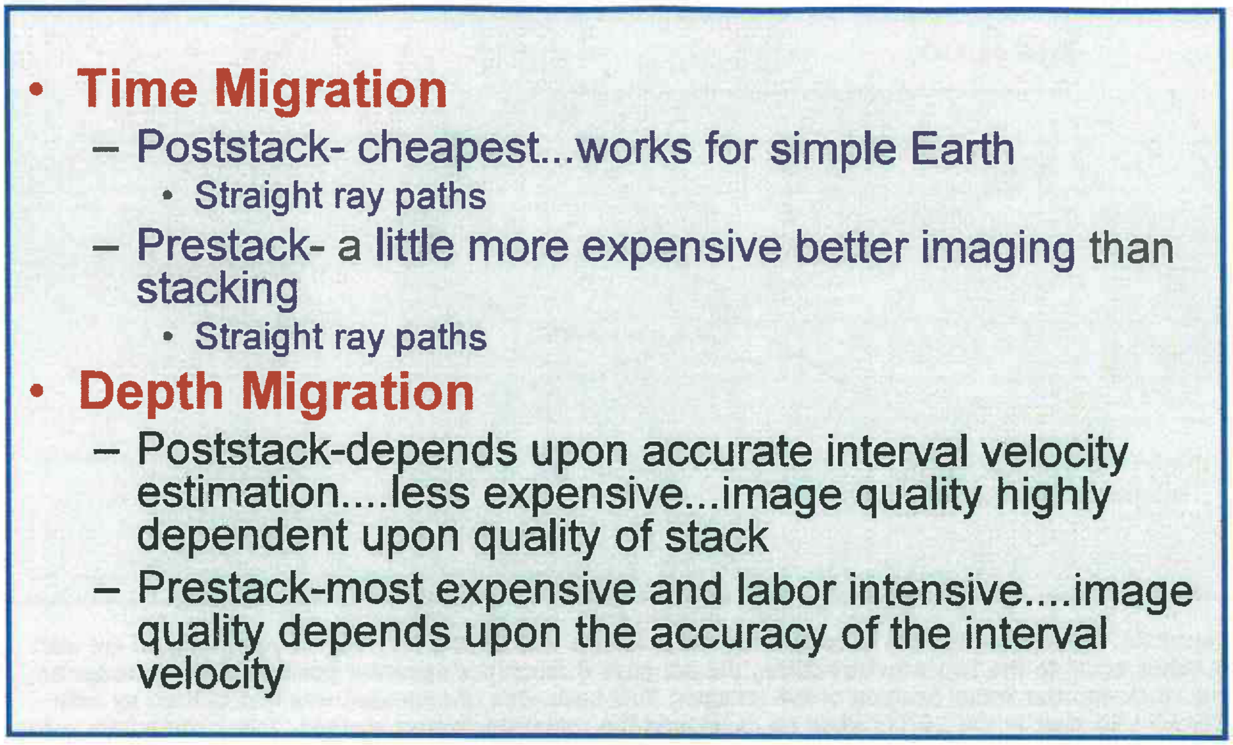
called ***prestack migration***. ***Poststack migration*** assumes that stacking has done a great job of imaging and that the migration primarily has to correct the location of the image. ***Prestack migration*** helps with the imaging as well as the location. Really nasty problems with a lot of structure, reflector dip, velocity variations and other factors require ***prestack migration***.

Within the realm of poststack and prestack migration you will find the terms time migration and depth migration. ***Time migration*** makes simplifying assumptions about the travelpaths (straight lines) while ***depth migration*** can be designed to account for all of the details in a model.

This means that the cheapest and most convenient method of migration for simple Earth models is ***poststack time migration***. If you want to spend a little bit more money to get a slight improvement in the imaging capability, you can order prestack time migration. Finally, if you have a very important prospect with a complicated geology and are willing to spend the money, you need ***prestack depth migration***. **Figure 27** lists the varieties of migration for easy reference. **Figure 28** illustrates a side view while **Figure 29** illustrates a horizontal slice through a 3D time migrated section. Time migration is the most common form of migration encountered but the simplifying assumptions in time migration should be remembered.

Treatment of Seismic Amplitudes

Geometrical Spreading describes the loss of signal amplitude due to the spreading of the wavefront as it travels down to a reflector a back. In addition, attenuation of some sort acts to further reduce the signal as it travels into the Earth and back to the surface. Often simple equations are used to approximate the



- **Time Migration**
  - Poststack- cheapest...works for simple Earth
    - Straight ray paths
  - Prestack- a little more expensive better imaging than stacking
    - Straight ray paths
- **Depth Migration**
  - Poststack-depends upon accurate interval velocity estimation....less expensive...image quality highly dependent upon quality of stack
  - Prestack-most expensive and labor intensive....image quality depends upon the accuracy of the interval velocity

Figure 27. Migration Categories. There are many ways to migrate data. Some of the basic categories for migration are listed in this figure.

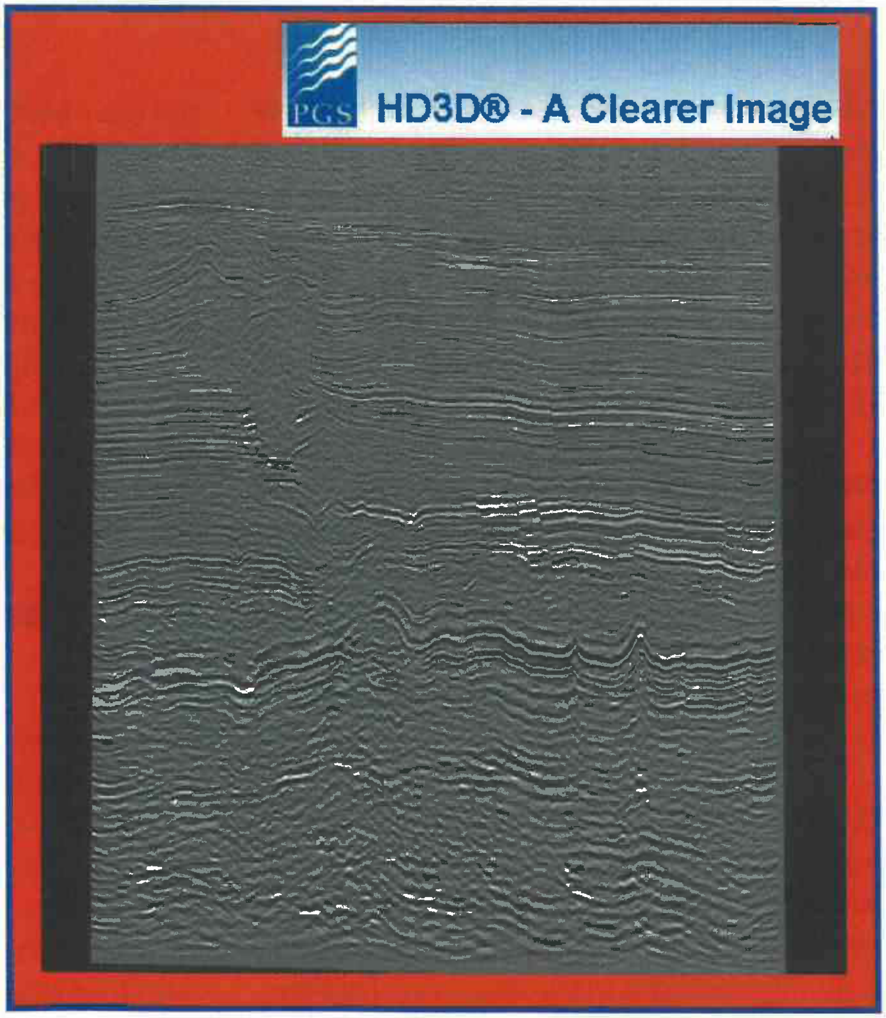


Figure 28. A selected xline after pre-stack time migration.

geometrical spreading and attenuation. If one views a ***common shot gather*** without any correction for the amplitude decay with time, one sees a trace that gets smaller with time as shown in **Figure 30**. In some types of interpretive situations (for example when you are interested in a strictly structural interpretation), it is desirable to raise the amplitudes of all the reflectors to practically the same level. In these cases a type of amplitude correction called Automatic Gain Control (AGC) is used. The basic idea is take a windowed section of the trace, determine the average amplitude within the window and then change the average amplitude to some desired value (**Figure 30**) for better viewing.

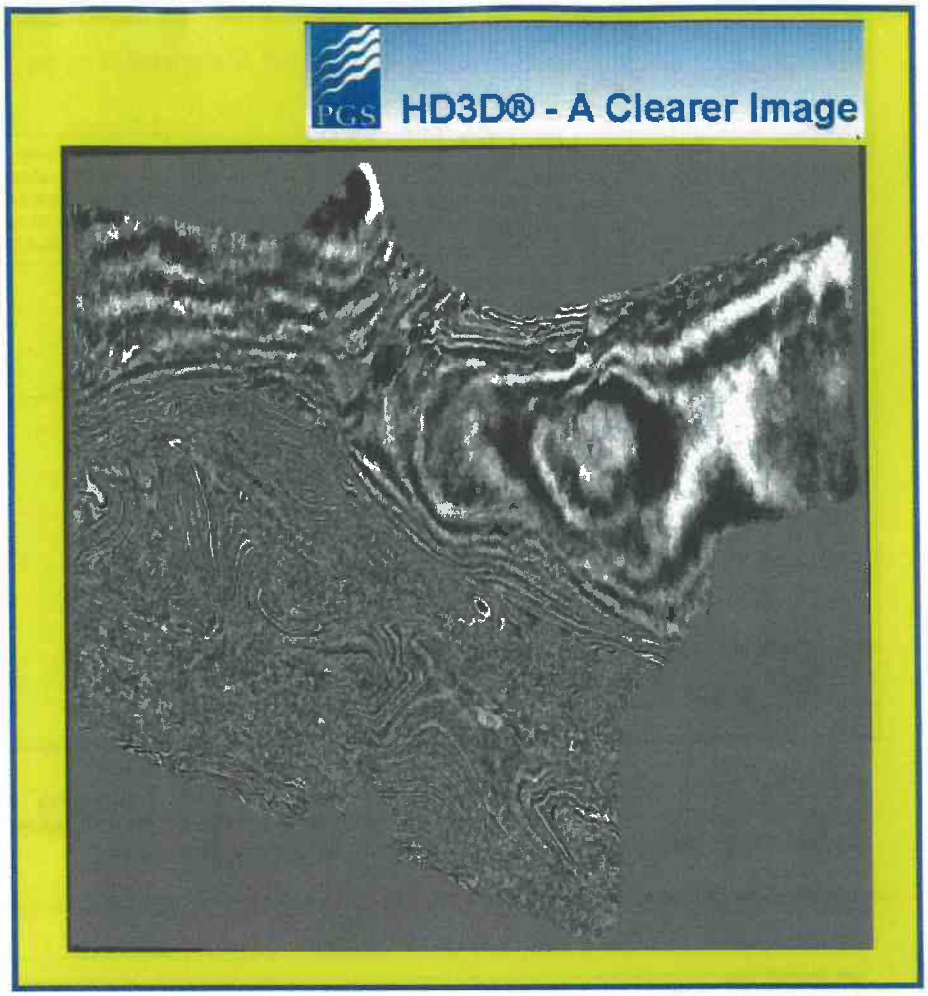


Figure 29. A selected time slice after pre-stack time migration: time 824 ms.

Many times the correction for geometrical spreading and attenuation equations are used to estimate the "true amplitude" correction to the data. The basic idea of true amplitude processing is to leave the relative amplitudes of reflectors in ratios that mimic the actual ratios in the Earth (**Figure 30**). When one is looking for the effects of gas or oil saturation or subtle stratigraphic effects, "true amplitude" treatment of amplitudes is preferred to AGC.

AVO

The reflection strength of a wave from an interface depends upon the angle of incidence. This angle depends upon the distance between the source and receiver (offset). The effort to study the angle dependent reflections of geological horizons is called ***Amplitude Versus Offset (AVO)***. **Figure 31** illustrates the idea behind AVO in interpreting reflection angle versus incidence. ***AVO*** is useful for detecting certain fluid properties and elastic properties associated with reflectors (**Figure 32**). For example, AVO was a very useful tool for certain companies exploring for gas in the San Juan Basin. The problem there was separating a gas reservoir from a coal bed because they both created "bright spots" or high amplitude reflectors.

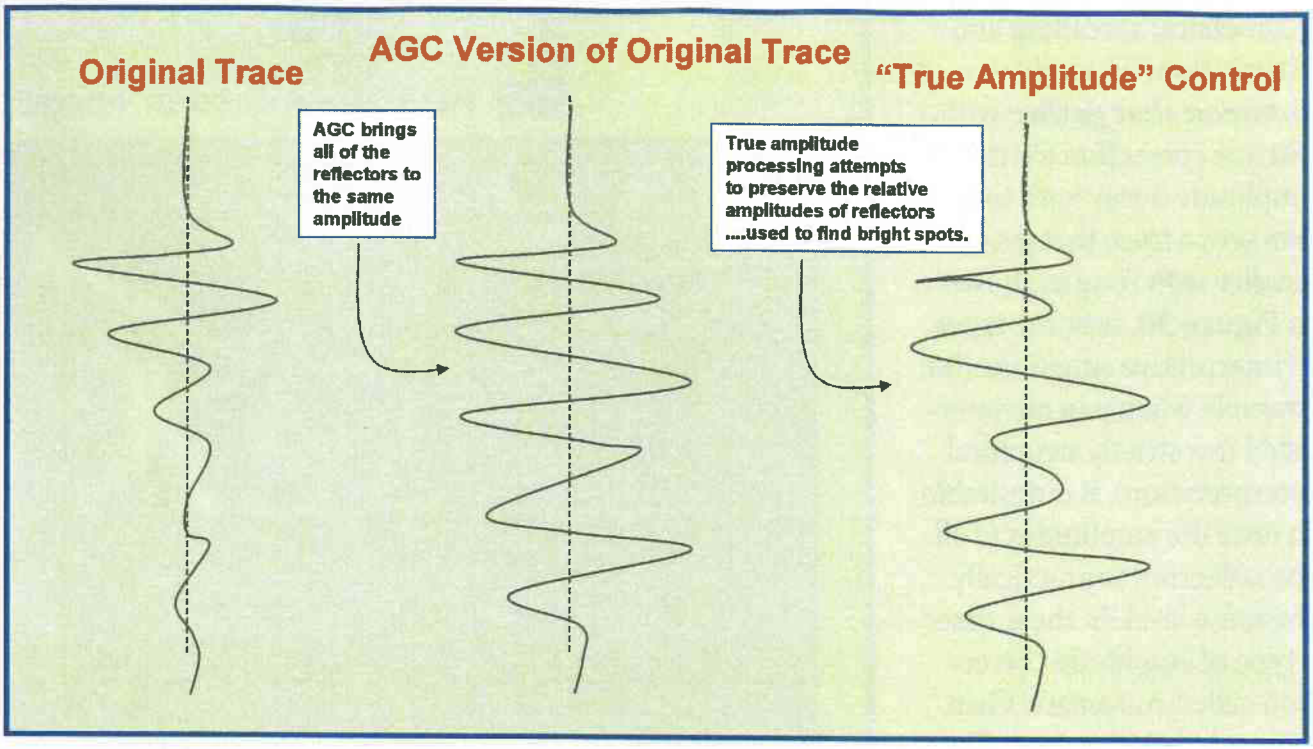


Figure 30. Automatic gain control (AGC) and "true amplitude processing" are used to make all the reflections visible on a seismic section. AGC is often used when structure is of interest while true amplitude processing is used when stratigraphic or fluid saturation issues are important.

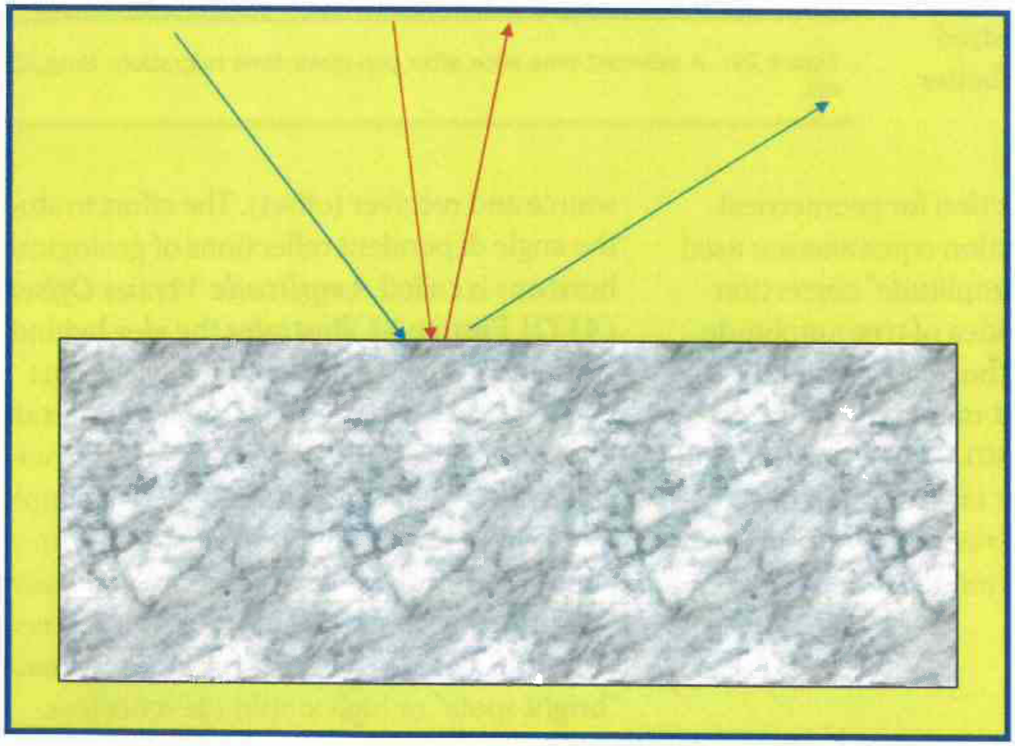
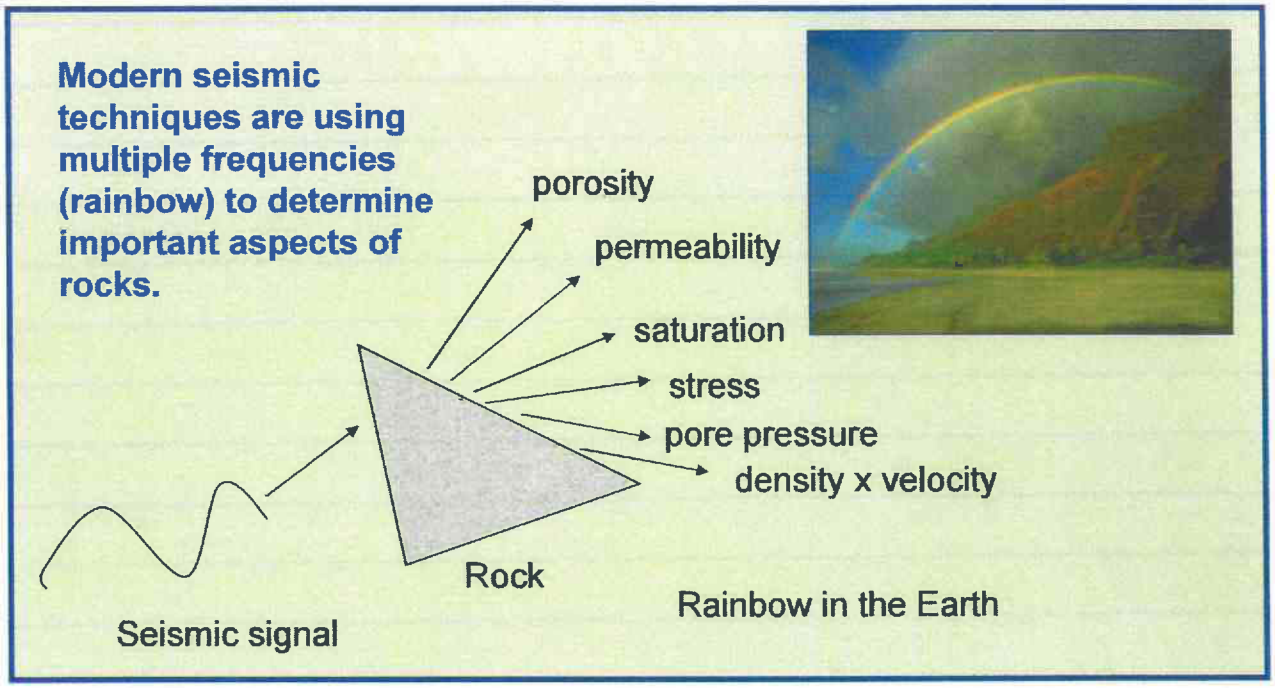


Figure 31. Amplitude Versus Offset (AVO)- The reflection coefficent of a rock varies as the angle of incidence changes. In other words, as the source-receiver distance (the offset) changes, the amplitude changes. When the amplitude of a reflection is being studied as a function of angle of incidence, it is referred to as AVO.

AVO Applications

- Lithology Changes
- Fluid Changes

Figure 32. AVO Applications. AVO can be used to map changes in lithology and/or changes in fluid content. For example, AVO was very useful in the San Juaquin Basin distinguishing gas sands from coal beds.



Modern seismic techniques are using multiple frequencies (rainbow) to determine important aspects of rocks.

Figure 33. Inversion is a very general term for going from seismic (and possibly other data) to a better picture of the reservoir. In the early days of seismic exploration, impedance (the product of the density times the velocity) was the primary interest with inversion. Today the combined use of frequency-dependent velocities and attenuation are used to invert for important reservoir properties (porosity, permeability, saturation, stress and pore pressure). Some geophysicists refer to this multifrequency view of seismic data as the "rainbow in the Earth" because using multiple frequencies gives a more complete understanding of the Earth's properties.

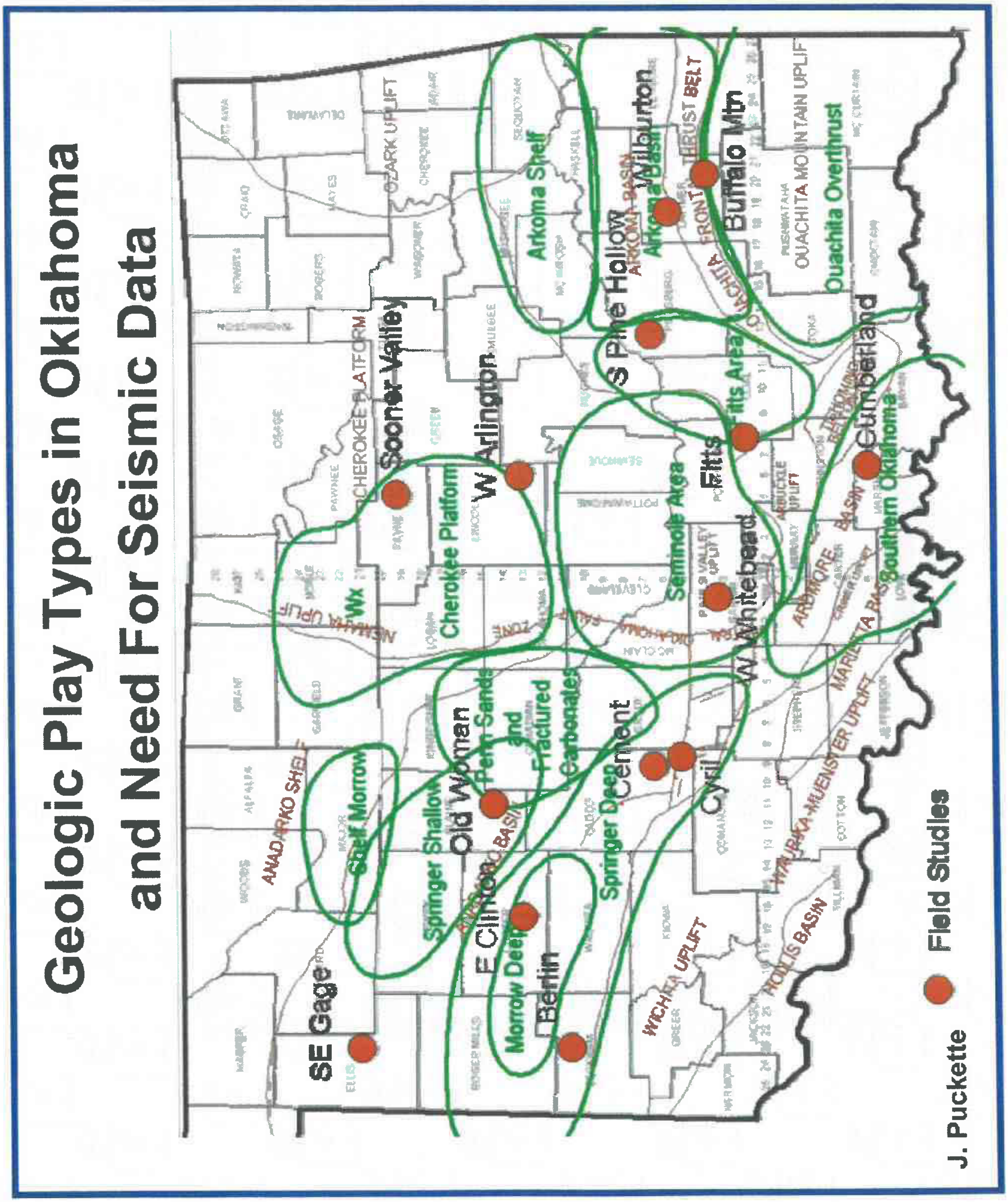
Inversion

Inversion is a broad term used to imply that one is going from the seismic trace to some estimation of an important property of the reservoir (Figure 33). An early form of inversion made estimates of the acoustic impedance (the product of the density times the velocity of a formation). Today inversion applies to all aspects of a reservoir that can be possibly obtained from seismic data. The term "seismic data" might imply the image, the velocities of the data or even the attenuation of the data). Thus one might consider using inversion to obtain the stress of the reservoir, the pore pressure, and the saturation using velocity, density (impedance) and attenuation effects of the reservoir. Inversion has come a long way since it was first initiated.

NOTES

Geologic Play Types in Oklahoma and Need for Seismic Data

James O. Puckette



Generalized Classification of Plays by Drive Mechanisms

Strong Water Drive: Hydrodynamic

Water Leg in Reservoir, But Not Overly Mobile: Hydrostatic

Water Not a Factor: Gas-Solution Drive, Including Compartmentalized Gas Accumulations in Deep Anadarko Basin

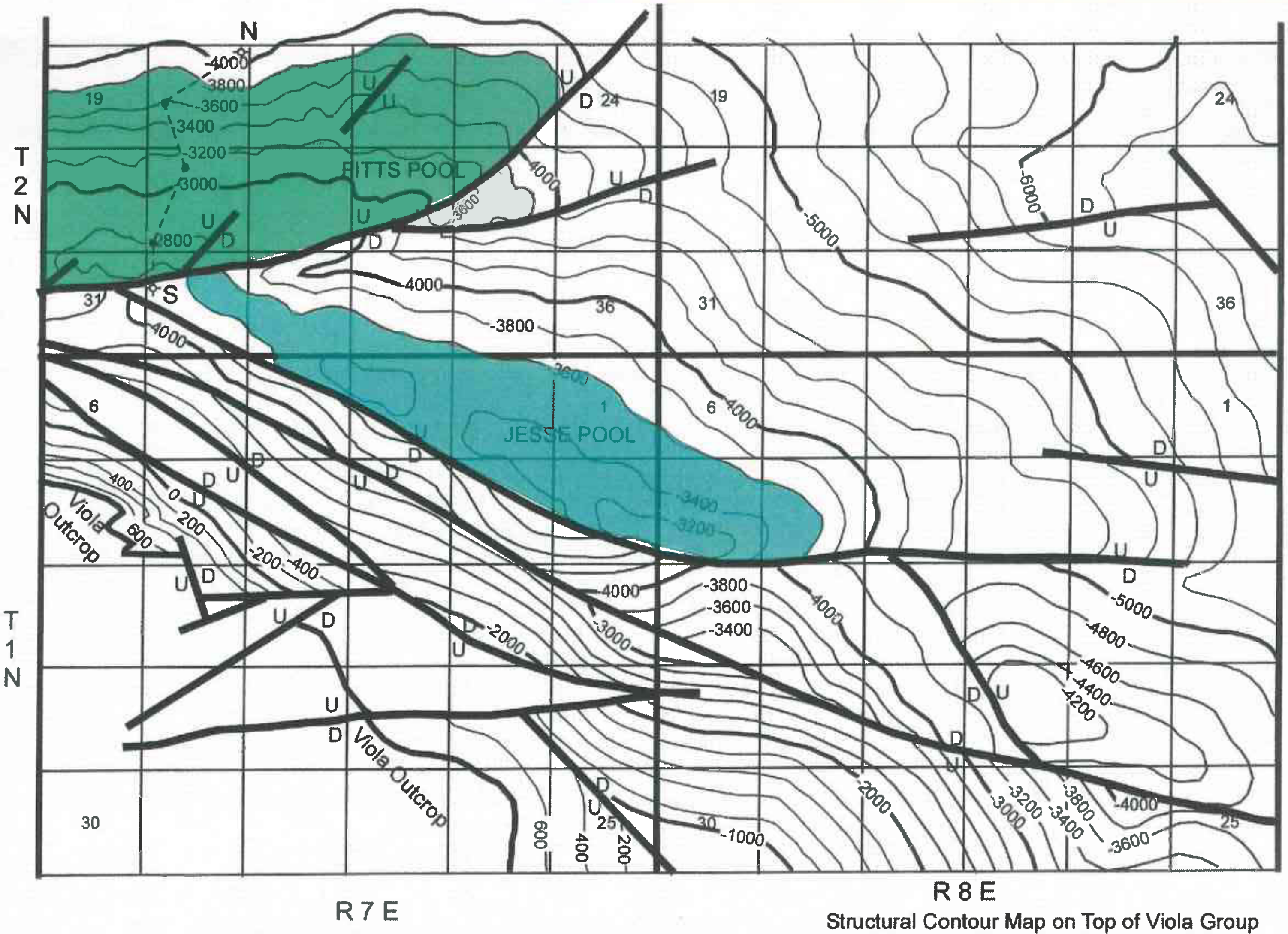
Hydrodynamic Reservoirs
Strong Water Drive

- Arbuckle Group Carbonates
- Simpson Group Sandstones
  - Wilcox Sandstones – Central, Northern and Eastern OK
  - Bromide Sandstones – Southern Oklahoma
  - McLish Sandstone - Southern Oklahoma
  - Oil Creek Sandstone – Southern Oklahoma

Structure: Anticlinal Folds or Faults are Necessary to Trap Oil and Gas

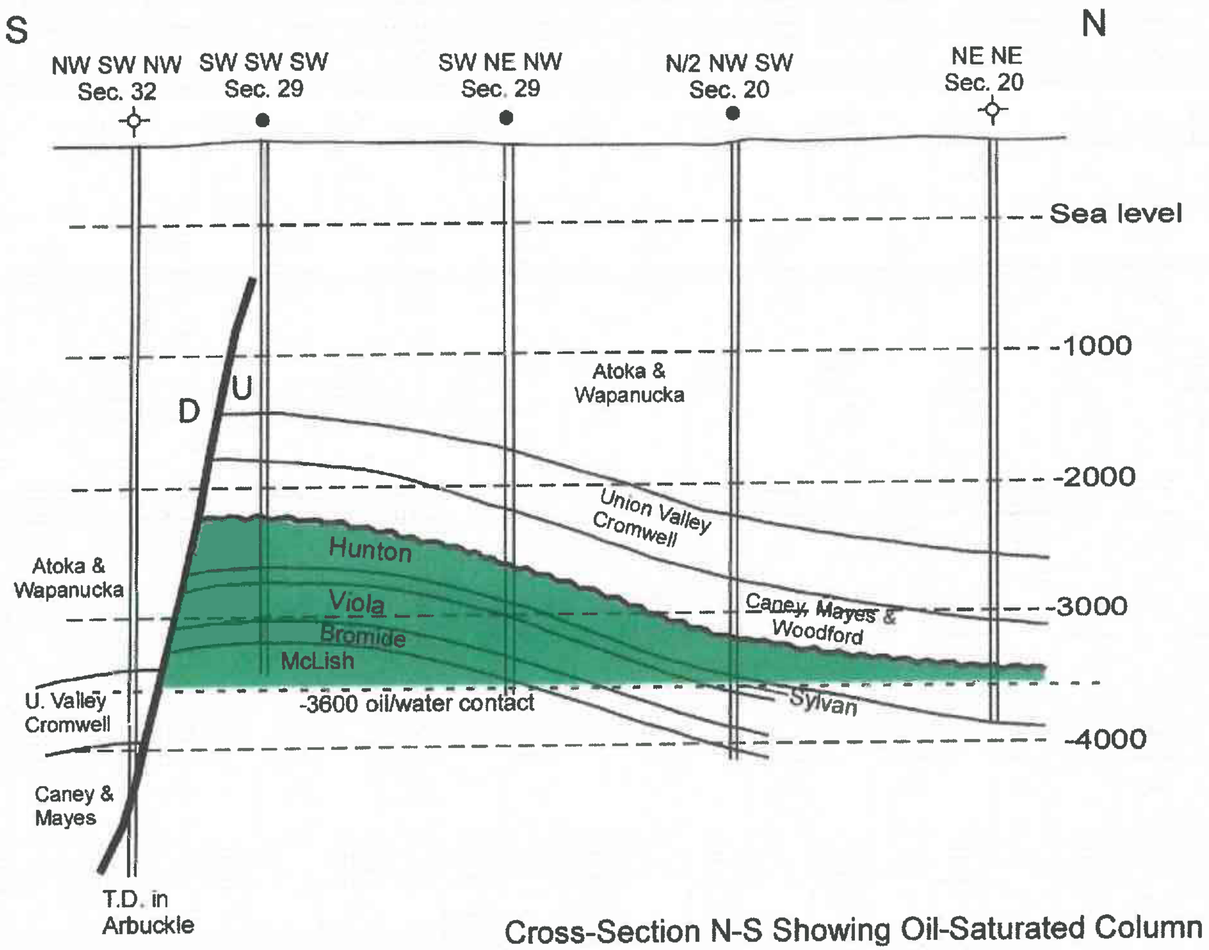
Variable Thickness in Simpson Sandstones Contributes to Trapping

Seismic Application: Define Structural Attitude of the Reservoir or Marker Bed



Structural Contour Map on Top of Viola Group
Fitts and Jesse Pools
Pontotoc County, Oklahoma

Anticlinal Folds (Faulted) in Franks Graben, Arkoma Basin: Need to Define Structure



Cross-Section N-S Showing Oil-Saturated Column
Fitts Pool
Pontotoc County, Oklahoma

After Puckette and others (2000)

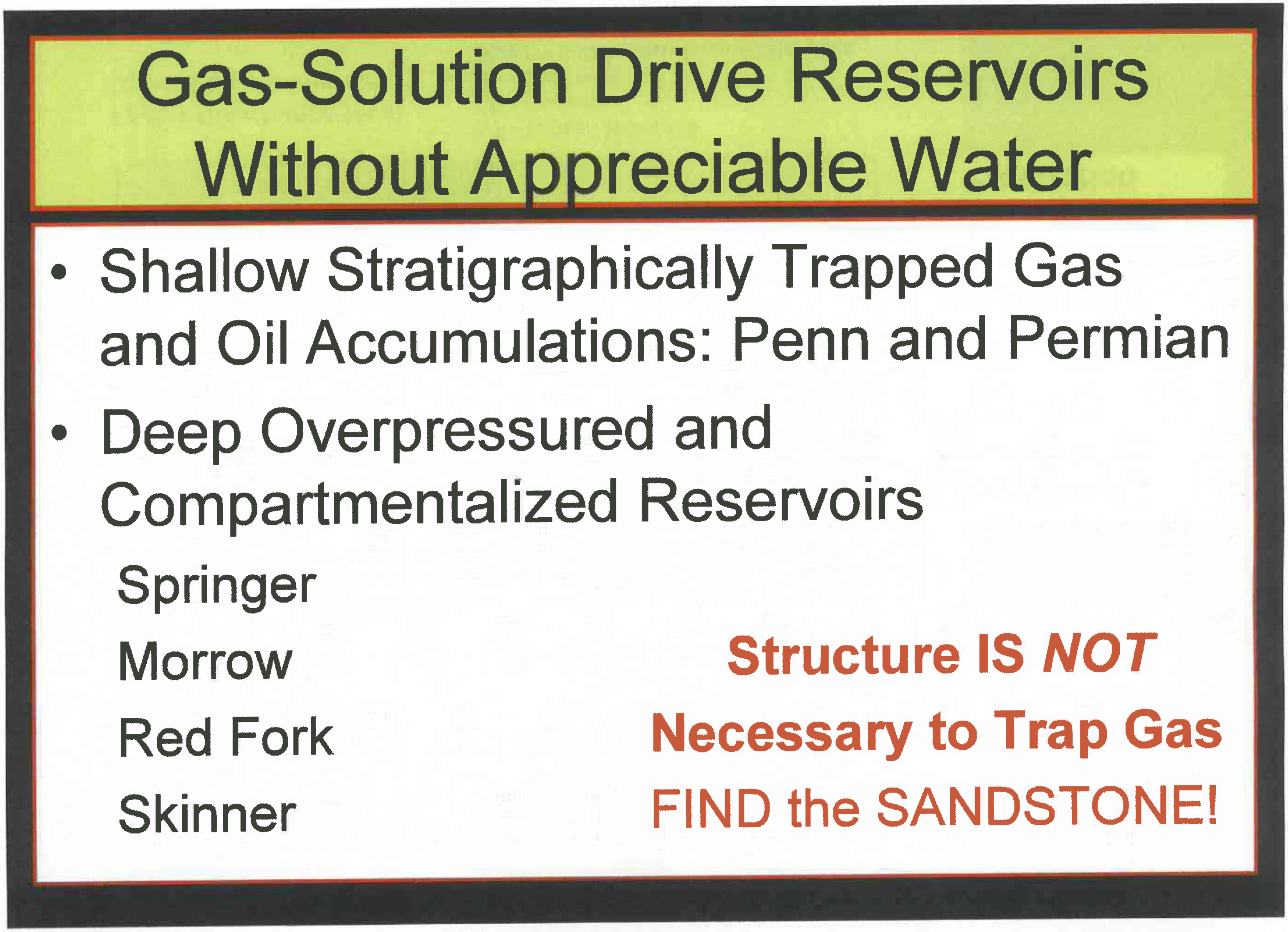
Cross-Section Through Fitts Structure Showing Accumulation of Oil and Gas Above the -3600 Feet (susbsea) Elevation

Hydrostatic Reservoirs
Relatively Static Water Leg Present

- Ordovician Carbonates: Viola Limestone
- Ordovician to Devonian: Hunton Group
- Pennsylvanian Sandstones:
  - Shelf of Anadarko and Arkoma Basins
  - Cherokee Platform

Structure is not entirely necessary to trap oil and gas. However, Structure Facilitates Conventional Trapping

3-D Seismic Can Define Structure; Delineate Sandstone Trends



Gas-Solution Drive Reservoirs Without Appreciable Water

- Shallow Stratigraphically Trapped Gas and Oil Accumulations: Penn and Permian
- Deep Overpressured and Compartmentalized Reservoirs

Springer

Morrow

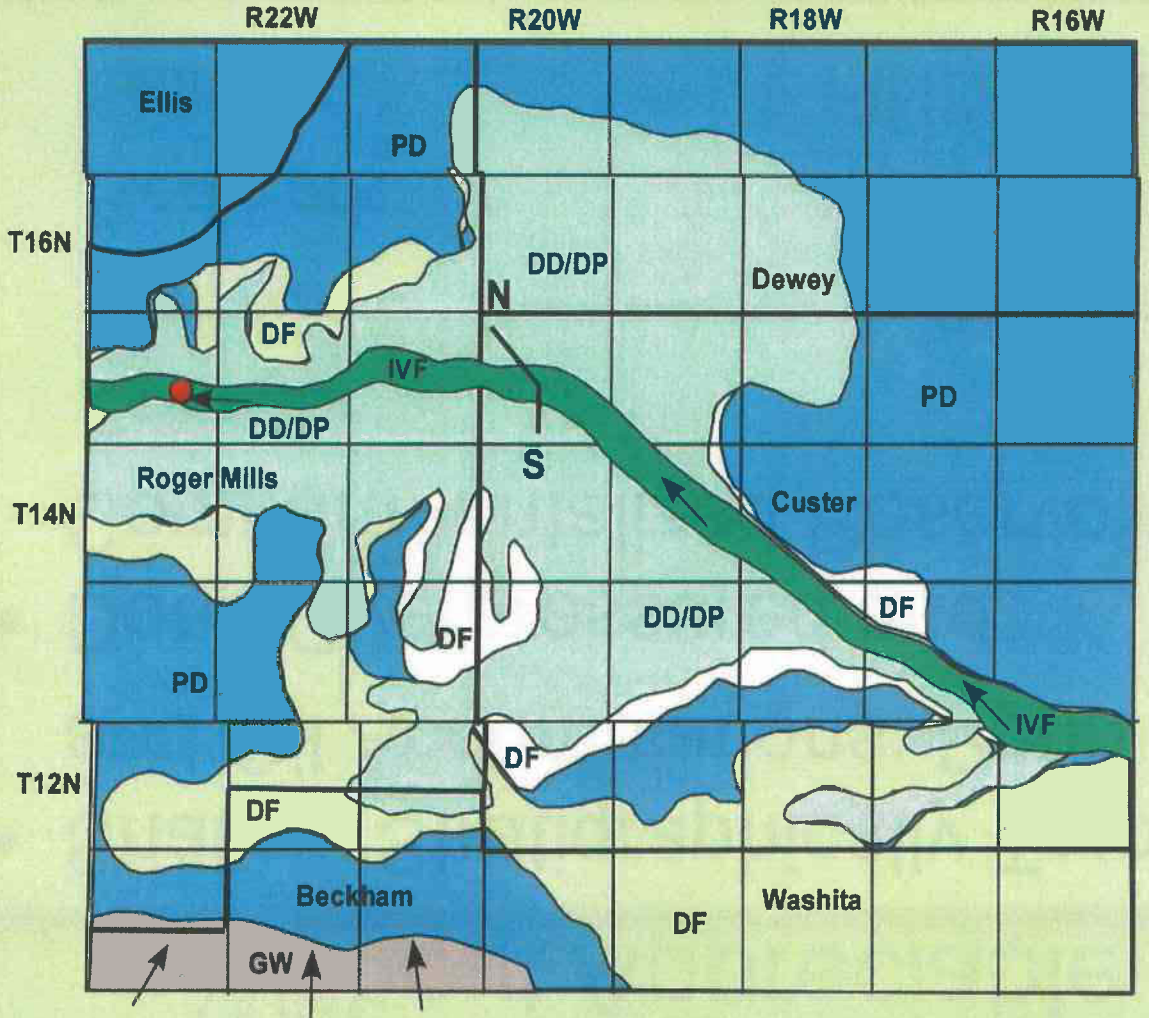
Red Fork

Skinner

Structure IS *NOT*

Necessary to Trap Gas

FIND the SANDSTONE!



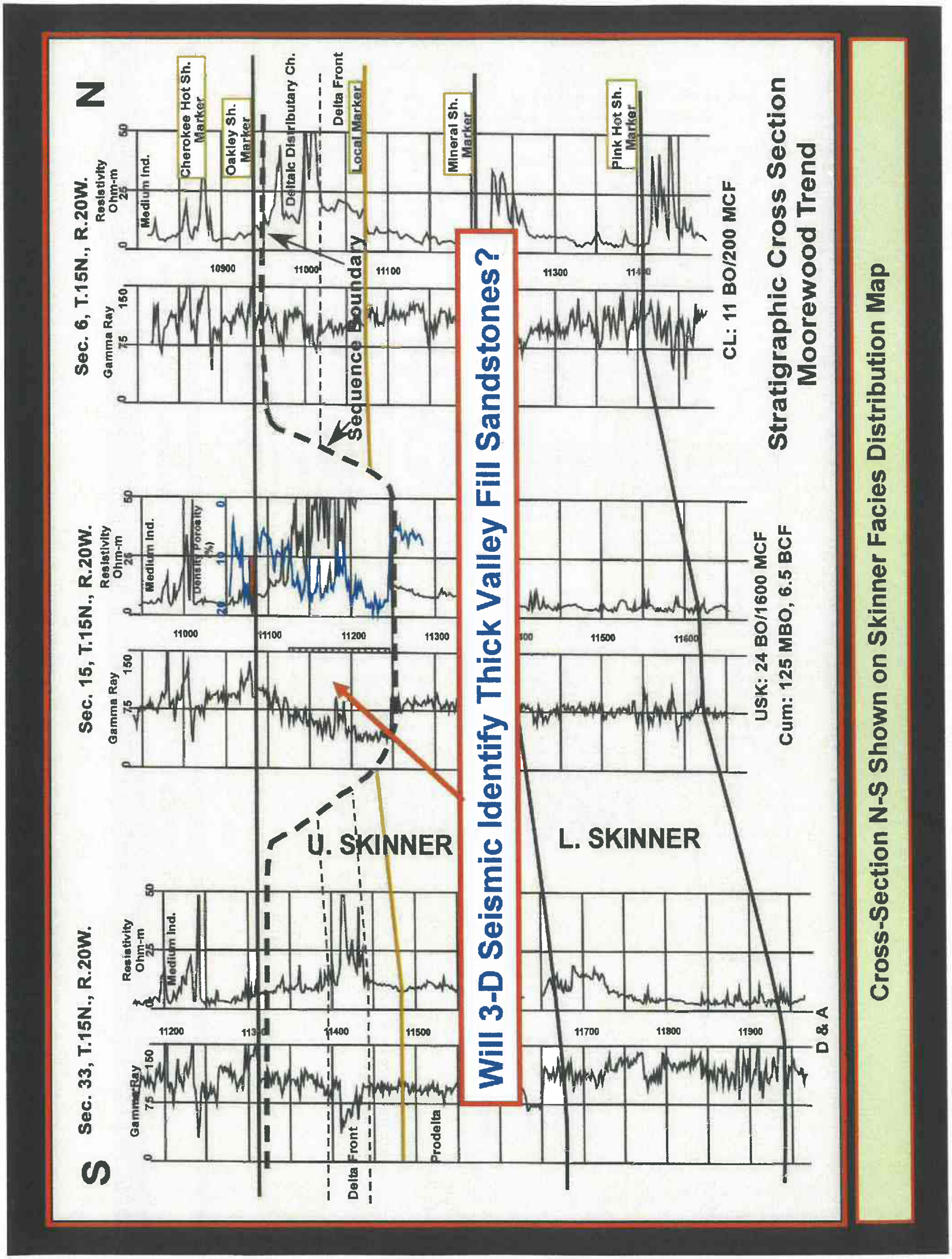
Facies Distribution Map:
Upper Skinner Interval

IVF - Incised Valley Fill
PD - Prodelta
DF - Delta front

Moorewood Trend

Depositional Facies and Production:

IVF: Incised Valley Fill Represents Better Reservoir and Production



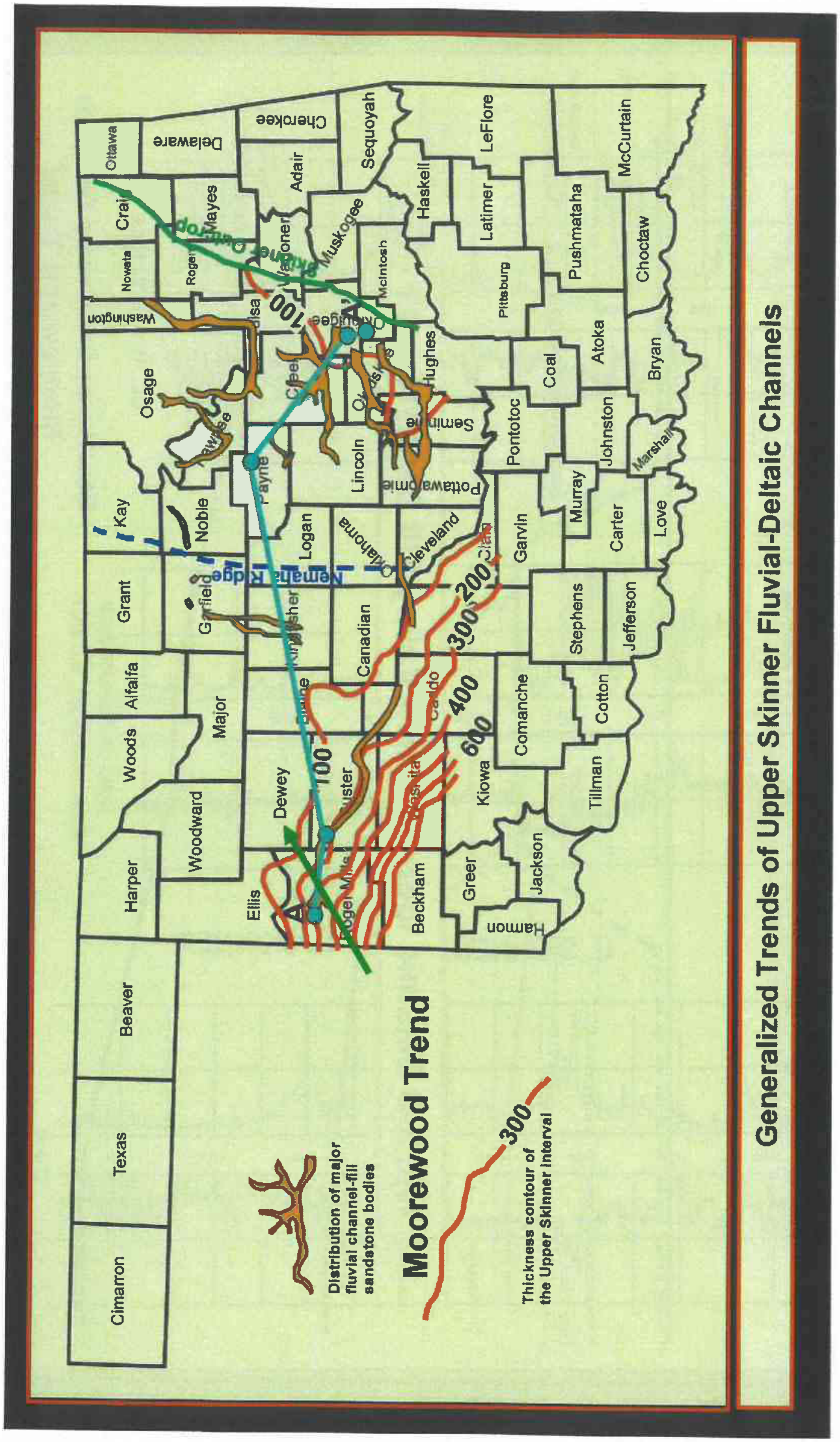
Will 3-D Seismic Identify Thick Valley Fill Sandstones?

Stratigraphic Cross Section
Moorewood Trend

CL: 11 BO/200 MCF

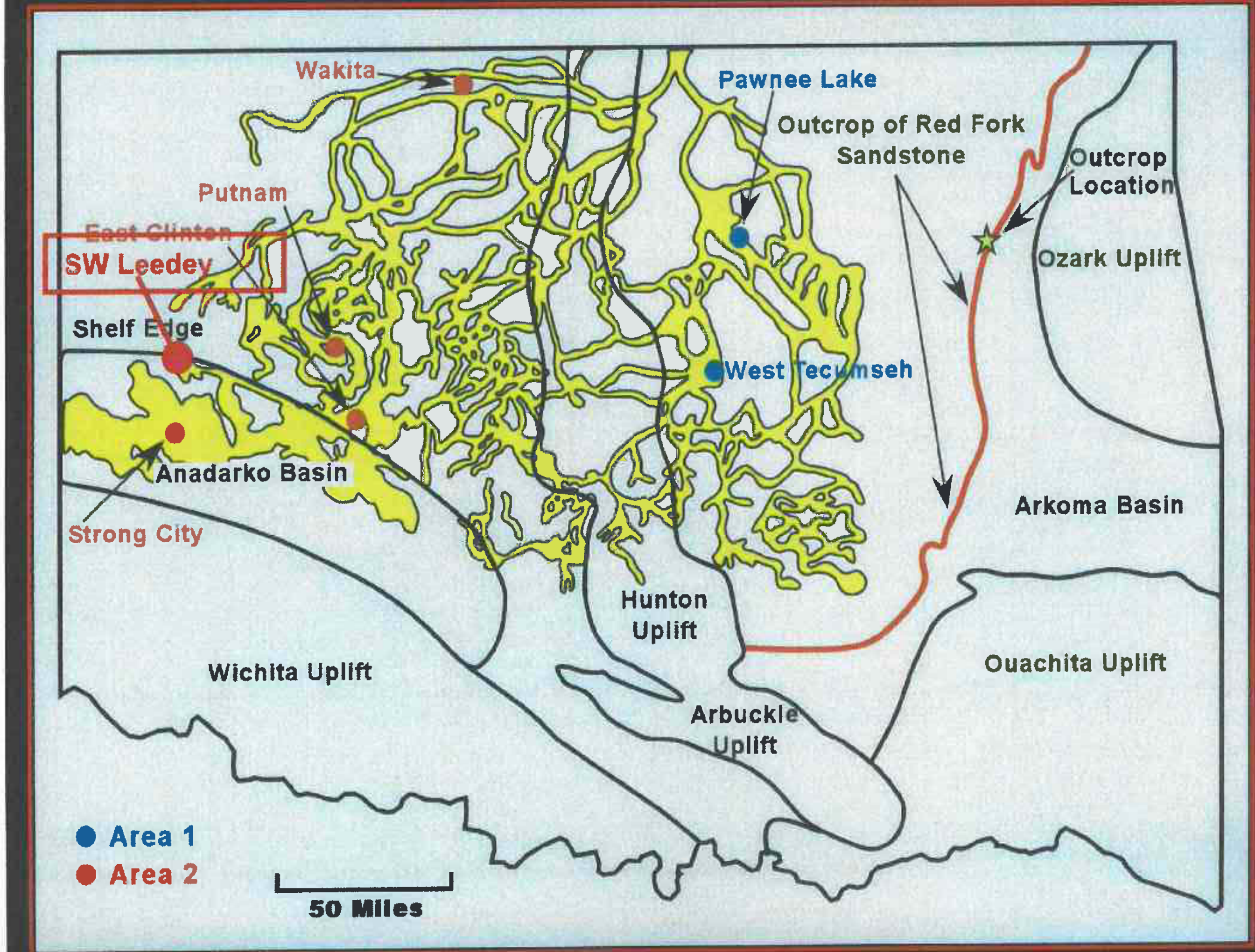
USK: 24 BO/1600 MCF
Cum: 125 MBO, 6.5 BCF

Cross-Section N-S Shown on Skinner Facies Distribution Map



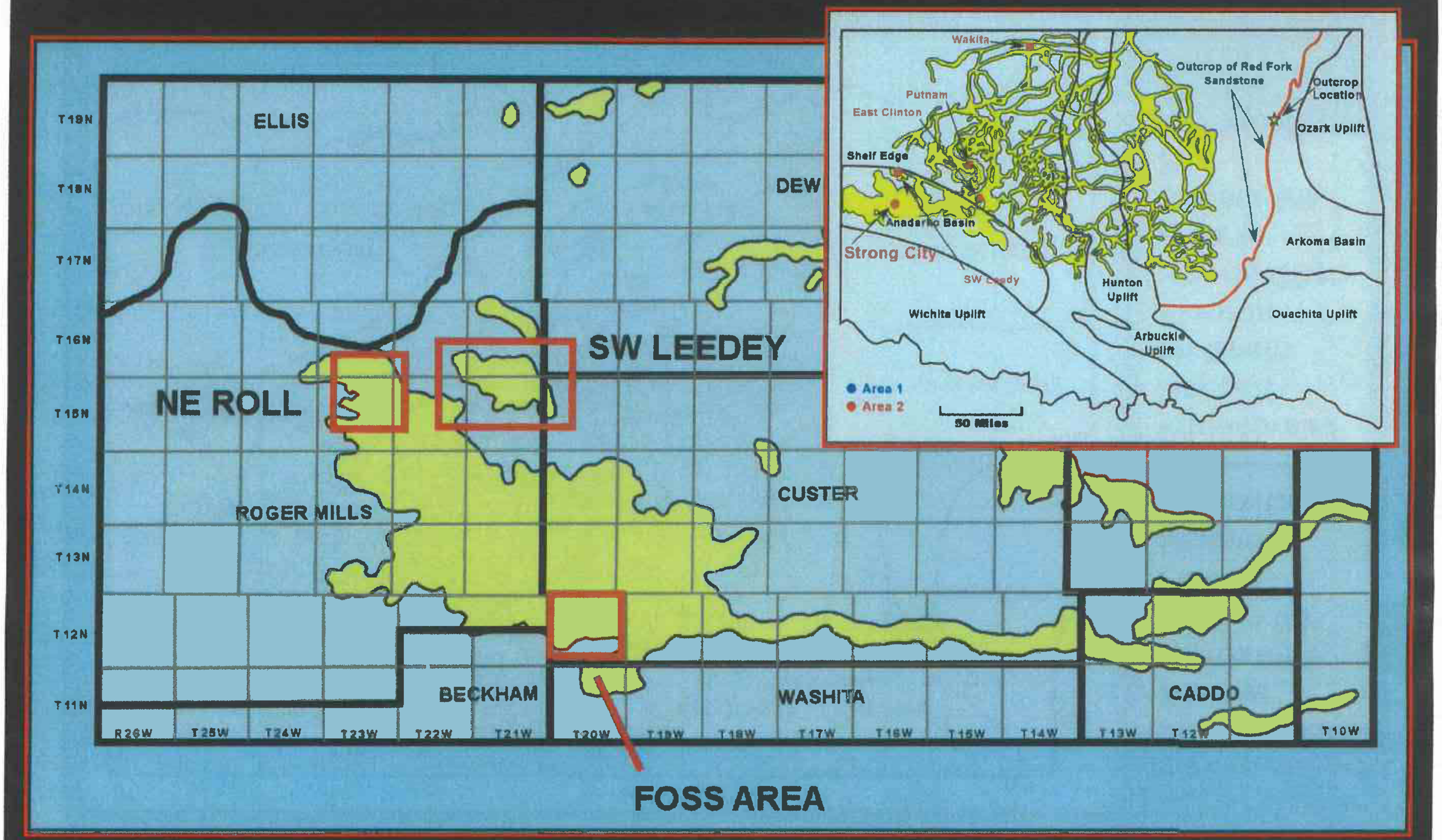
Generalized Trends of Upper Skinner Fluvial-Deltaic Channels

Surface and Subsurface Extent of the Red Fork Sandstone



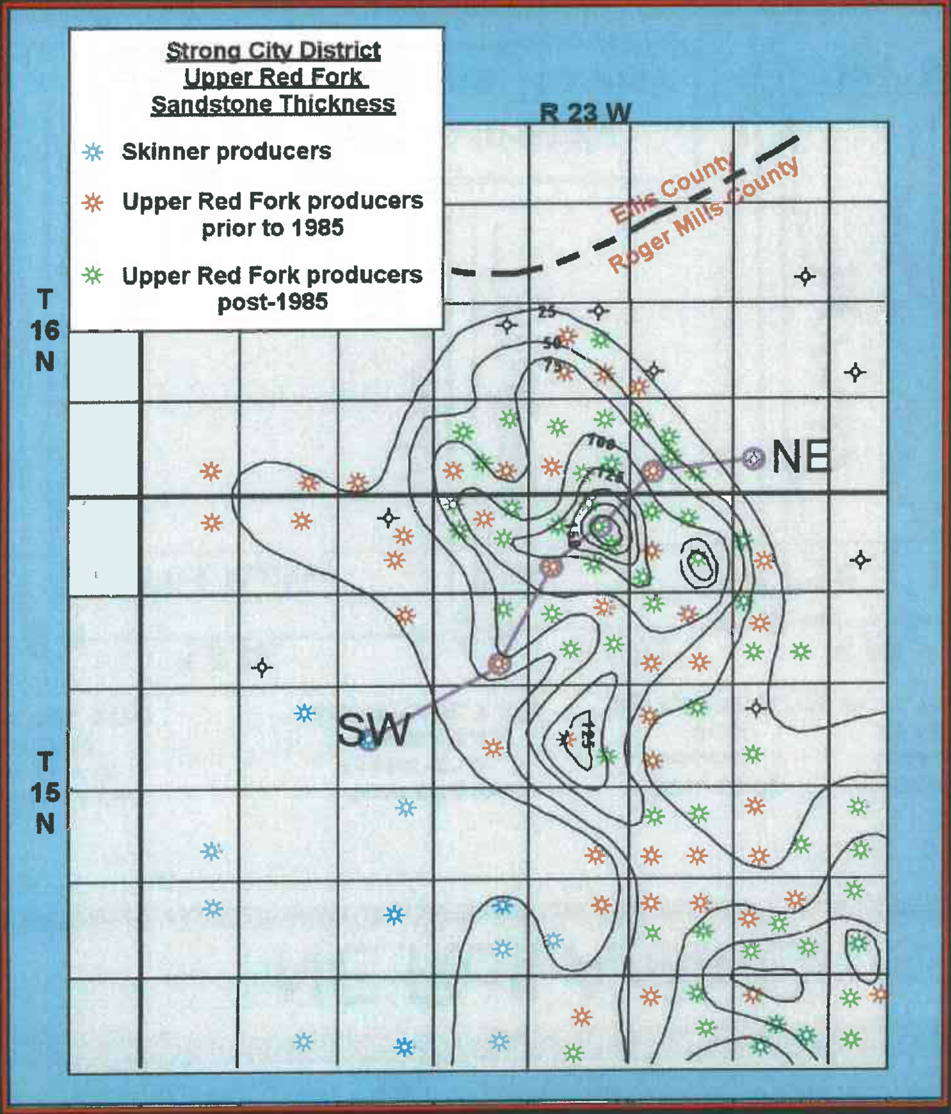
Narrow Sandstone Bodies are Fluvial-Deltaic Deposits

Widespread Deposit on Basin Floor in Strong City Area is Submarine Fan



Shelf and Deep Basin-Floor Accumulations of Red Fork Sandstone:
Finding Thicker Sandstone is Key to Economic Success

Strong City District Thickness Map



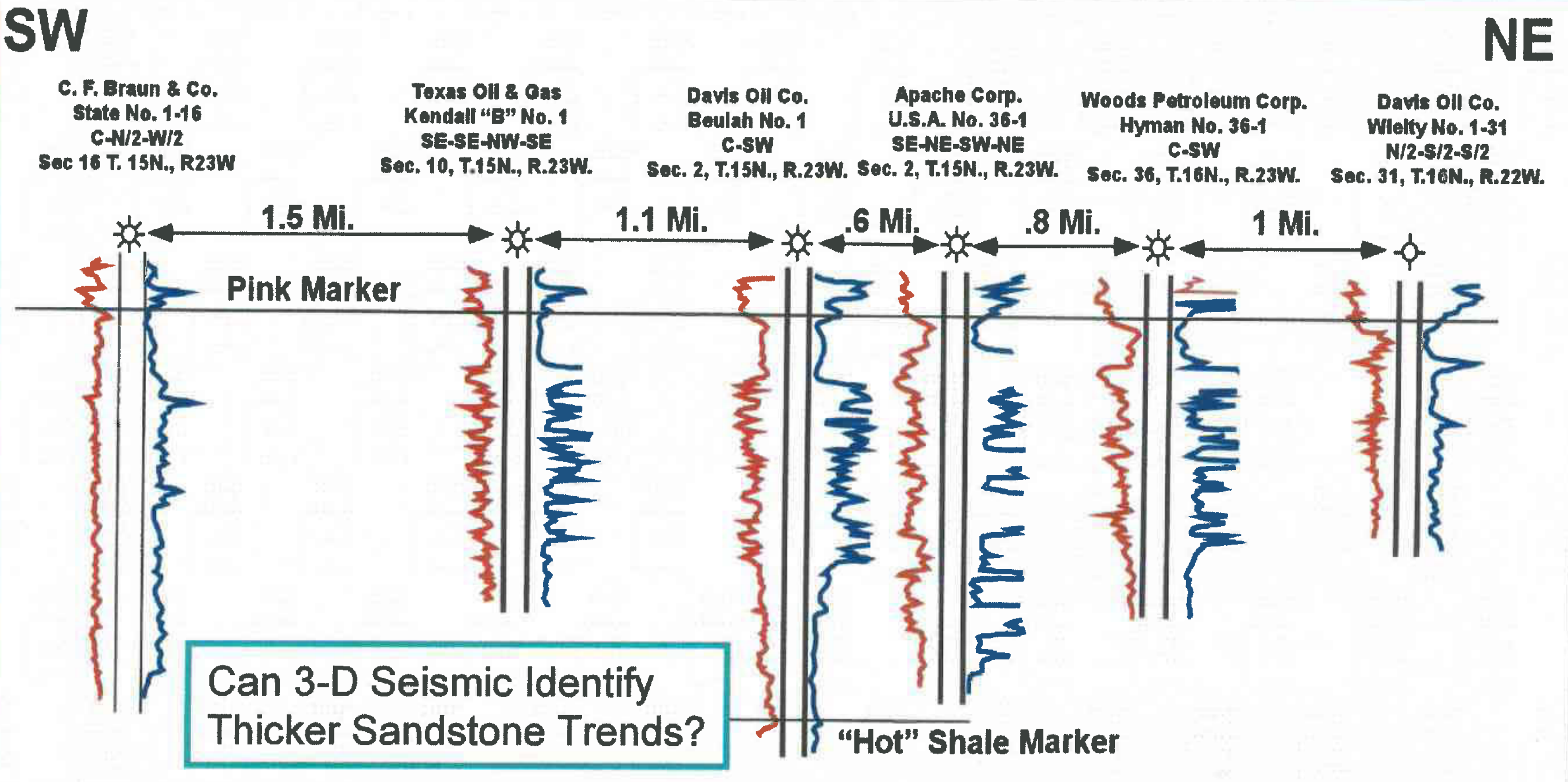
NE Roll Area

Key to Production is Finding Thicker Sandstone Bodies

Wells in Thicker Sandstone Trend are Higher Volume Producers

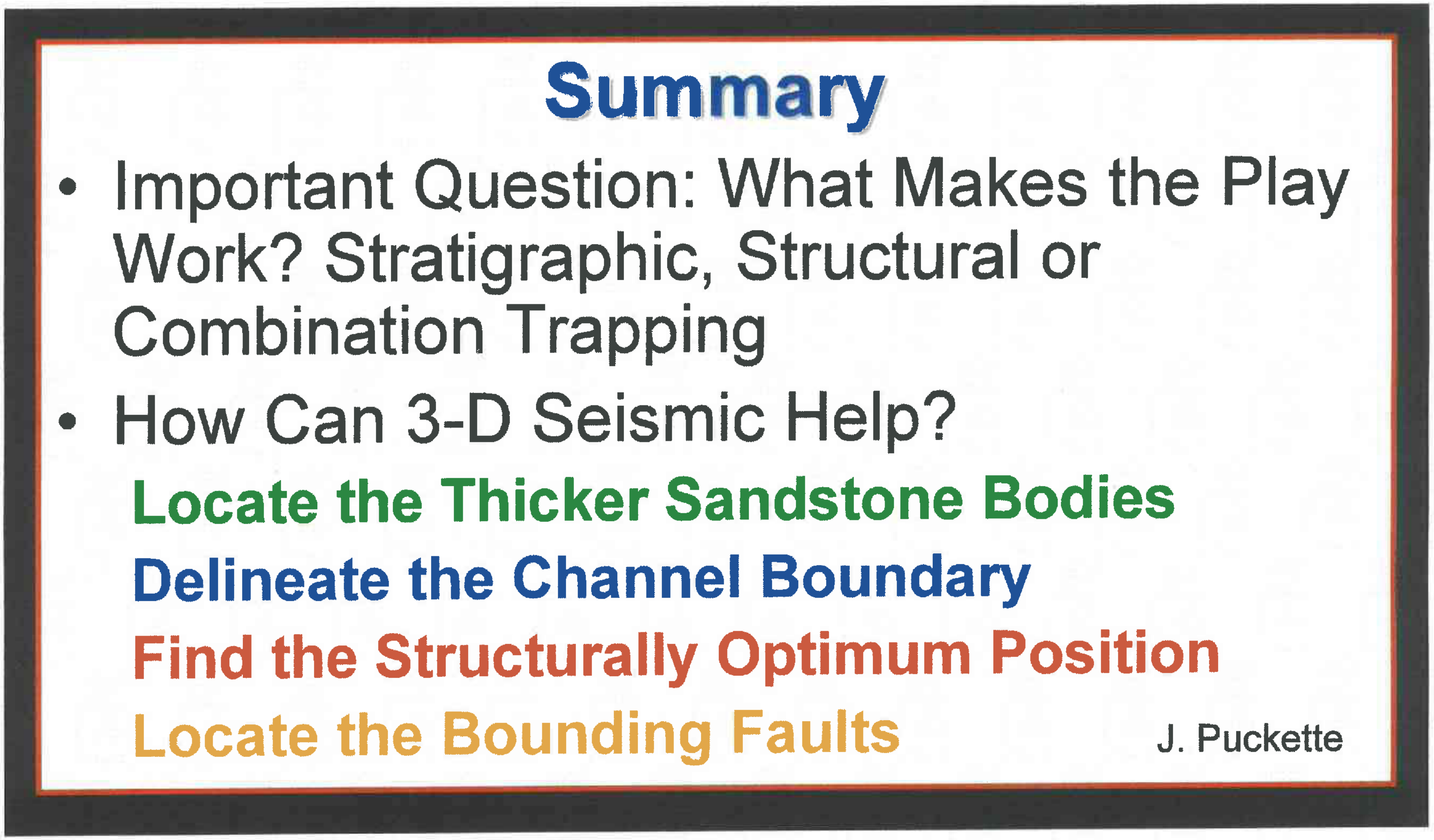
Can 3-D Seismic Delineate Trend of Thicker Sandstone?

NE Roll Area Cross Section



Can 3-D Seismic Identify Thicker Sandstone Trends?

Cross-Section SW NE Shown on NE Roll Area Thickness Map



Summary

- Important Question: What Makes the Play Work? Stratigraphic, Structural or Combination Trapping
- How Can 3-D Seismic Help?

Locate the Thicker Sandstone Bodies

Delineate the Channel Boundary

Find the Structurally Optimum Position

Locate the Bounding Faults

J. Puckette

NOTES

OLD WOMAN CHANNEL
WATONGA-CHICKASHA TREND
T.14N., R.10W. and R.11W.
Blaine and Canadian Counties, OK

LOCATION

Northern shelf of the Anadarko Basin.

PRIMARY PRODUCING RESERVOIRS

Sandstone bodies in the "Springer" interval

DEPOSITIONAL SETTING

Sandstone bodies are located in a valley that was eroded into "Springer" shales during a drop in sea level. Reservoirs are seldom wider than 0.5 mile, but extend for several miles (verified by pressure data).

DISTRIBUTION of RESERVOIR

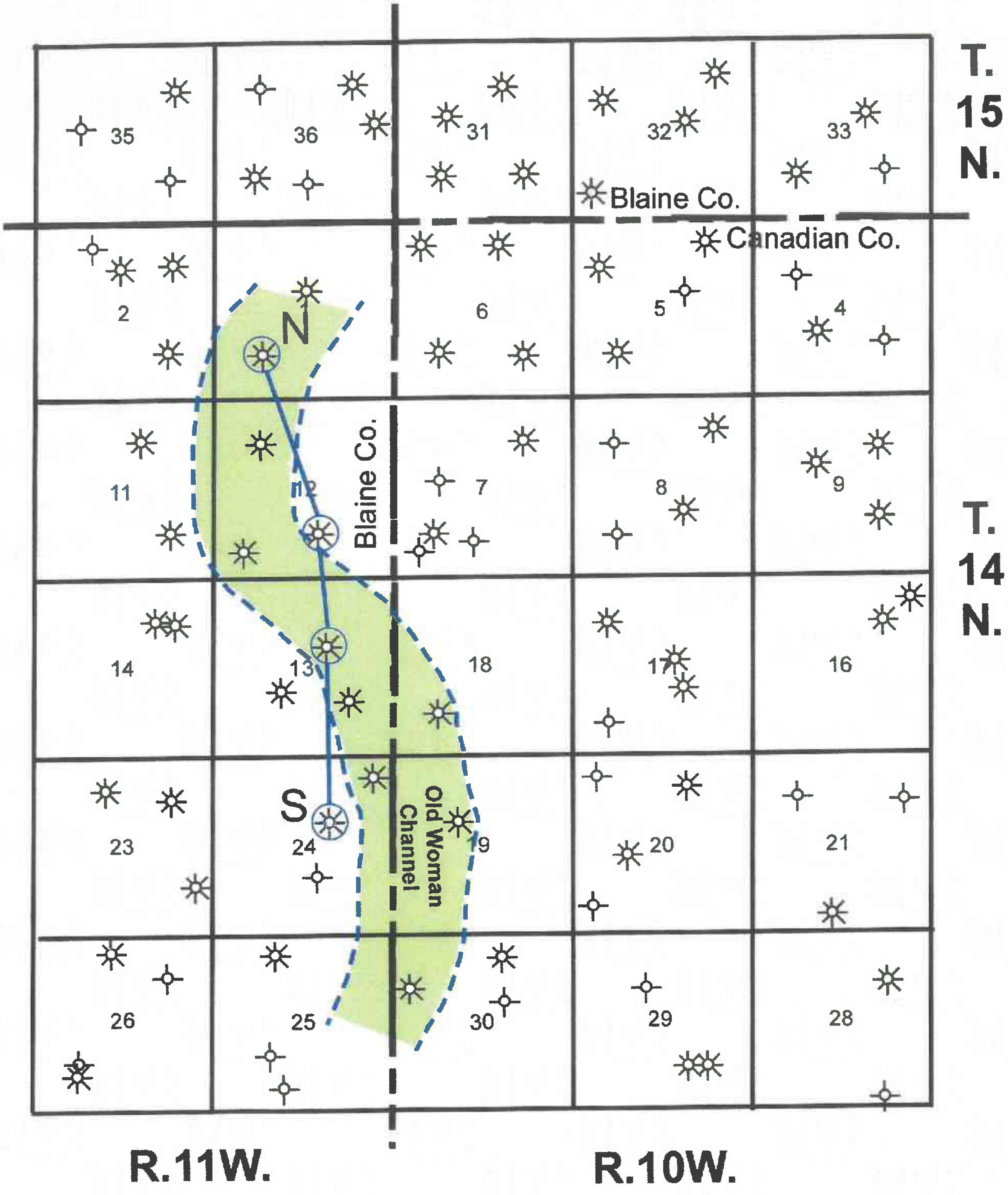
Elongate and narrow channel-filling sandstone that reaches 80 feet in thickness.

TRAPPING MECHANISM and TYPE of DRIVE

Stratigraphic. Gas-solution drive reservoir with no evidence of water leg in the reservoir.

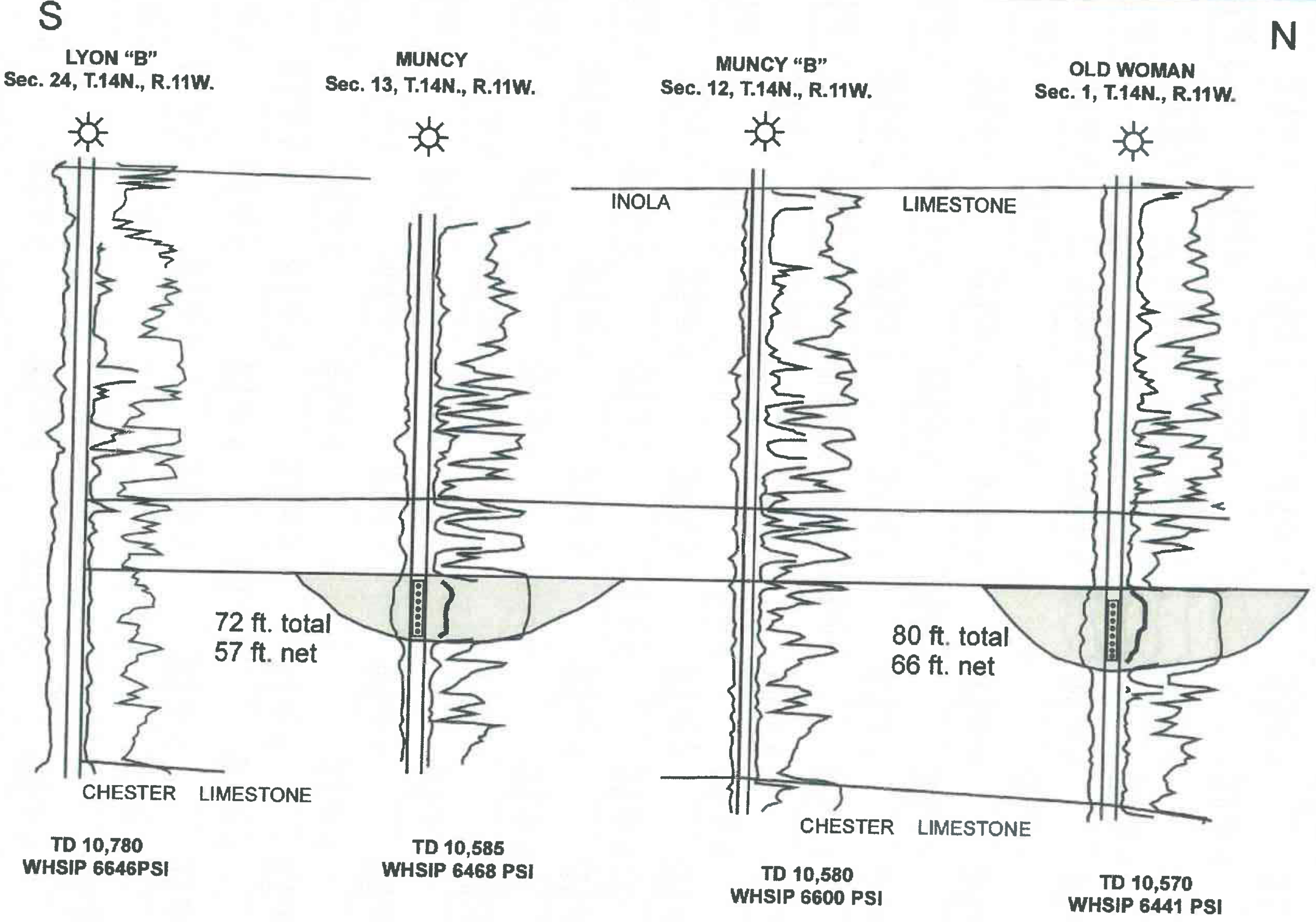
RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Wells in the thickest part of the channel fill are projected to ultimately produce approximately 20 BCF gas.



(From Davis, 1976)

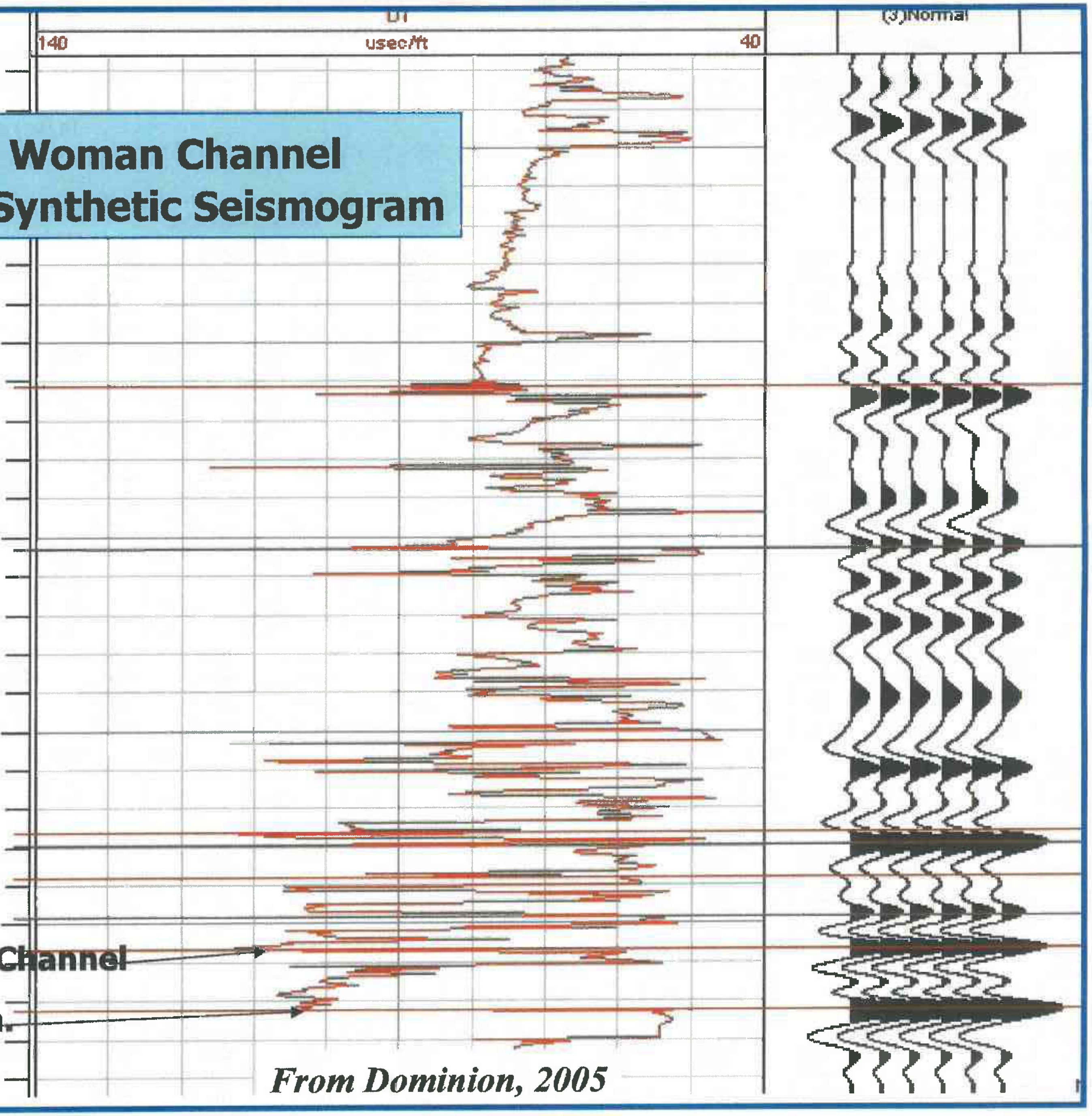
Distribution of “Old Woman” Channel Sandstone
Blaine and Canadian Counties, Oklahoma



After Davis (1976)

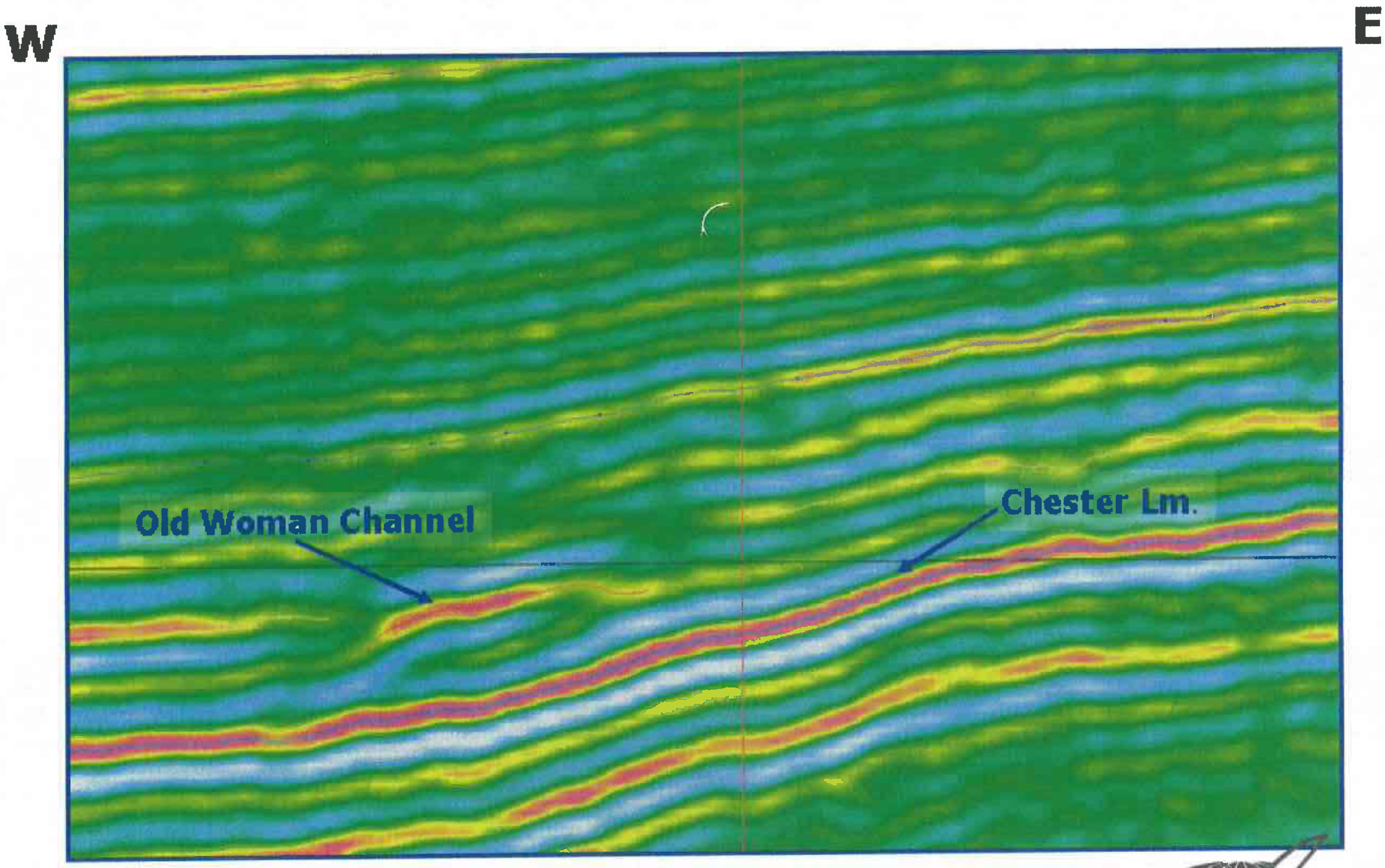
Cross Section N-S
"Old Woman" Channel Sandstone
Blaine and Canadian Counties

Old Woman Channel Type Synthetic Seismogram



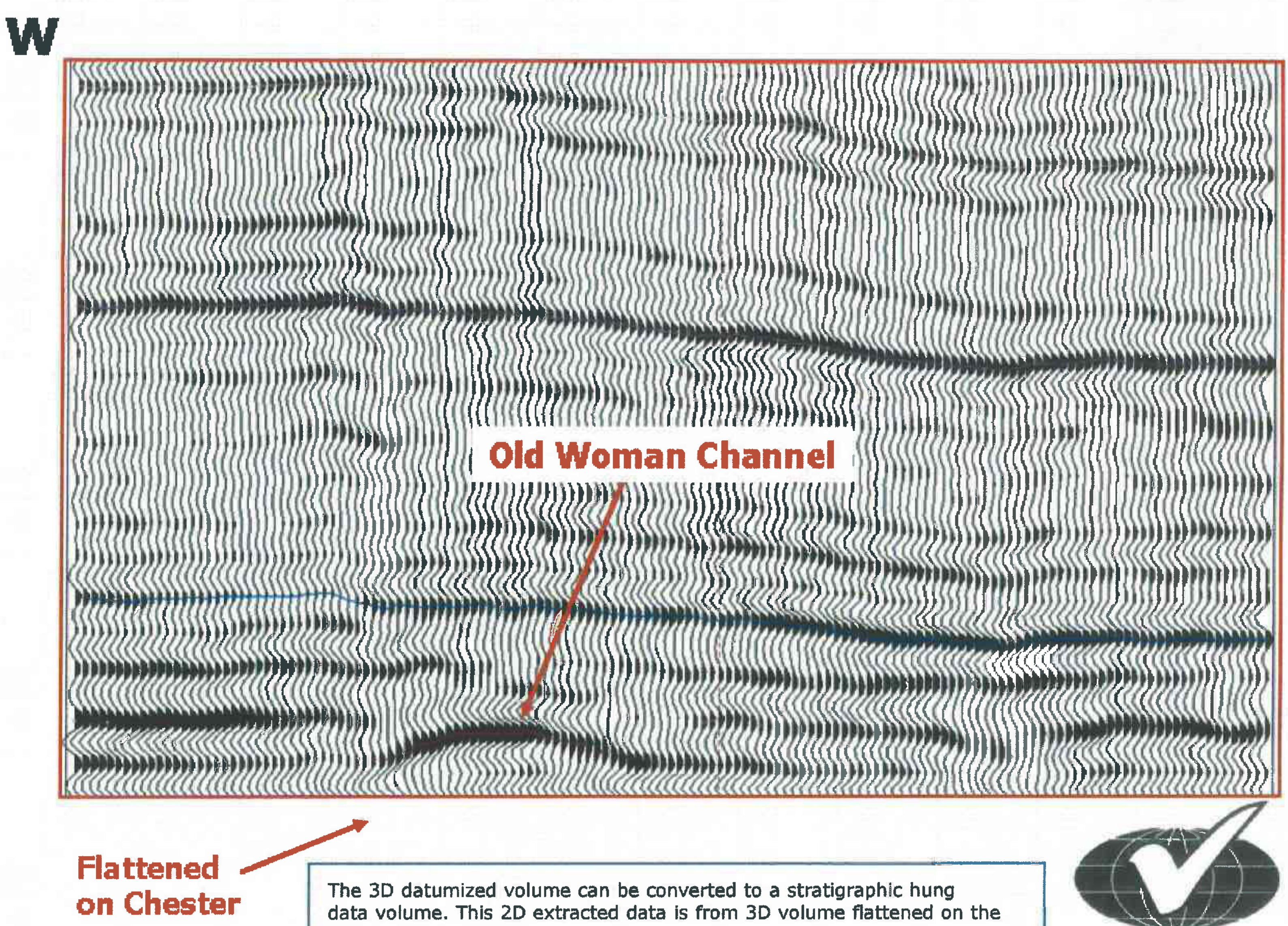
The type synthetic seismogram for the Old Woman channel illustrates what a good seismic reflector the Old Woman channel complex is. The high impedance reflector (high velocity encased in lox velocity) is the result of the Old Channel encased in overpressure shale.

From Dominion, 2005



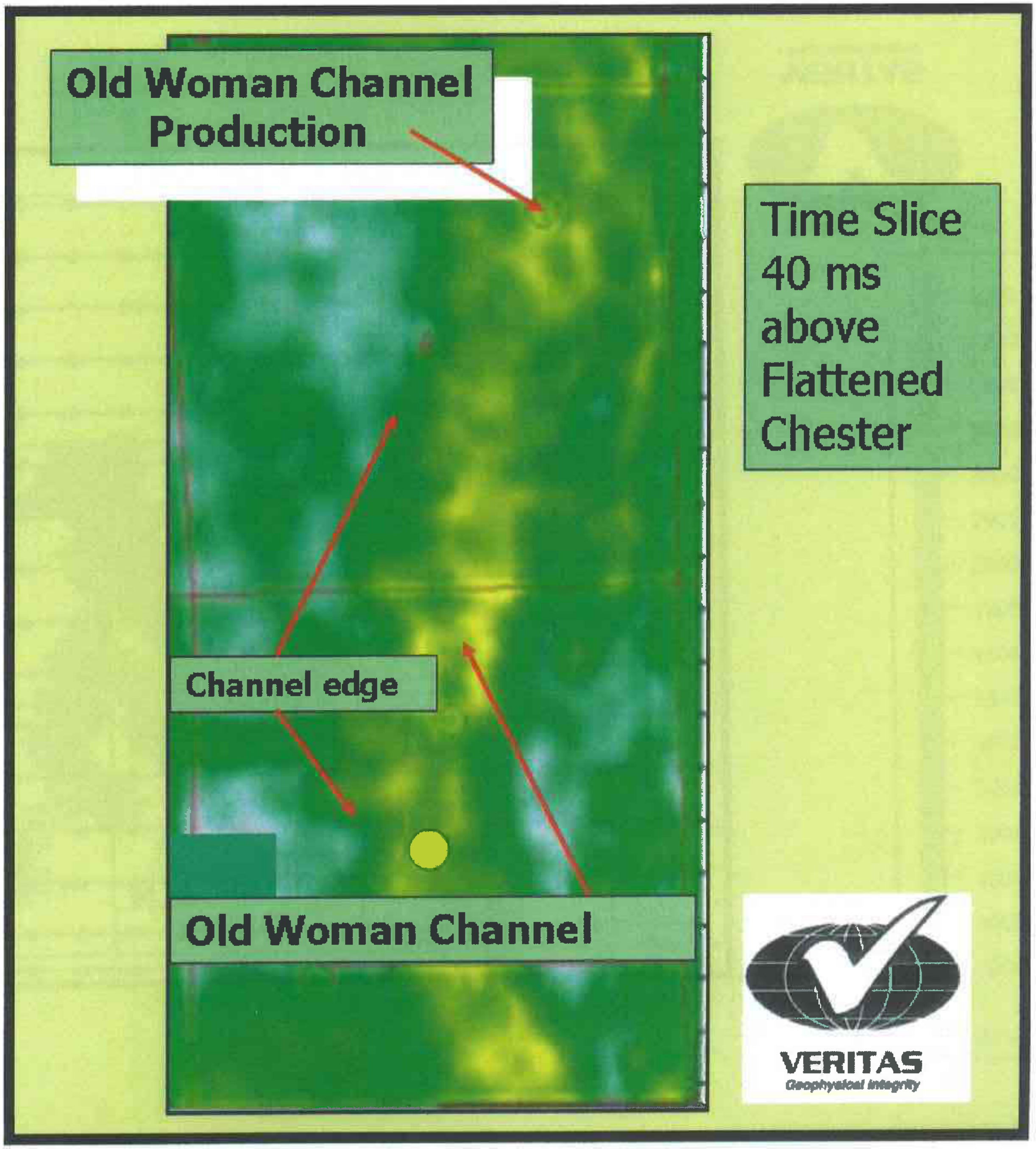
The high impedance Old Woman channel is obvious on the 2D extracted seismic from the 3D volume. The red color represents the positive reflector (low velocity to high velocity interface) and the blue color represents the negative reflector (high velocity to low velocity interface).

VERITAS
Geophysical Integrity

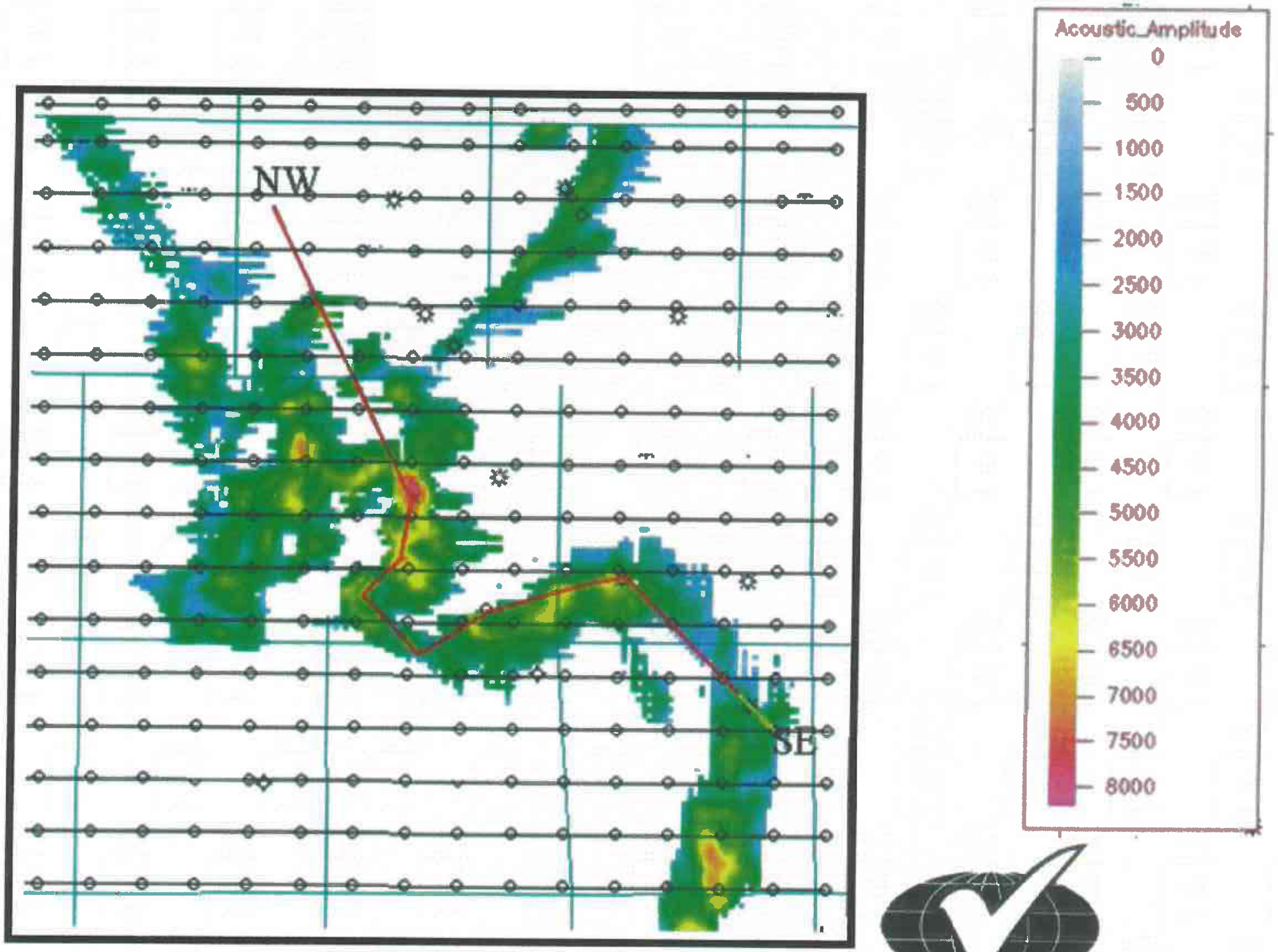


The 3D datumized volume can be converted to a stratigraphic hung data volume. This 2D extracted data is from 3D volume flattened on the Chester lime reflector.

VERITAS
Geophysical Integrity

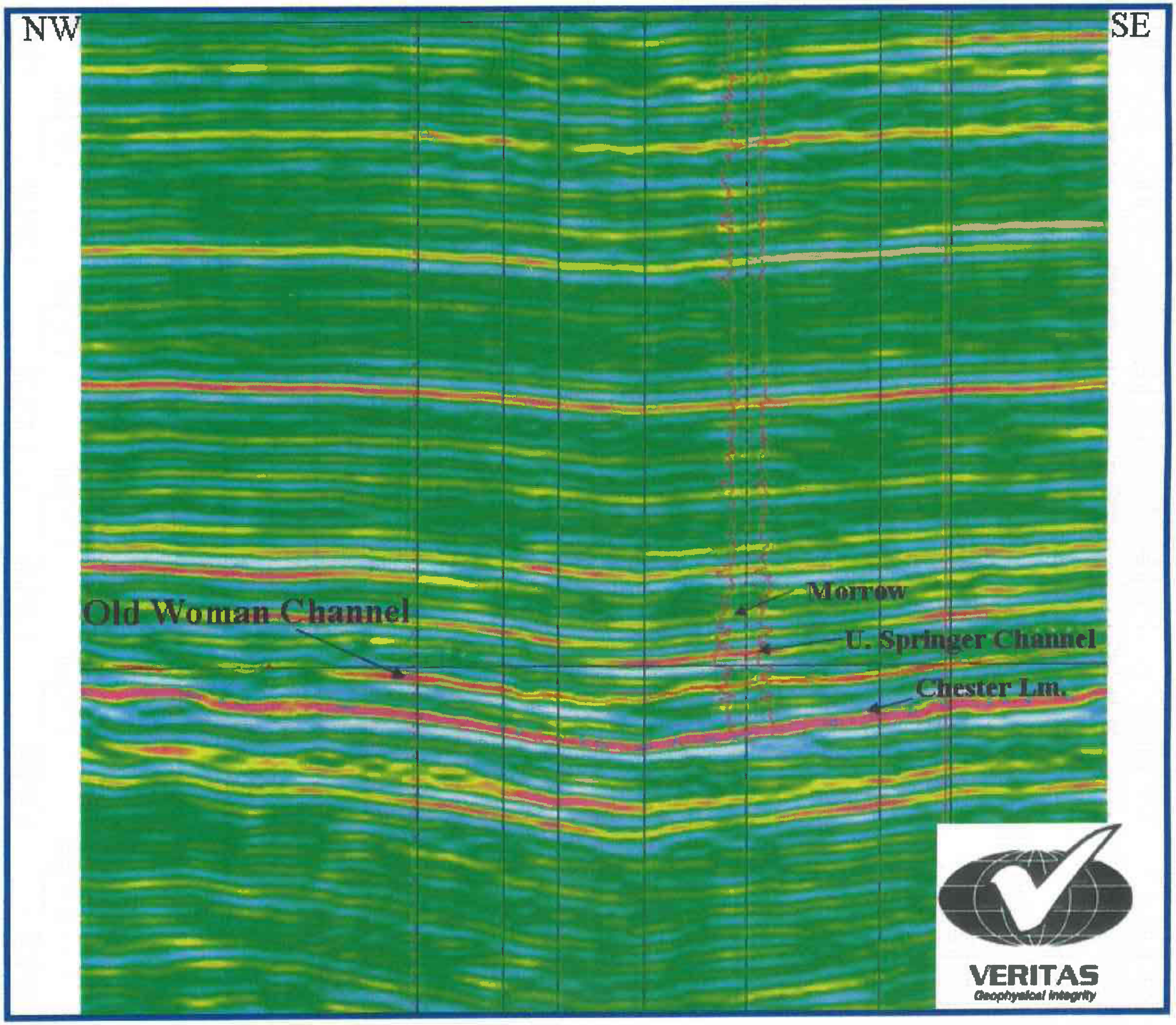


A map view of the time slice from 3D flattened volume defines the Old Woman channel edge.



An arbitrary 2D extraction can be made from the 3D seismic volume traversing the center of the Old Woman channel.

VERITAS
Geophysical Integrity



Numerous secondary sand bodies in the Morrow and Springer formations are detected on the arbitrary extraction.

NOTES

SOUTHEAST GAGE FIELD
T.20-21N., R.23-25W.
Ellis County, OK

LOCATION

Northern Shelf of the Anadarko Basin.

PRIMARY PRODUCING RESERVOIR

Cottage Grove sandstone

DEPOSITIONAL SETTING

The Cottage Grove sand was deposited as a shallow marine bar on the Northern Shelf of the Anadarko depositional basin.

DISTRIBUTION of RESERVOIR

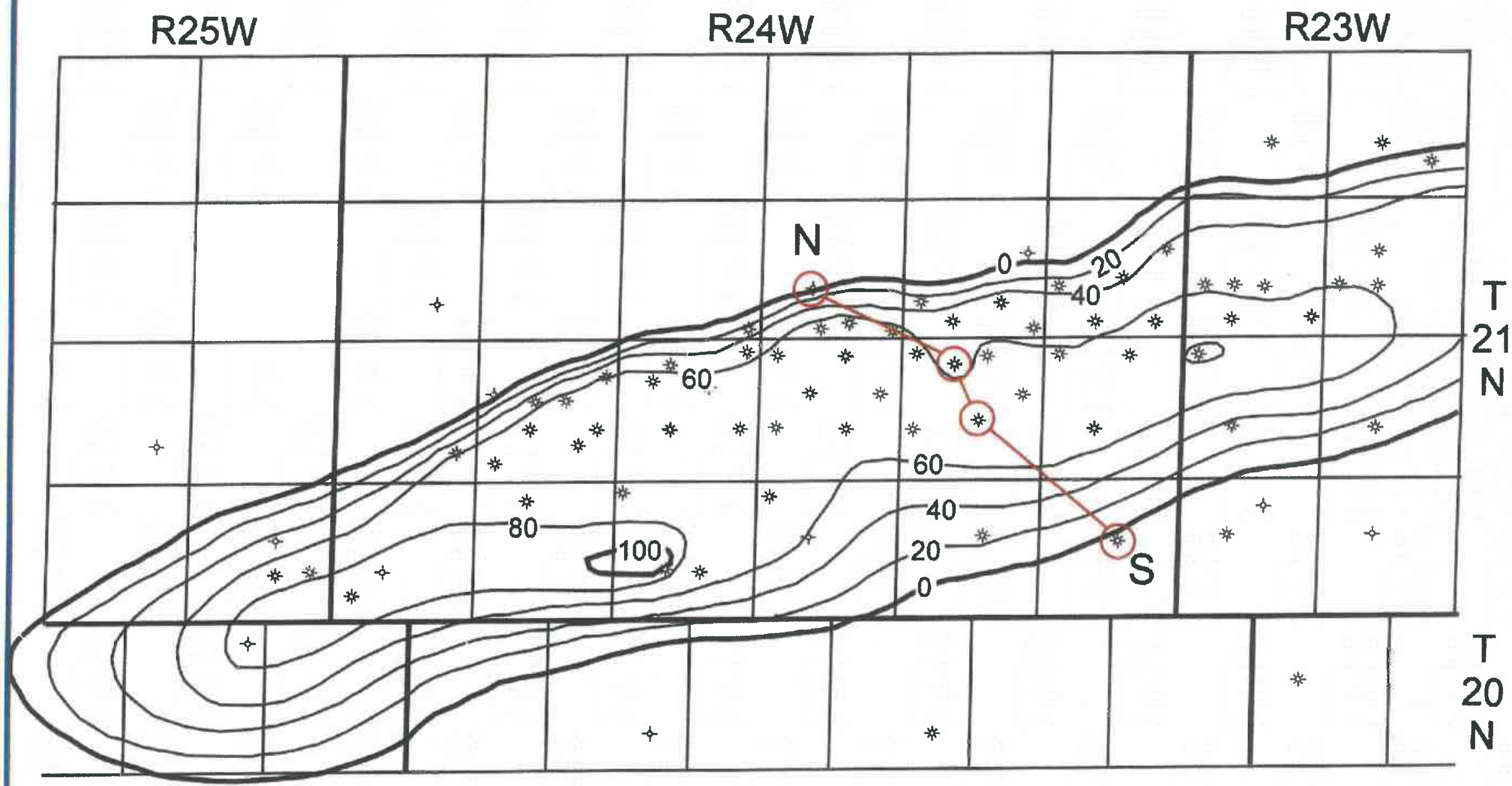
The Cottage Grove Sandstone forms a northeast to southwest trend that is approximately 2 miles wide and 10 miles long.

TRAPPING MECHANISM and TYPE of DRIVE

Stratigraphic trapping is responsible for the accumulation of natural gas and oil in the Cottage Grove Sandstone. The field boundary along the down dip end is influenced by a water leg in the sandstone.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

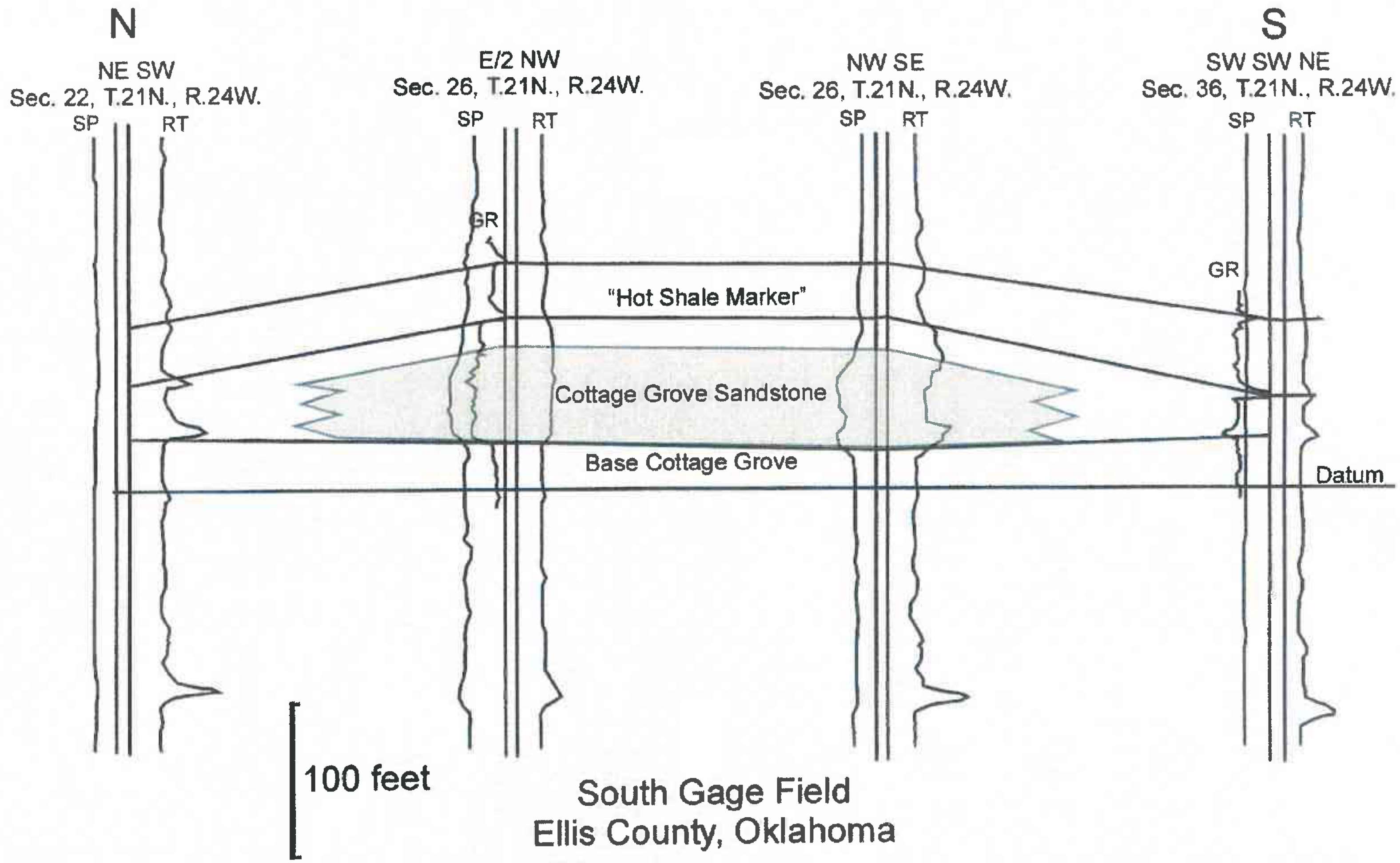
The average production for Cottage Grove producers in the SE Gage field is 27 thousand barrels of oil and 450 million cubic feet of gas. Better wells in the field produced in excess 1 BCF gas and 40 thousand barrels of oil.



Cottage Grove Sandstone Thickness
SE Gage Field, Ellis County, Oklahoma

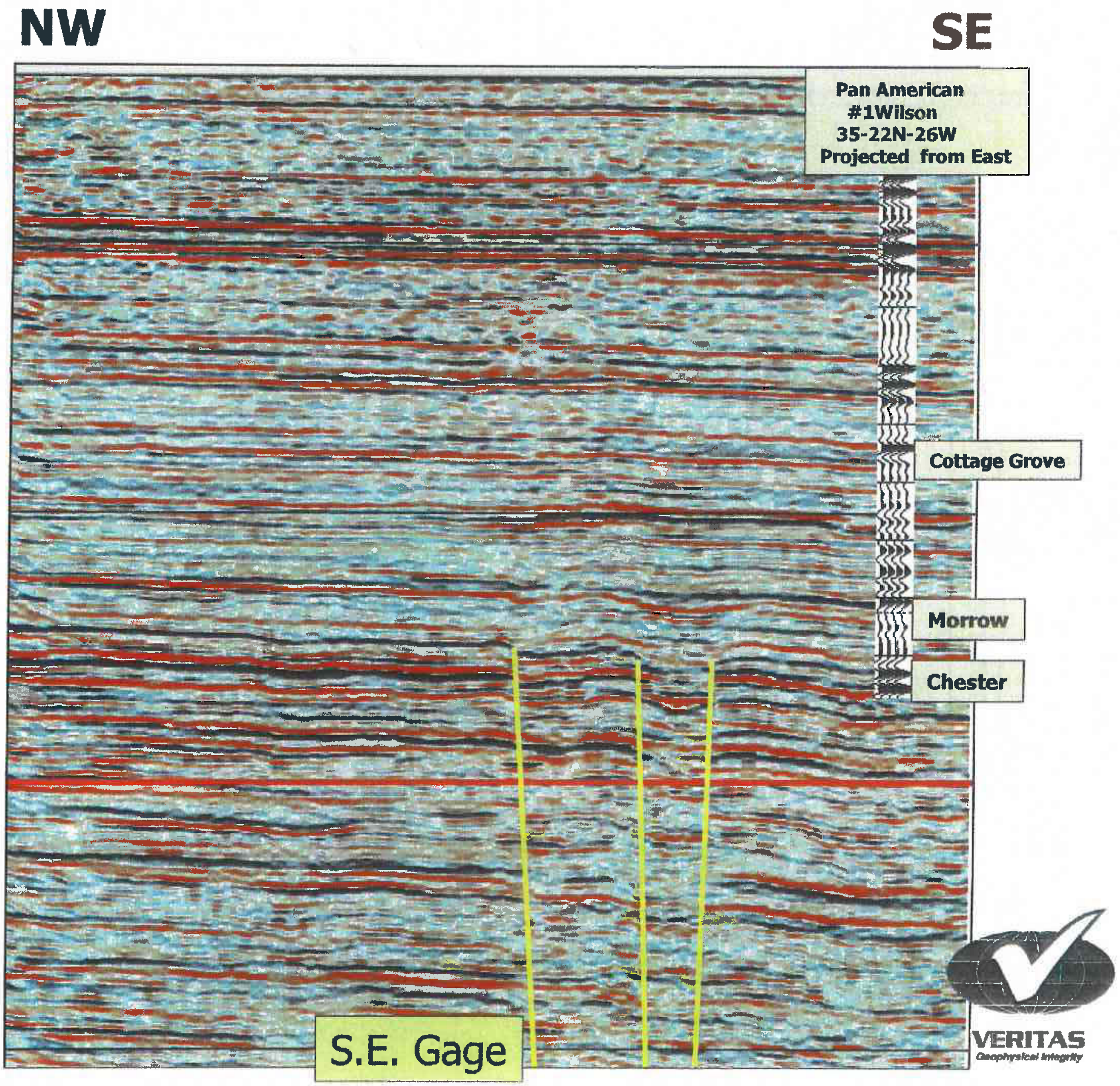
After Towns (1978)

C.I. = 20 feet



South Gage Field
Ellis County, Oklahoma

After Towns (1978)



A synthetic seismogram is projected to tie the correlation of the Cottage Grove, Morrow and Chester to the extracted data from a 3D survey near the S.E. Gage Field. Defining the stratigraphic Cottage Grove trap is not evident in the data. However, an updip pinchout of the Morrow may be mapped.

NOTES

NOTES

CYRIL AREA
NE FLETCHER FIELD
T.3-7N., R.7-12W.
Caddo, Comanche and Grady Counties, OK

LOCATION

Southeastern portion of Anadarko Basin; near the axis of the depositional basin

PRIMARY PRODUCING RESERVOIRS

Sandstone bodies in the "Springer" interval. The Upper Britt Sandstone is shown as a representative example of the sandstones in the interval.

DEPOSITIONAL SETTING

Sandstone bodies represent marine bars that were deposited subparallel to the paleoshoreline.

DISTRIBUTION of RESERVOIR

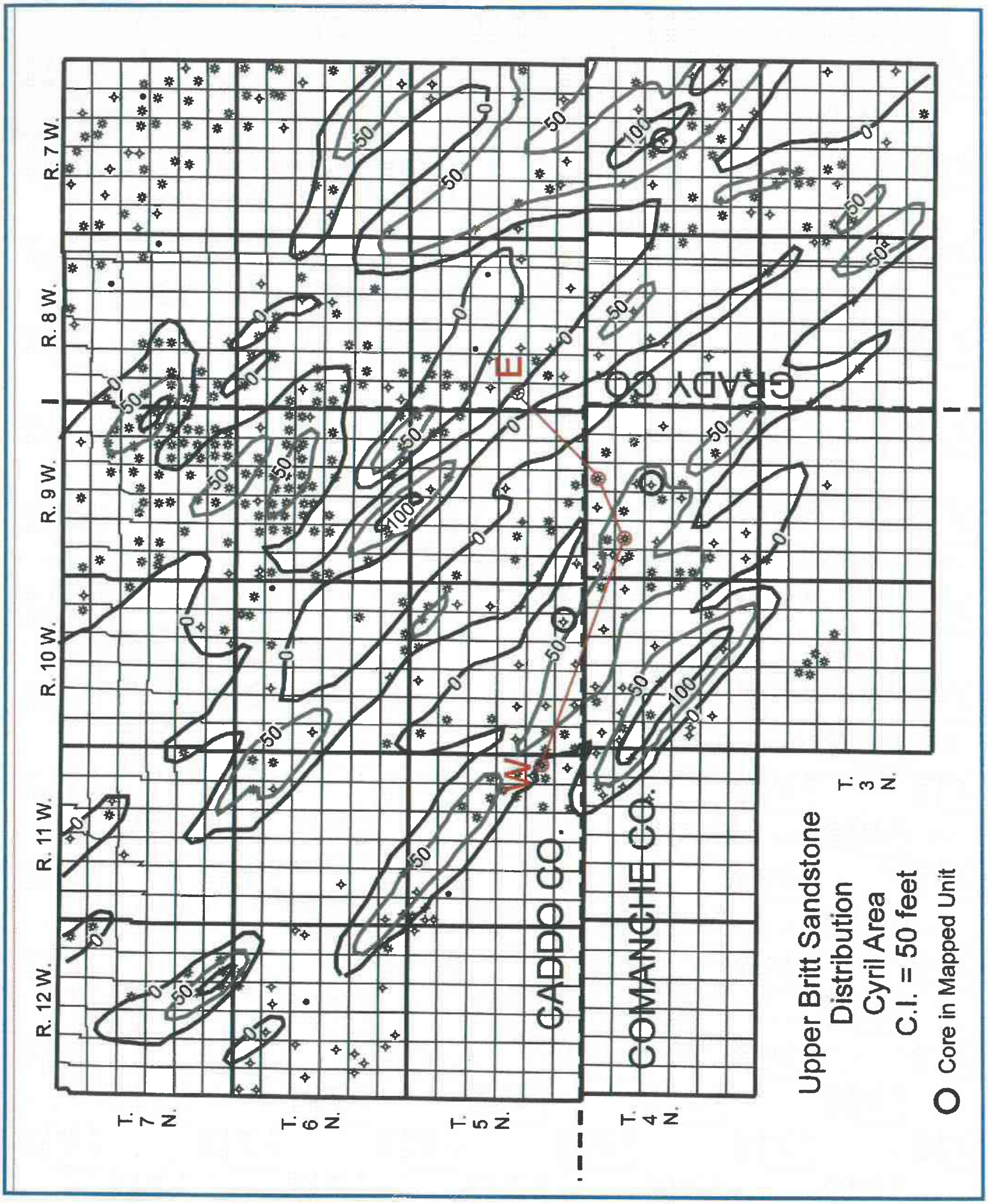
Elongate and narrow sandstone ridges that may reach thicknesses that exceed 100 feet.

TRAPPING MECHANISM and TYPE of DRIVE

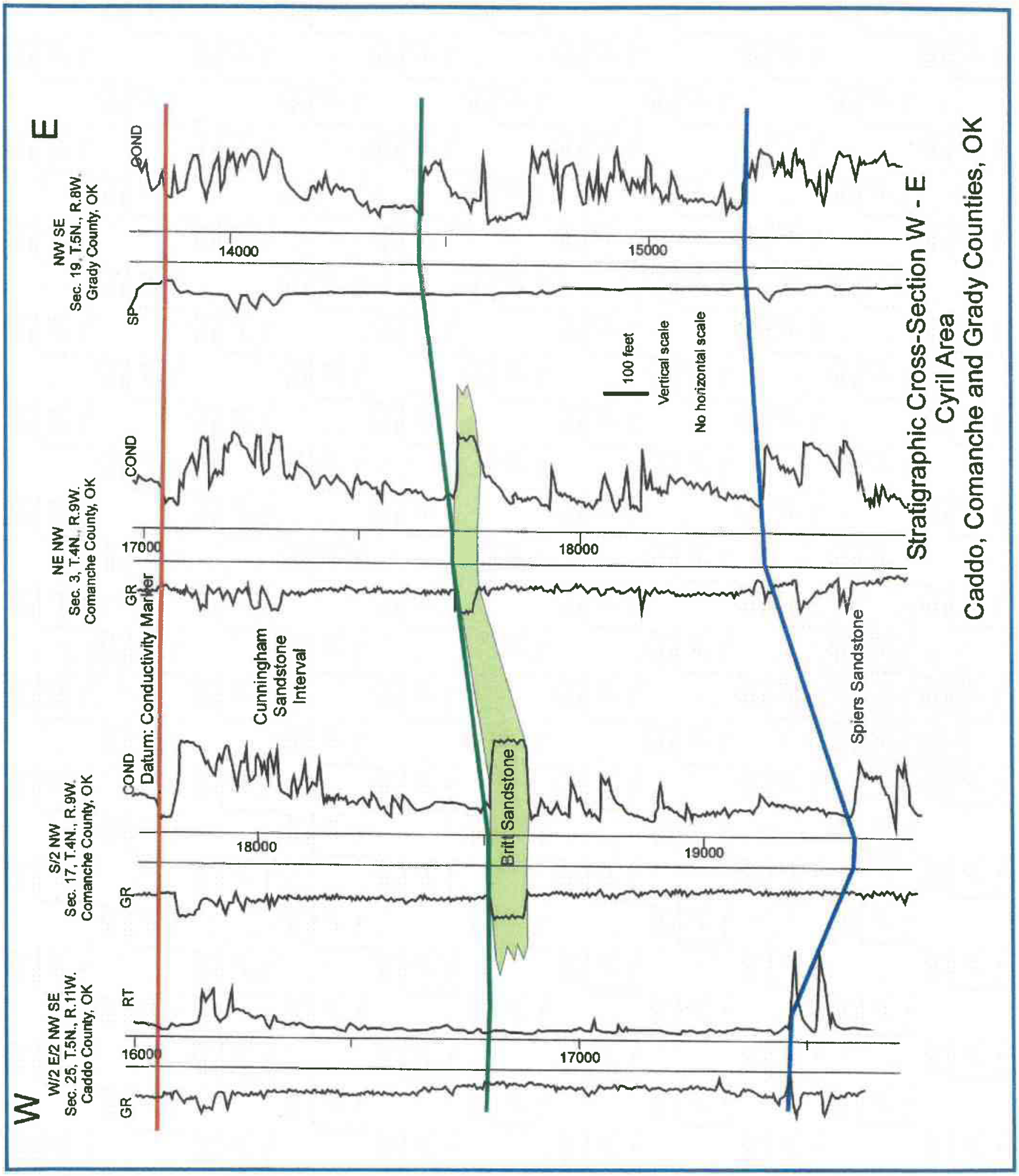
Stratigraphic. Gas-solution drive reservoirs with little evidence of water leg in the deeper reservoirs. Locating sandstone bodies is key to production. However, diagenetic processes are key to preserving or generating porosity.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Better wells in the thicker sandstone trends produce in excess of 6 BCF gas.

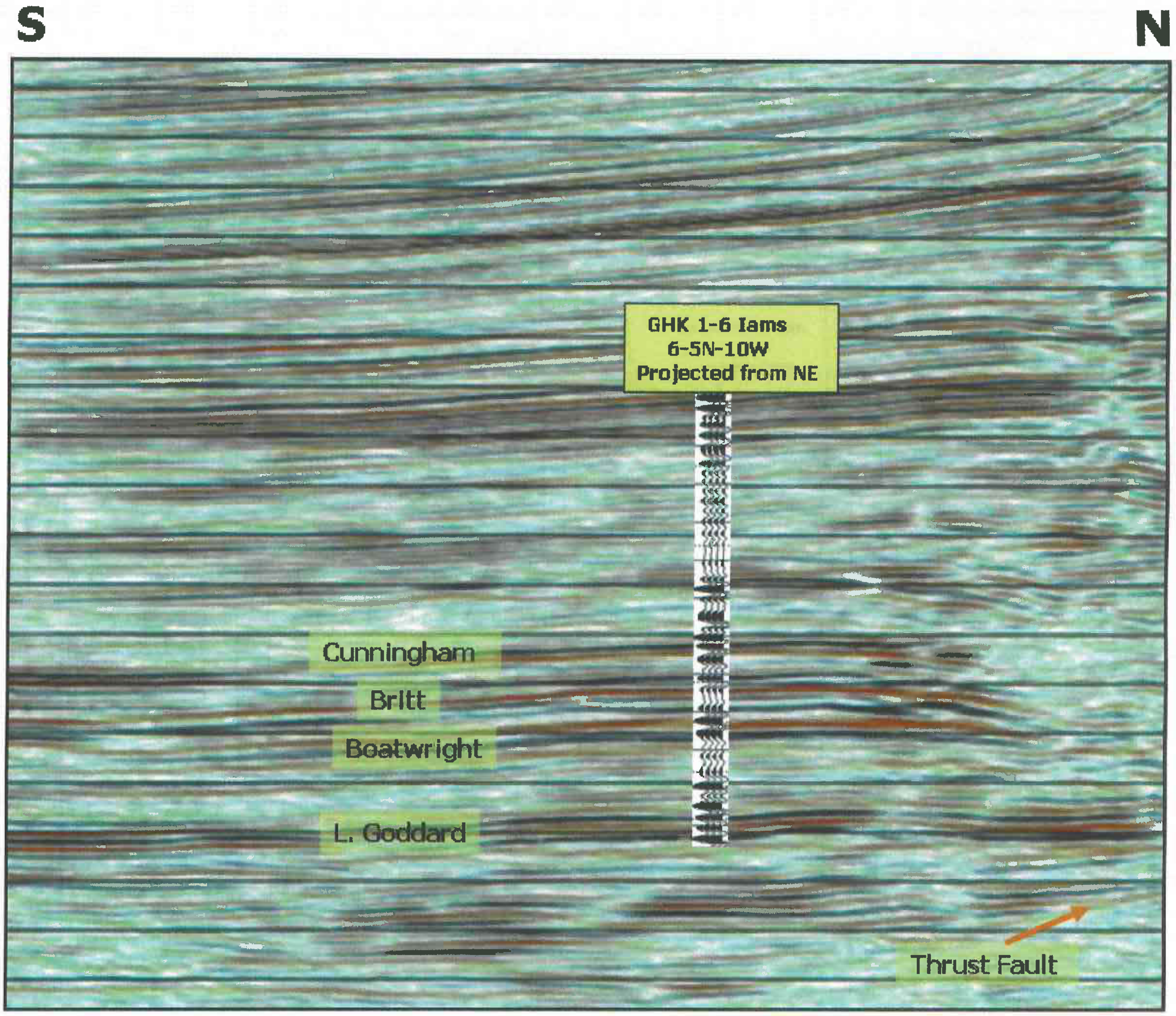


Upper Britt Sandstone
Distribution
Cyril Area
C.I. = 50 feet



Stratigraphic Cross-Section W - E
Cyril Area
Caddo, Comanche and Grady Counties, OK

The high impedance Cunningham, Britt, Boatwright and Lower Goddard sands can be confidently mapped in the Cyril-Fletcher Area.



From: Western-Geco

NOTES

NOTES

CEMENT FIELD
T.5-6N., R.8-10W.
Caddo and Grady Counties, OK

LOCATION

Southeastern portion of Anadarko Basin; near the axis of the depositional basin

PRIMARY PRODUCING RESERVOIRS

Sandstone bodies in the "Springer", Morrow, Desmoinesian interval. In addition, a number of shallow stratigraphic intervals produce oil leaked from deeper sources.

DEPOSITIONAL SETTING

Springer sandstone bodies represent marine bars that were deposited subparallel to the paleoshoreline. A variety of settings from fluvial to marine are represented in the shallower intervals.

DISTRIBUTION of RESERVOIRS

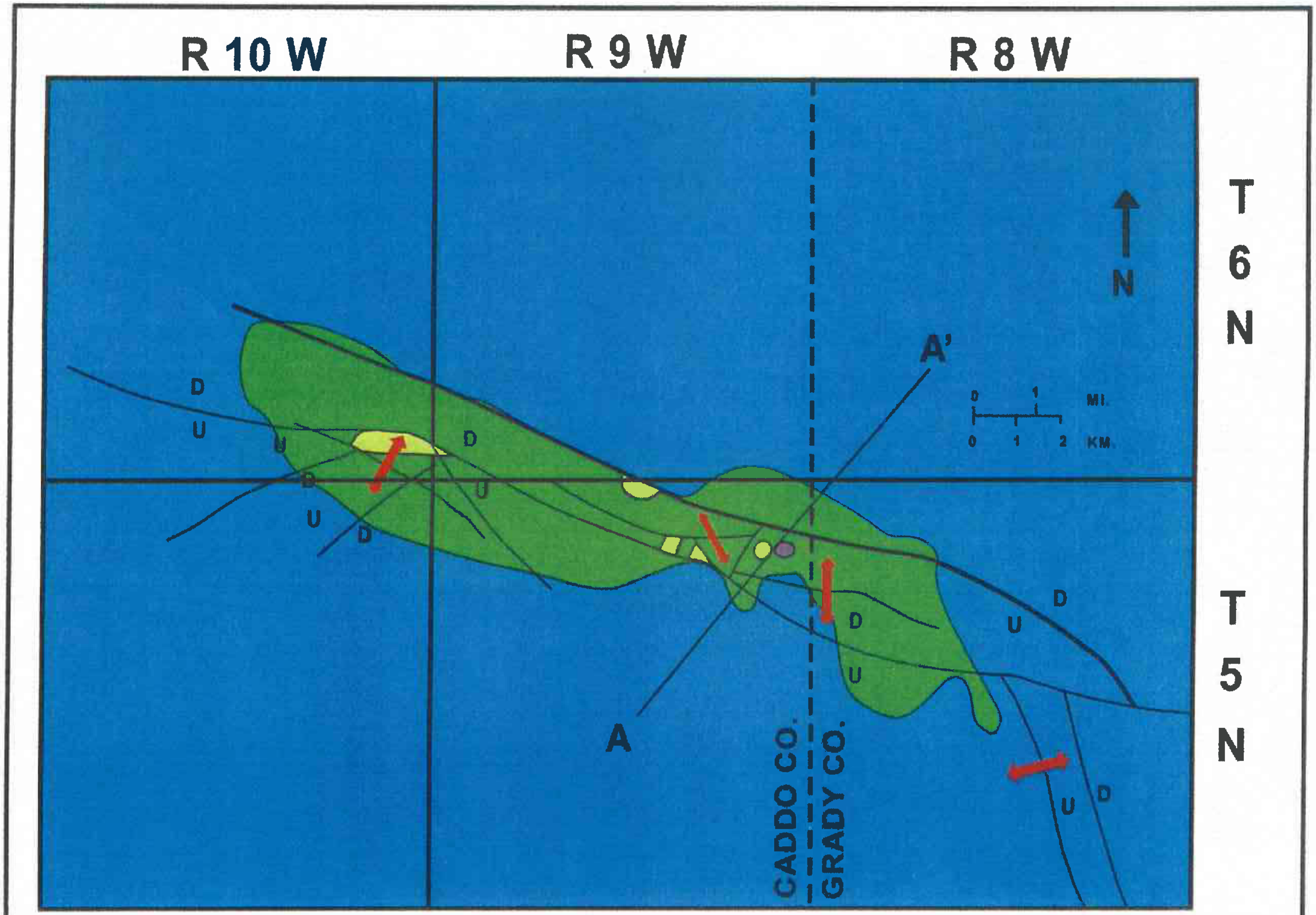
Reservoirs are widely distributed across the Cement structure. As a result of depositional processes and faulting, these reservoir are highly compartmentalized.

TRAPPING MECHANISM and TYPE of DRIVE

Structural and stratigraphic. Gas-solution drive reservoirs with little evidence of water leg in the deeper reservoirs. Determining the locations of faults and mapping sandstone trends is paramount to locating isolated compartments.

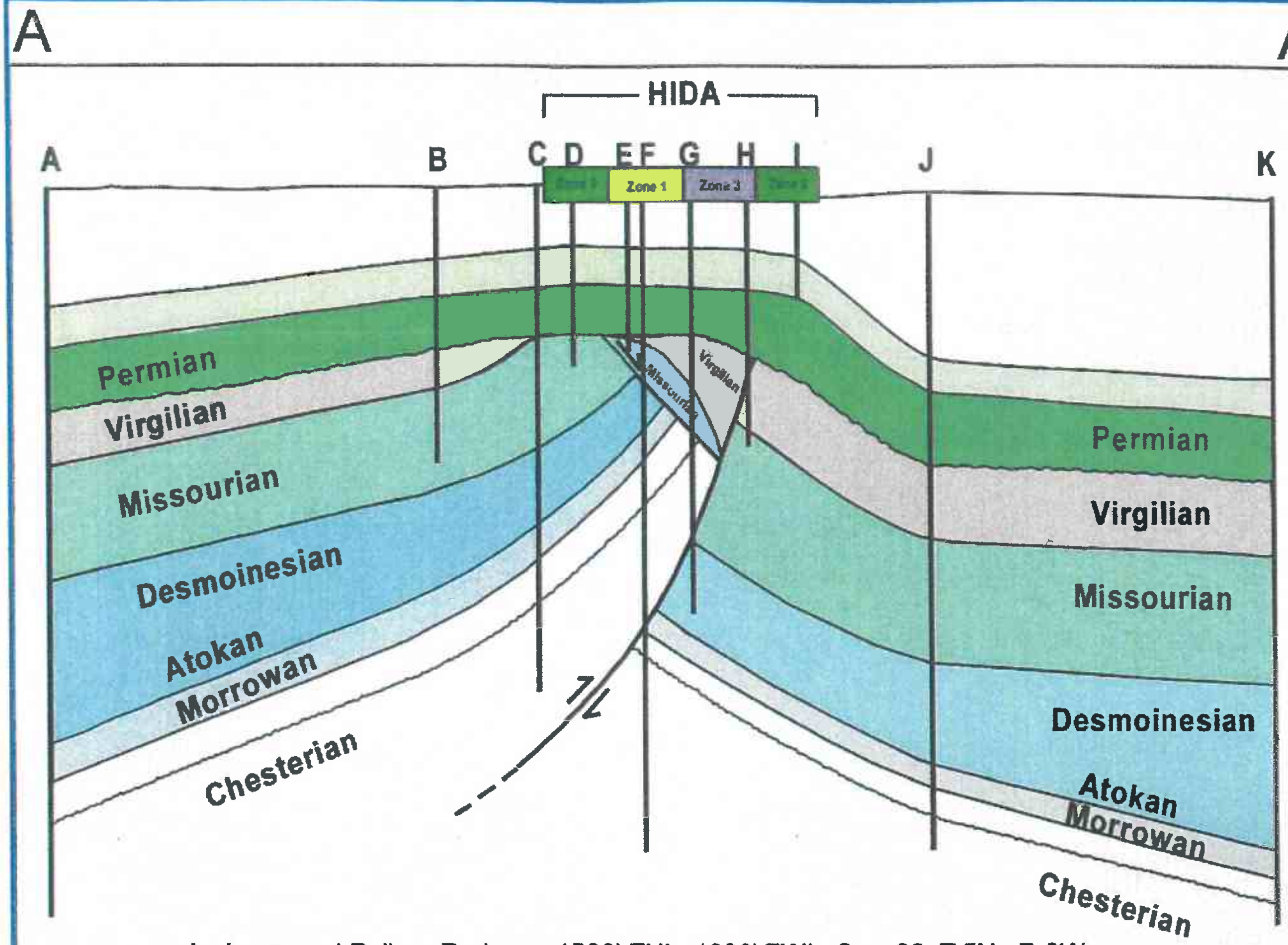
RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Better wells in the deep Springer sandstone trends produce in excess of 8 BCF gas. The deep lower Paleozoic (Arbuckle, Simpson, Viola and Hunton) are not well tested on the structure. Estimated recoveries for individual shallow Pennsylvanian and Permian oil wells are difficult to determine due to commingling and unitization.



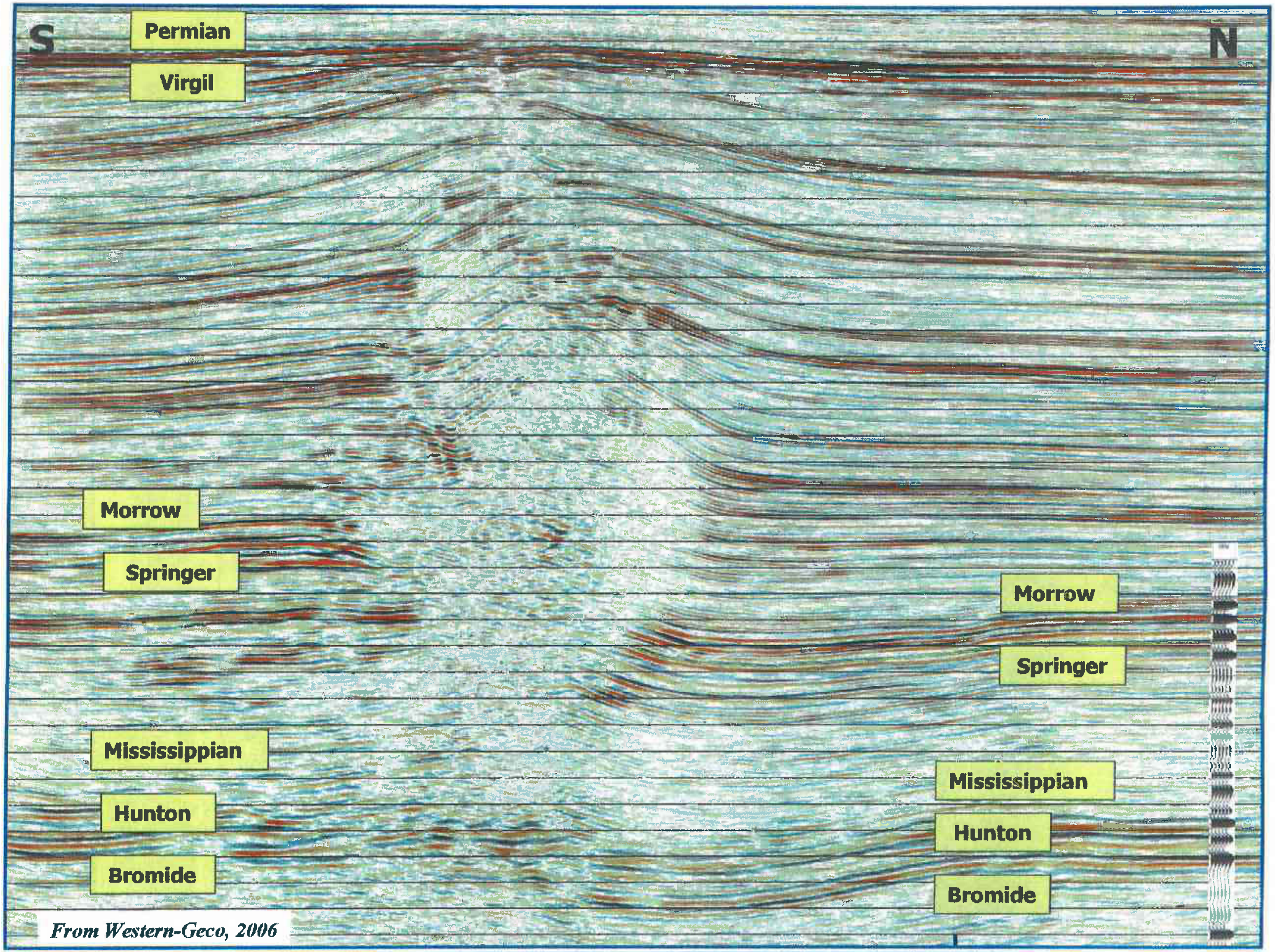
(After Allen, 1980.)

Surface diagenetic alteration zones and pre-Permian structural configuration of the Cement anticline (after Allen, 1980).



A. Jones and Pellow, Redmon, 1500' FNL, 1900' FWL, Sec. 22, T.5N., R.9W.
B. Gulf Oil Corp., Westselline, NE NE NE Sec. 14, T.5N., R.9W.
C. Oxley Petroleum Corp., Wagner, S/2 N/2 SW Sec. 12, T.5N., R.9W.
D. Ohio Petroleum, Wagner, SW NE SW Sec. 12, T.5N., R.9W.
E. Little Nick Oil Corp., Royce, SW SW NE Sec. 12, T.5N., R.9W.
F. Mobil Oil Corp., Royce, SE SW NW Sec. 12, T.5N., R.9W.
G. Little Nick Oil Corp., Royce, SW NW NE Sec. 12, T.5N., R.9W.
H. Stanolind, Royce, NW NE NE Sec. 12, T.5N., R.9W.
I. Deardorf, Funk, SW SW SW Sec. 6, T.5N., R.8W.
J. Oxley Petroleum Corp., Davidson, E/2 SW NE Sec. 6, T.5N., R.8W.
K. Anson Corp., Anderson, NE Sec. 32, T.6N., R.8W.

Cross-section A-A' that illustrates the structural configuration of the Cement anticline. Major faults served as conduits for petroleum migration from deeper reservoirs to shallow Permian strata.



From Western-Geco, 2006

The data across Cement show all the potential producing formation from the Permian through the Arbuckle. The Permian is draped over the deep seated Cement structure. The thrusted Virgil through the Lower Springer is thrusted riding over the tentional faulted Mississippian through Arbuckle (basement).

NOTES

NOTES

EAST CLINTON FIELD
T.12N., R.15-17W.
Custer County, OK

LOCATION

Central Anadarko Basin

PRIMARY PRODUCING RESERVOIRS

The Red Fork Sandstone

DEPOSITIONAL SETTING

The Red Fork Sandstone reservoirs formed from sediments deposited in a valley that eroded into the older Red Fork deltaic and shallow marine deposits during a drop in sea level.

DISTRIBUTION of RESERVOIRS

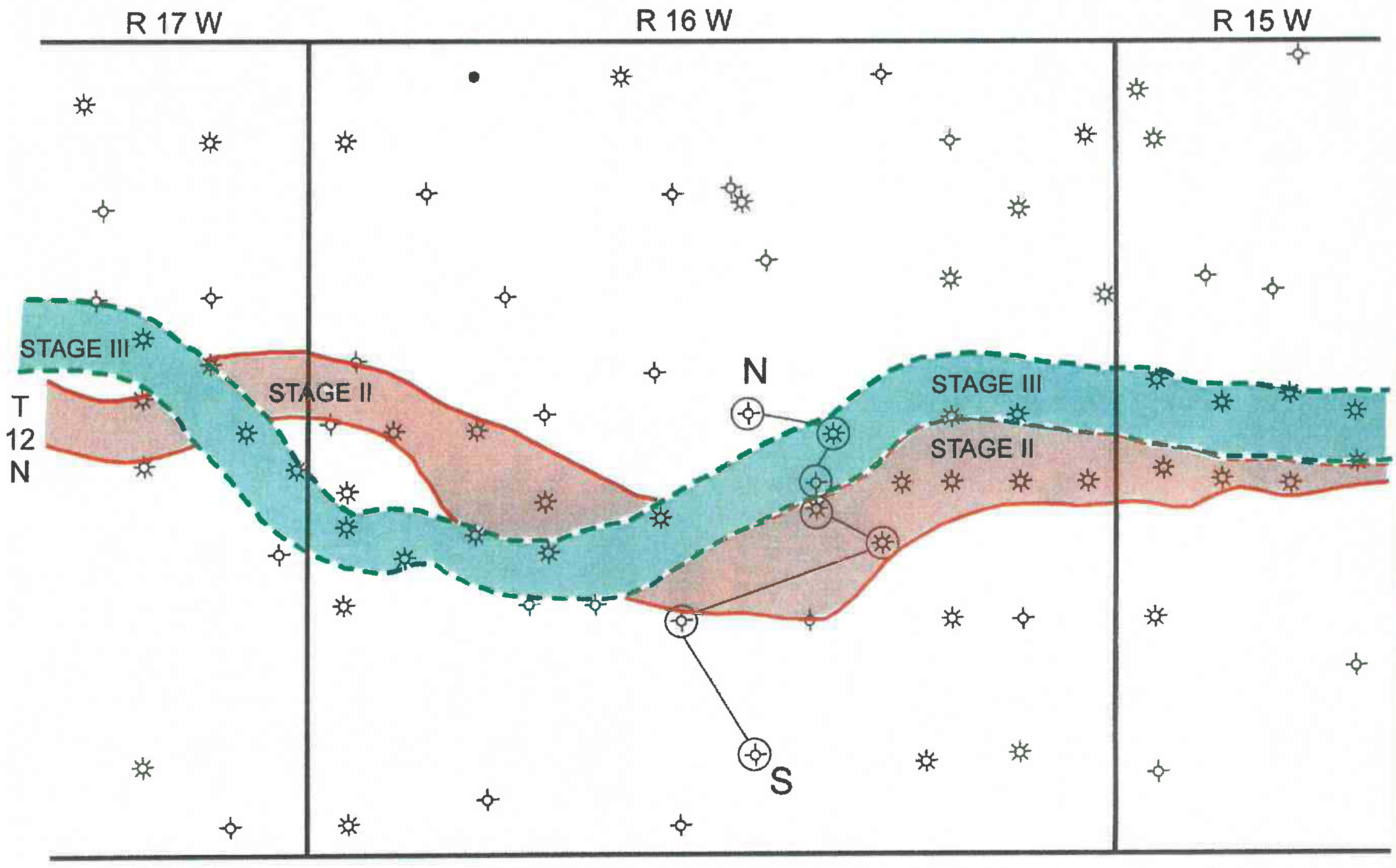
The Red Fork reservoirs are elongate and sinuous sandstone bodies. Sandstone bodies are less than 0.5 to 0.75 miles wide, the estimated width of the E. Clinton valley. Older sandstone bodies are truncated by younger ones, which are believed to cannibalized sediment from the existing older sands (Clement, 1994).

TRAPPING MECHANISM and TYPE of DRIVE

Stratigraphic trapping is responsible for the accumulation of natural gas in the Red Fork sandstone reservoirs.

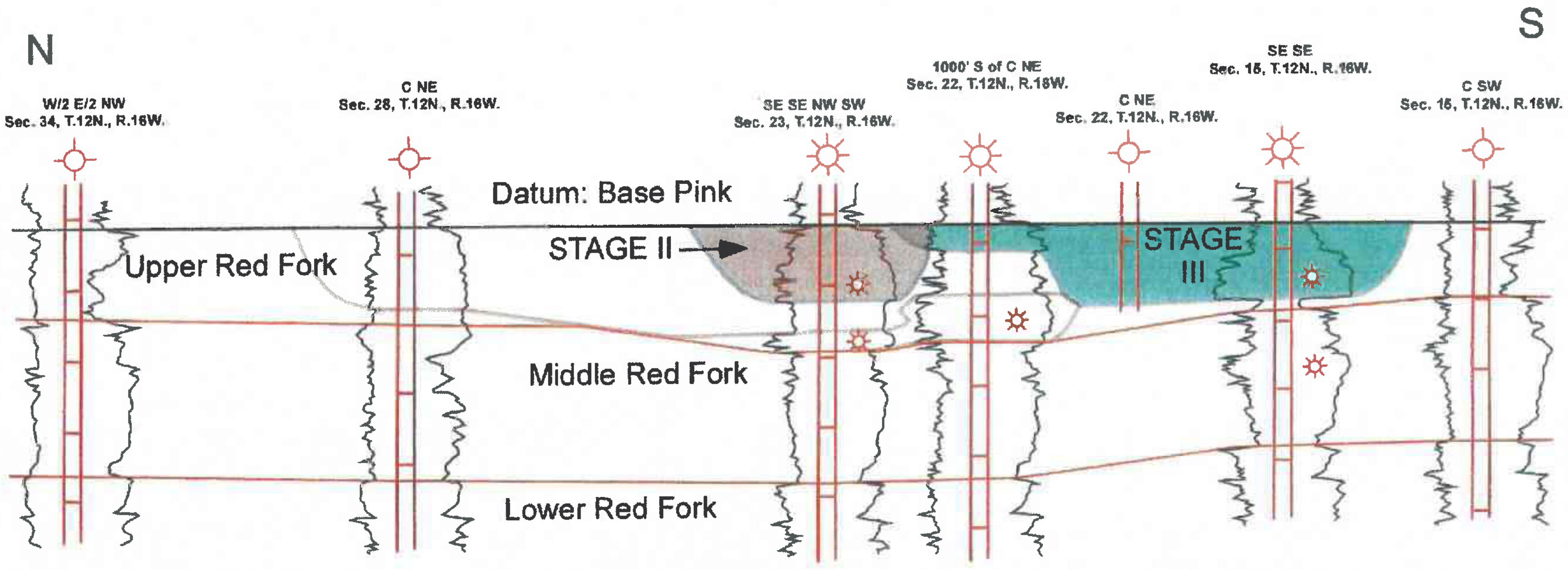
RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Many individual Red Fork wells produce in excess of 6 BCF gas in the East Clinton field. Wells in Stage III sandstones have estimated recoveries of >15 BCF and 250 thousand barrels of liquids (Clement, 1994).



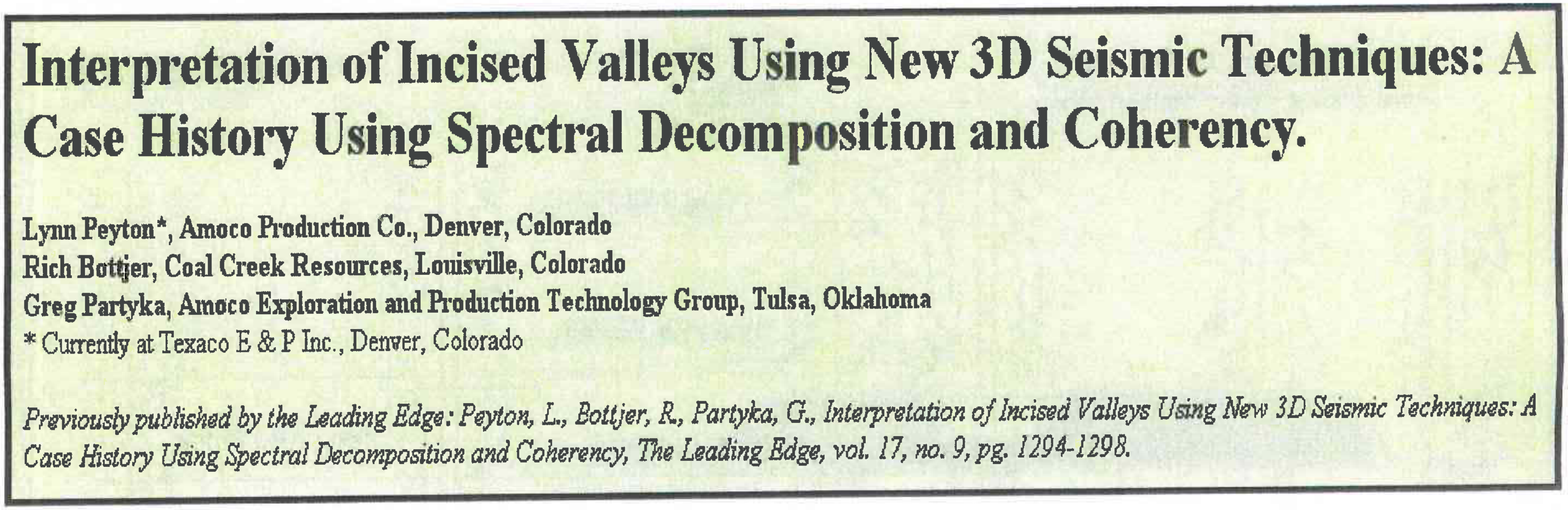
After Clement (1994)
Oil and Gas Fields of Oklahoma

Distribution of STAGE II and III Sandstone Bodies
East Clinton Field
Custer County, Oklahoma



From Clement (1994)
Oil and Gas Fields of Oklahoma

Cross Section: East Clinton Field
Custer County, Oklahoma

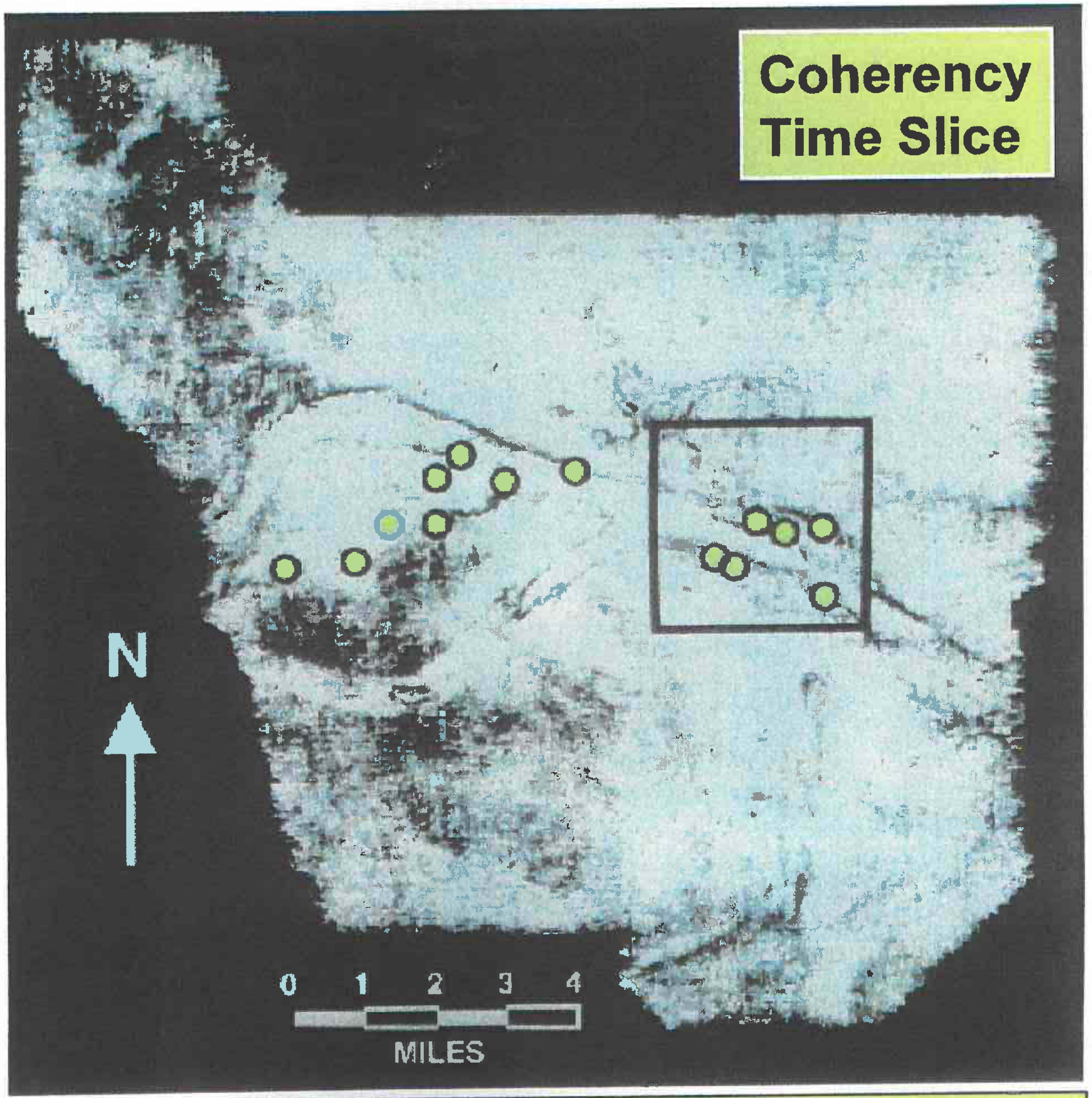


Interpretation of Incised Valleys Using New 3D Seismic Techniques: A Case History Using Spectral Decomposition and Coherency.

Lynn Peyton*, Amoco Production Co., Denver, Colorado
Rich Bottjer, Coal Creek Resources, Louisville, Colorado
Greg Partyka, Amoco Exploration and Production Technology Group, Tulsa, Oklahoma
* Currently at Texaco E & P Inc., Denver, Colorado

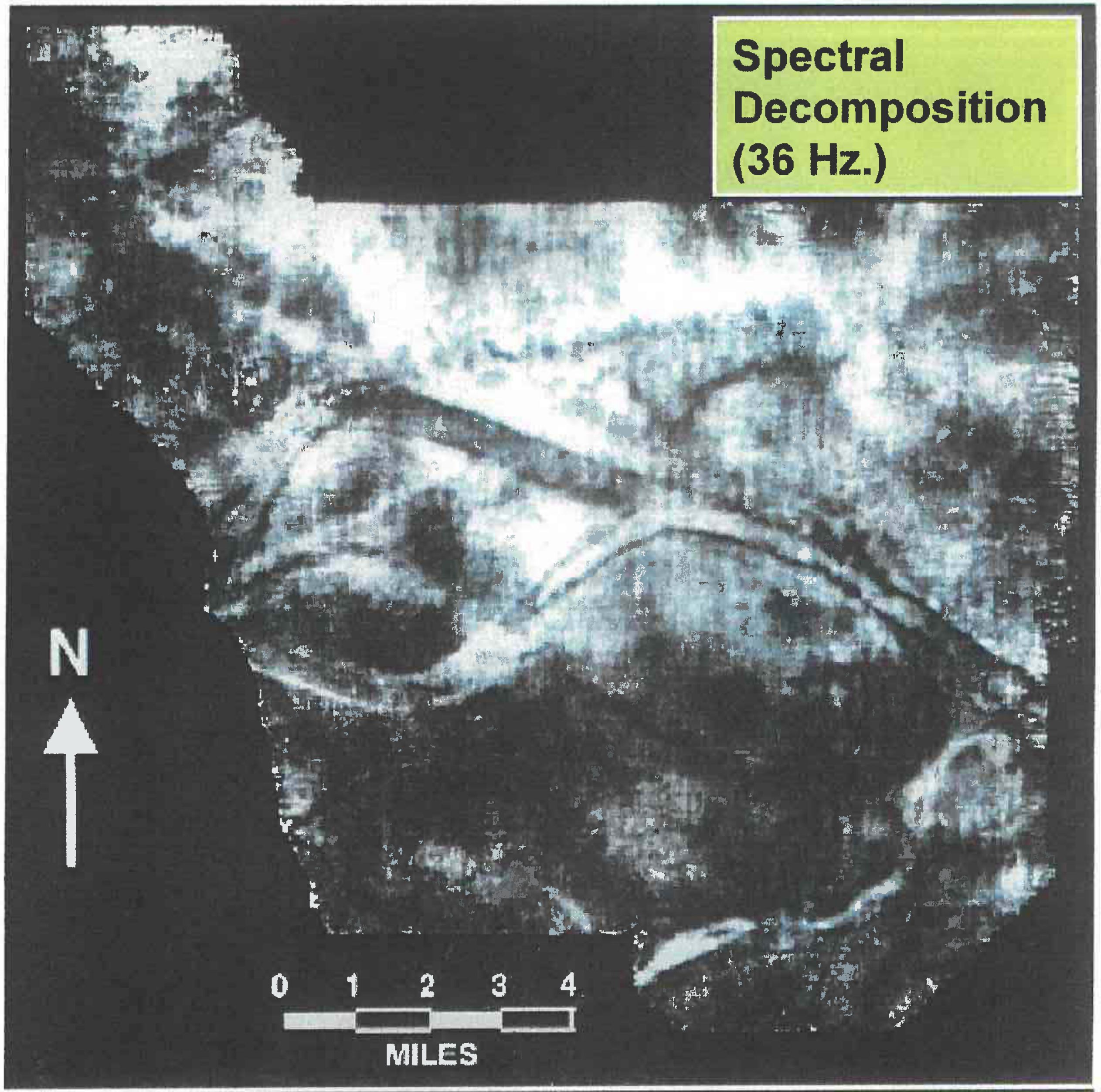
Previously published by the Leading Edge: Peyton, L., Bottjer, R., Partyka, G., Interpretation of Incised Valleys Using New 3D Seismic Techniques: A Case History Using Spectral Decomposition and Coherency, The Leading Edge, vol. 17, no. 9, pg. 1294-1298.

Coherency and spectral decomposition are two good techniques to define subtle channel edges and faults. Peyton, Bottjer and Partyka defined the Red Fork channel using these techniques.

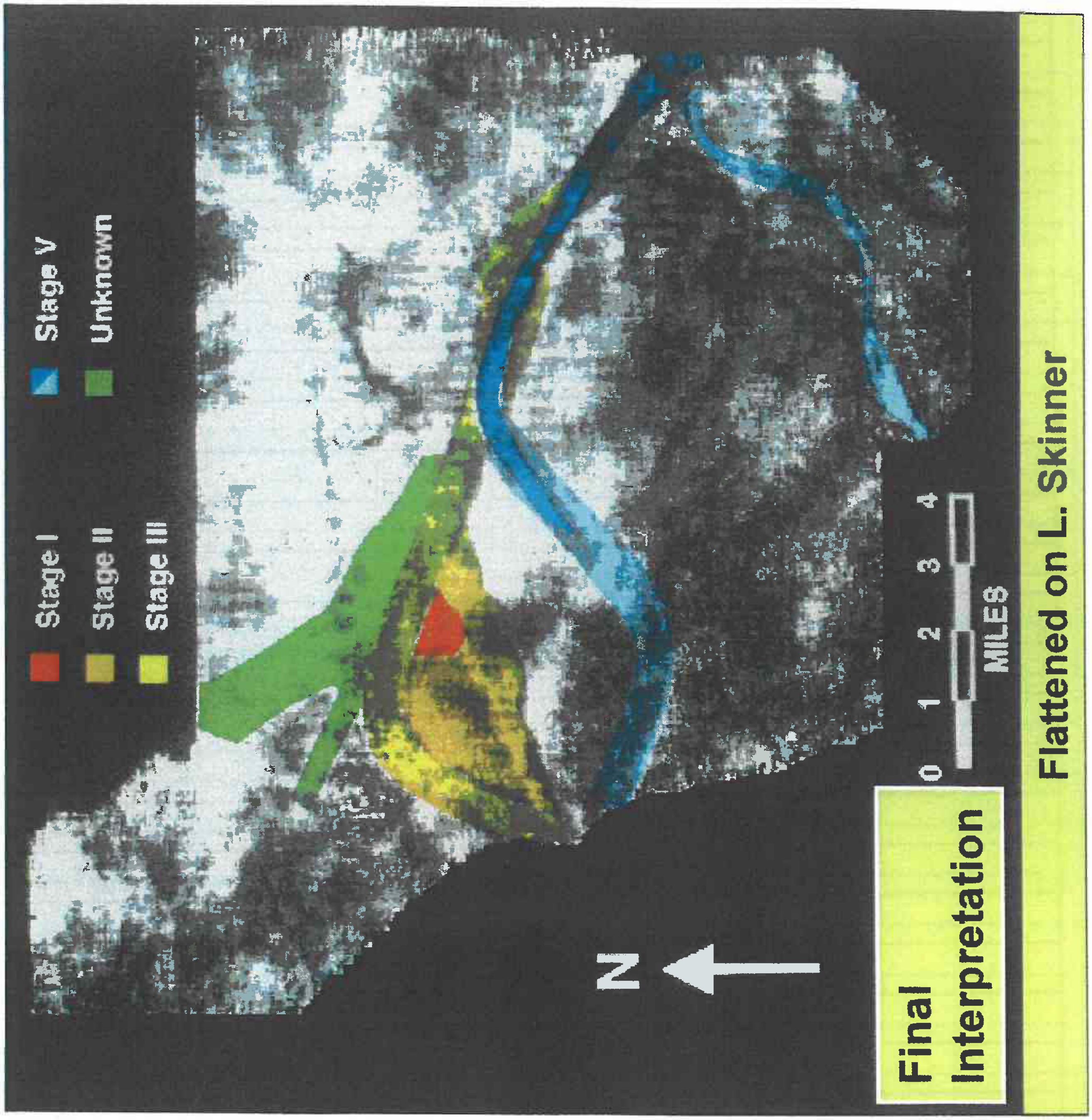


Flattened on L. Skinner

Spectral Decomposition (36 Hz.)



Flattened on L. Skinner


Stage I
Stage II
Stage III
Stage V
Unknown
N
0 1 2 3 4
MILES
Final Interpretation
Flattened on L. Skinner

NOTES

CARPENTER FIELD
BERLIN AREA
T.9-13N., R.21-26W.
Beckham and Roger Mills Counties, OK

LOCATION

Central Anadarko Basin adjacent to the Wichita Mountain Uplift.

PRIMARY PRODUCING RESERVOIRS

Atokan Carbonate "Granite" Wash

DEPOSITIONAL SETTING

The Atokan carbonate washes were formed as alluvial fans and fan deltas deposited sediments along the northern margin of the Wichita Mountains.

DISTRIBUTION of RESERVOIRS

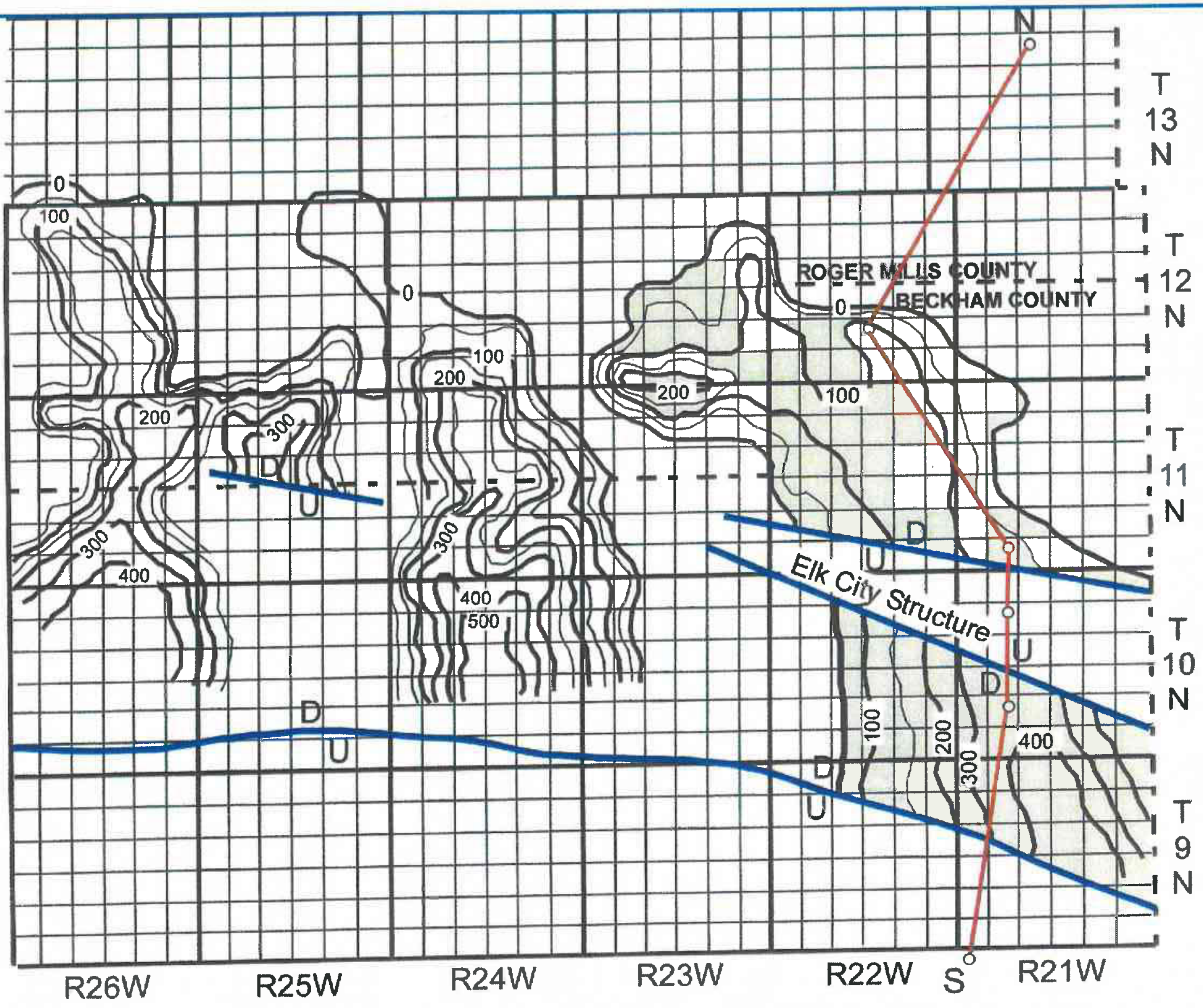
The Atokan carbonate deposits have the fan-shaped distribution that is typical of alluvial fan and fan delta deposits. The deposits were eroded from the Elk City fault block. The distribution pattern for the Atokan washes is an analog for older (Morrowan) chert conglomerate and younger Desmoinesian and Missourian washes.

TRAPPING MECHANISM and TYPE of DRIVE

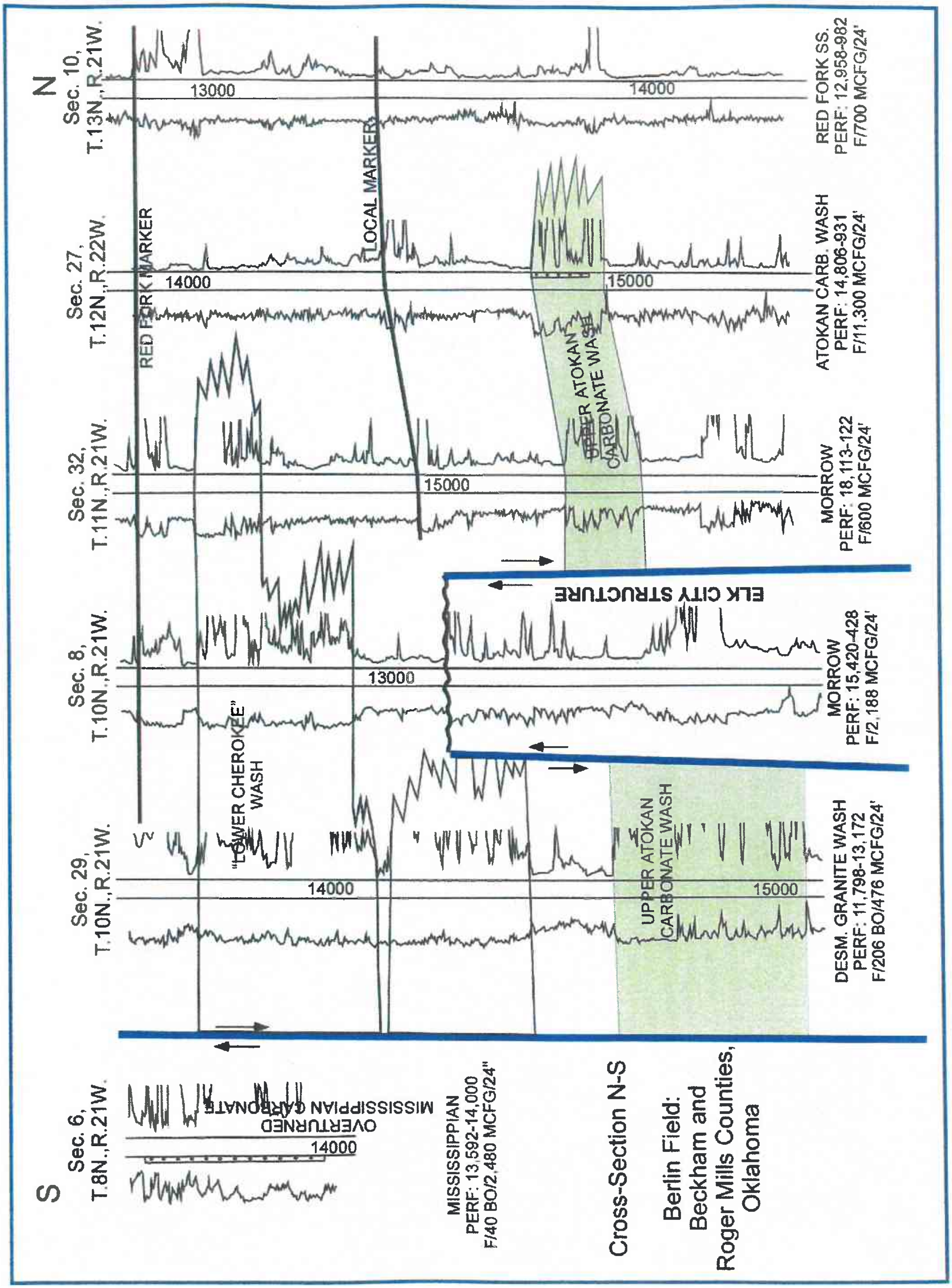
Stratigraphic trapping is responsible for the accumulation of natural gas in the Arokan washes.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Typical Atokan carbonate wash wells are expected to ultimately produce of 6-8 BCF gas, whereas exceptional wells may produce 30 BCF (Lyday, 1985)

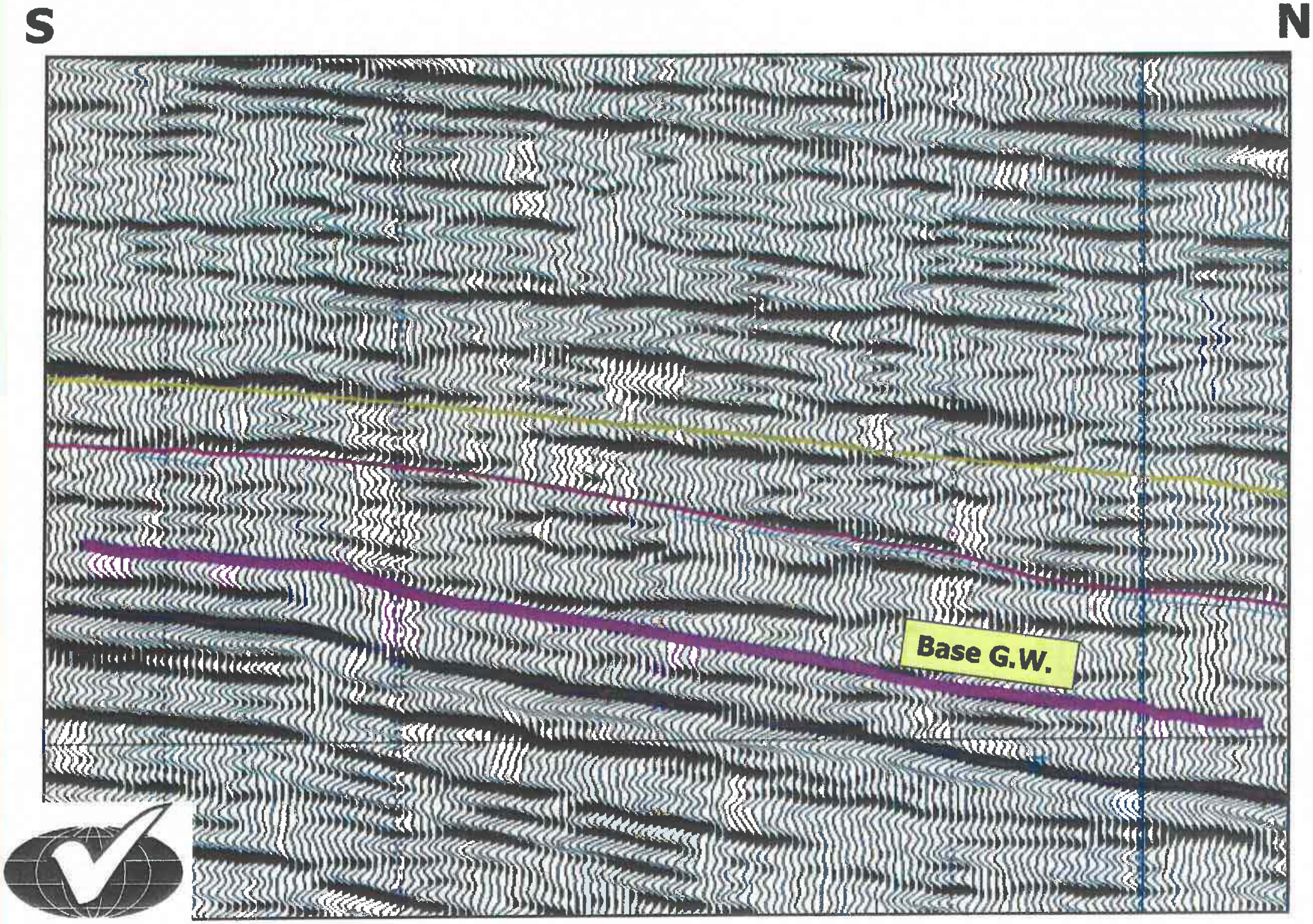


Distribution of the "Atoka A" Conglomerate
Berlin Field Area
Beckham and Roger Mills Counties, Oklahoma
C.I. = 50 and 100 feet



Cross-Section N-S

Berlin Field: Beckham and Roger Mills Counties, Oklahoma



Berlin Granite Wash

The Granite Wash is not consistent enough horizontally to develop coherent reflectors mappable with the 3D seismic. Beneath the Granite Wash zone the reflectors appear to be confidently mappable.

NOTES

NOTES

WEST ARLINGTON FIELD
T.13N., R.5-6E.
Lincoln County, OK

LOCATION

Cherokee Platform

PRIMARY PRODUCING RESERVOIRS

Hunton Group carbonates and Simpson (2nd Wilcox) sandstone

DEPOSITIONAL SETTING

The Hunton and Simpson reservoirs formed from sediments deposited in shallow-marine settings

DISTRIBUTION of RESERVOIRS

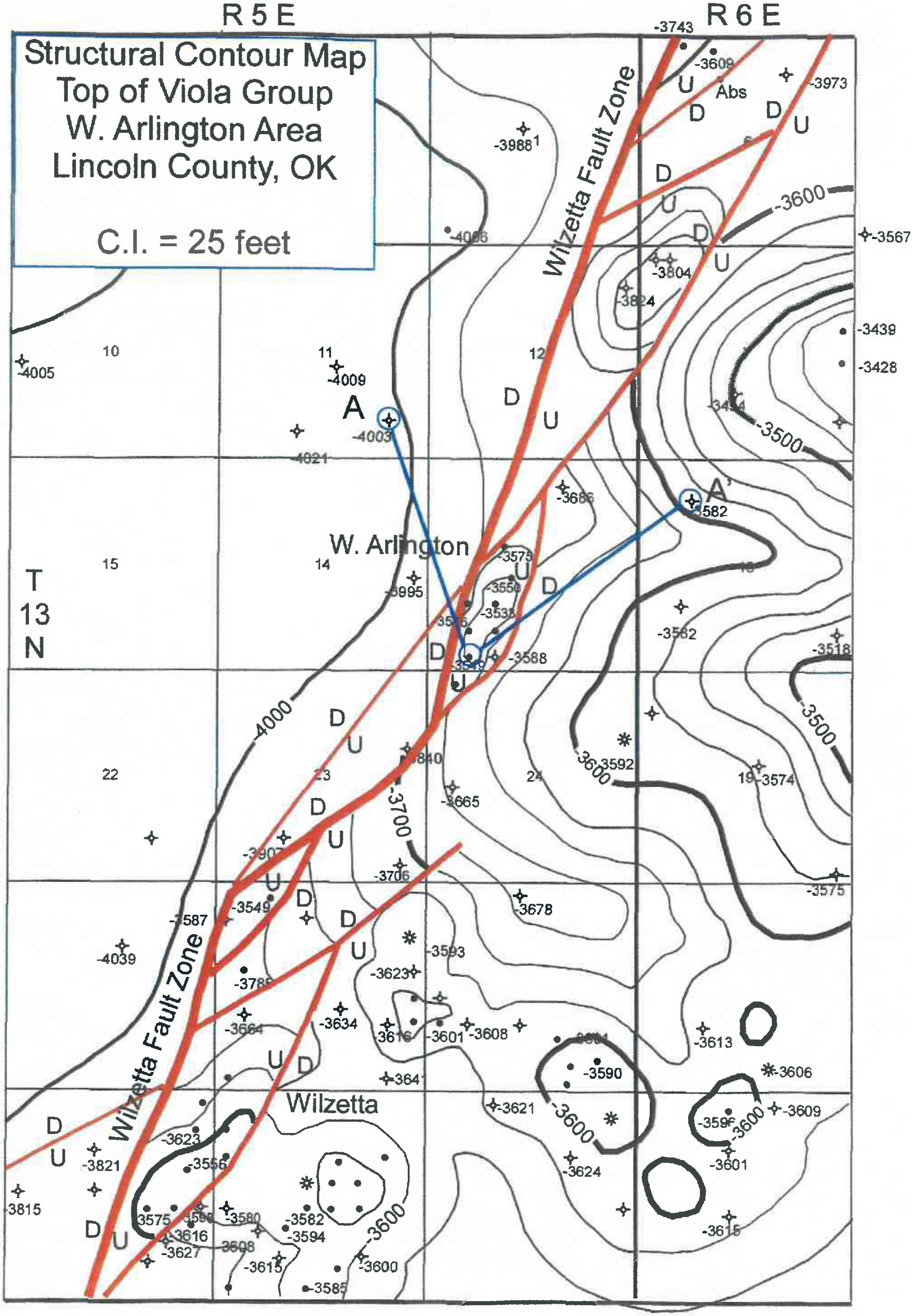
Both reservoirs are widely distributed. However, they form the best accumulations over anticlinal folds and horst blocks.

TRAPPING MECHANISM and TYPE of DRIVE

Structural trapping is responsible for the accumulation of oil in the Hunton and Simpson reservoirs on the West Arlington horst block. Both reservoirs have water legs that help define the limits of the productive areas.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

The average oil production is 200 thousand barrels for commingled Hunton Group and 2nd Wilcox (Simpson) producers in the West Arlington field.


Structural Contour Map
Top of Viola Group
W. Arlington Area
Lincoln County, OK
C.I. = 25 feet
R 5 E
R 6 E
T
13
N
Wilzetta Fault Zone
Wilzetta Fault Zone
W. Arlington
Wilzetta
A
A'
Abs
-4000
-3700
-3600
-3500
-3600
-3500
-3600
-3600
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24
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-3743
-3609
-3973
-3988
-4006
-3567
-3804
-3824
-3439
-3428
-4005
-4009
-4003
-4021
-3686
-3582
-3575
-3550
-3538
-3588
-3995
-3582
-3518
-3840
-3665
-3592
-3574
-3907
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-3556
-3821
-3624
-3601
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-3616
-3627
-3580
-3582
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-3600
-3585
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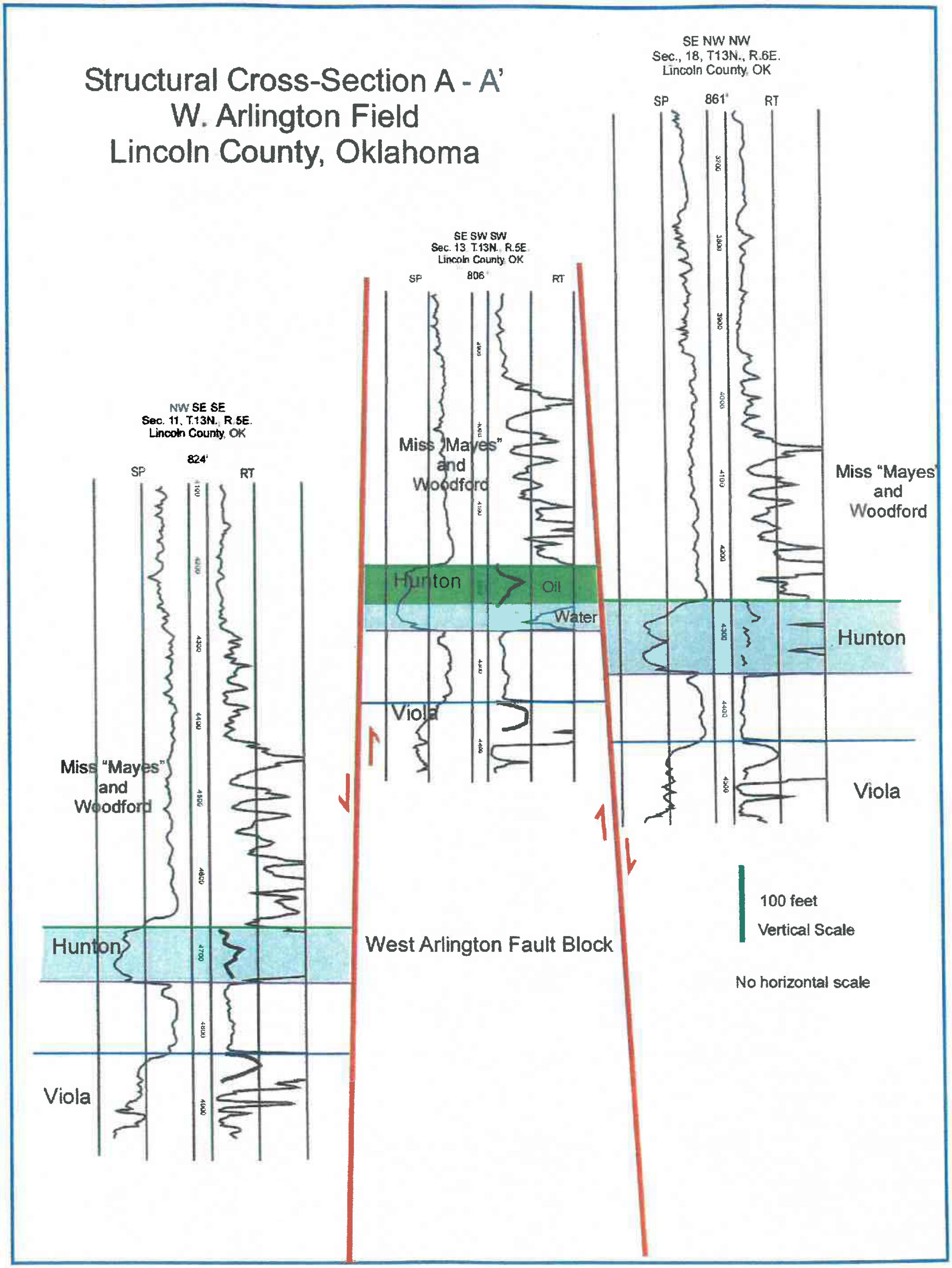
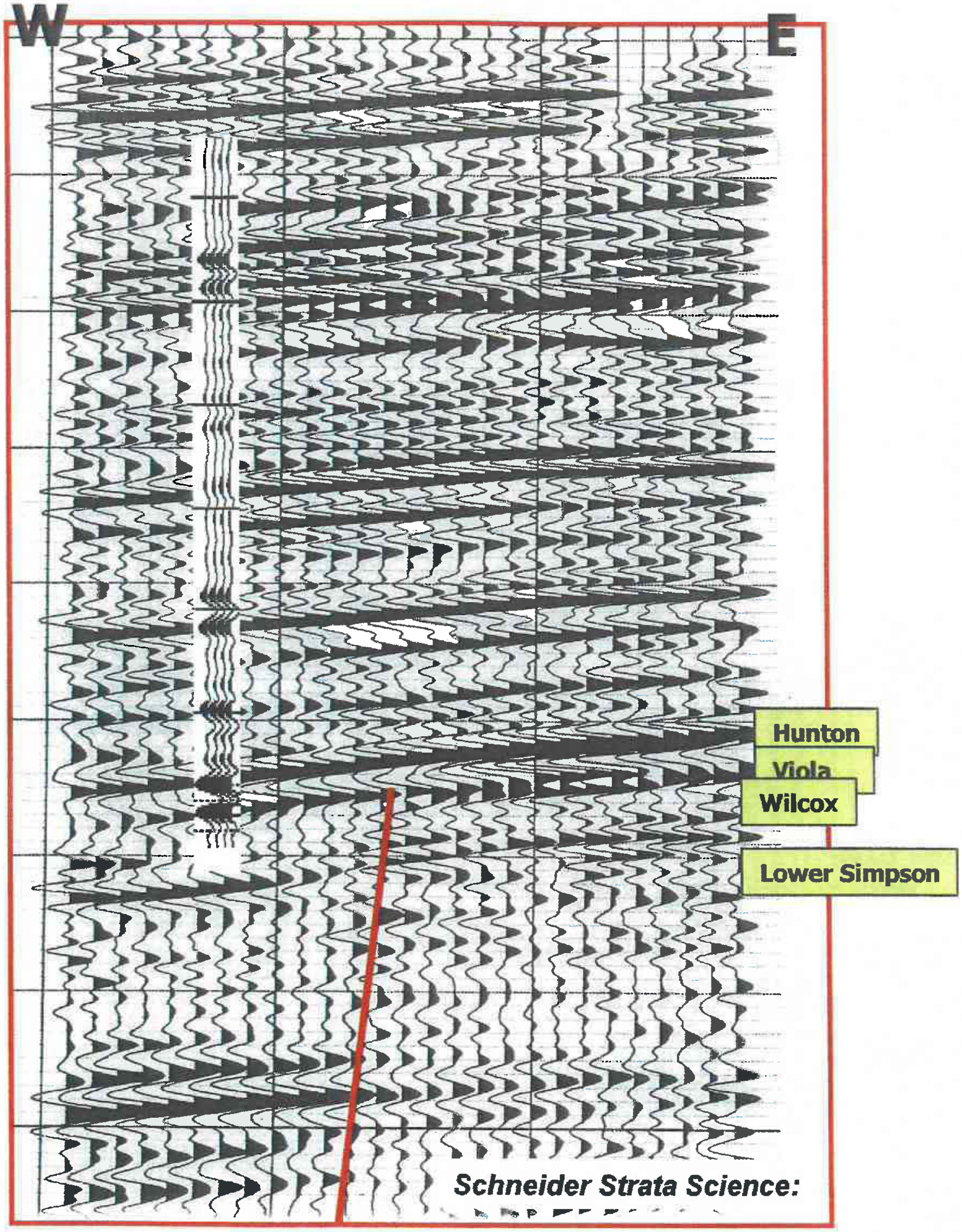
D
U

Structural Cross-Section A - A'
W. Arlington Field
Lincoln County, Oklahoma





The 3D seismic data near the Arlington Field is excellent quality and very accurate for structurally mapping of the Hunton lime and Wilcox sand.

NOTES

NOTES

SOONER VALLEY FIELD
T.19N., R.4E.
Payne County, OK

LOCATION

Cherokee Platform

PRIMARY PRODUCING RESERVOIRS

Skinner sandstone and Simpson (1st Wilcox) sandstone

DEPOSITIONAL SETTING

The Skinner sandstone formed from sediments deposited in a valley eroded into older Skinner deltaic deposits and the Pink Limestone during a drop in sea level. The Simpson reservoir formed from sediments deposited in a shallow-marine setting.

DISTRIBUTION of RESERVOIRS

The Skinner Sandstone is a narrow and sinuous deposit that is less than 1 mile wide and traceable for over 10 miles. The Simpson sandstone is widespread, but produces on anticlinal folds and fault blocks.

TRAPPING MECHANISM and TYPE of DRIVE

Structural trapping is responsible for the accumulation of oil in the Simpson (Wilcox) reservoir. The Skinner valley filling sandstone produces when the valley trend drapes over an anticlinal fold.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

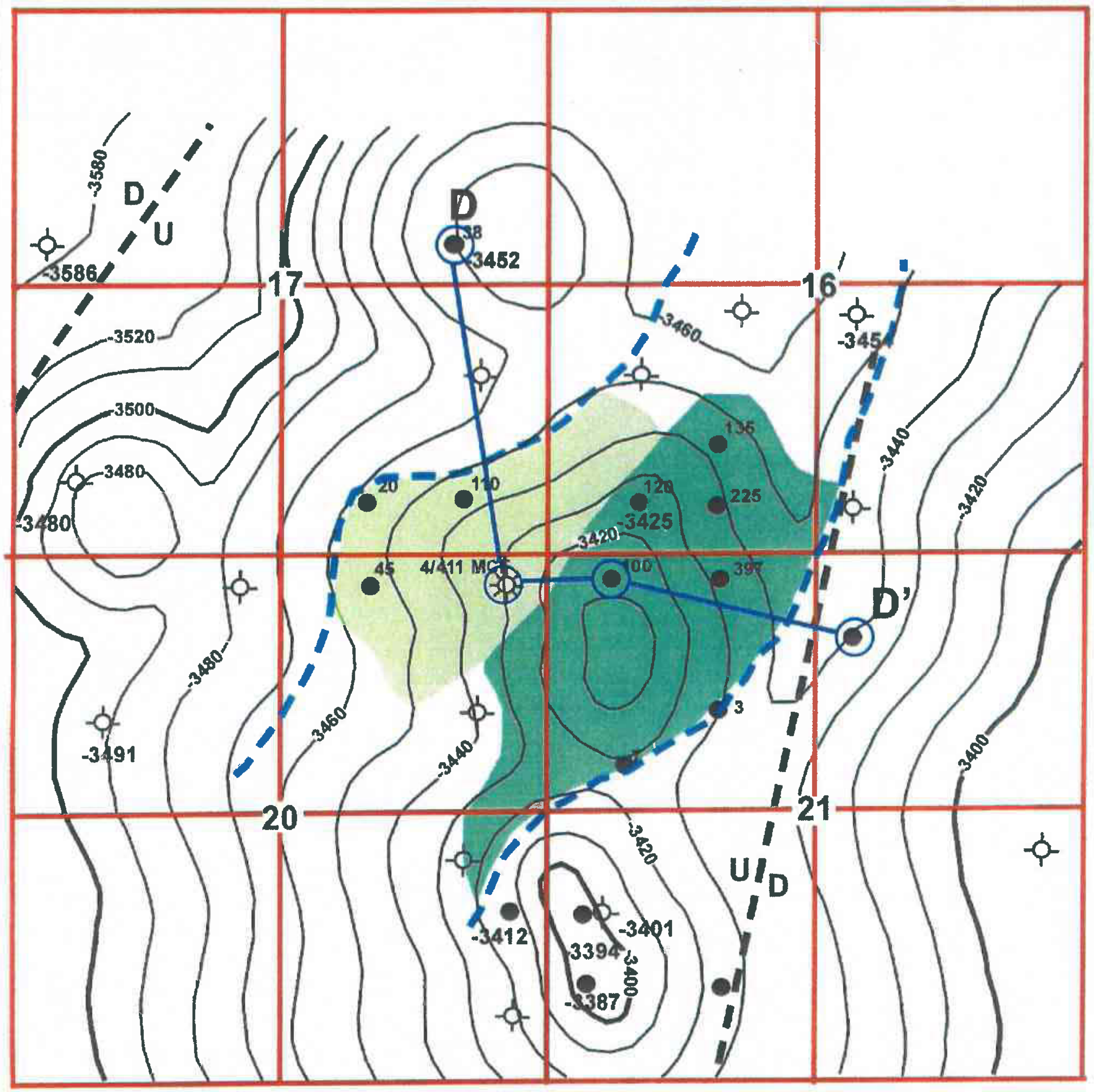
The average well production for the thicker (20 – 30 feet) valley filling Skinner sandstone exceeds 200 thousand barrels per well. Some Skinner wells have produced in excess of 400 thousand barrels. The Wilcox producer located near the crest of the anticlinal fold in Sooner Valley produced in excess of 60 thousand barrels of oil.

NW SOONER VALLEY FIELD

T.19N., R.3E.
PAYNE COUNTY, OK

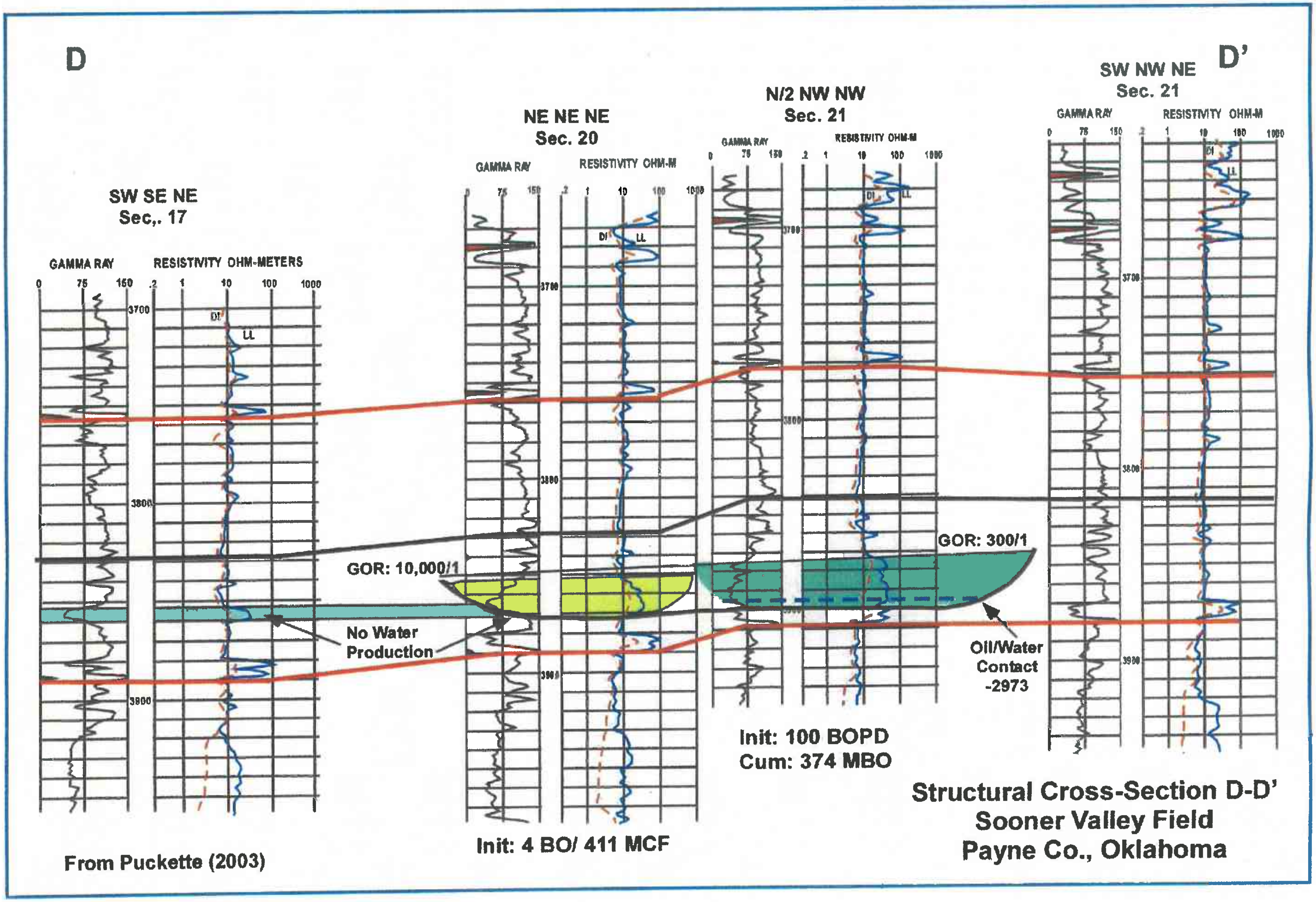
VIOLA LIMESTONE STRUCTURE

C.I. = 10 Feet



From Puckette (2003)

L. SKINNER VALLEY TREND SUPERIMPOSED



Structural Cross-Section D-D’
Sooner Valley Field
Payne Co., Oklahoma

From Puckette (2003)

No 3D seismic data was found available near the NW Sooner Valley Field. The seismic data should be excellent quality, similar to the Arlington Field area. The Hunton and Wilcox should be mappable but the Skinner sand may not be a good reflector from 2D experience in the area.

NOTES

NOTES

SOUTH PINE HOLLOW FIELD
T.5-6N., R.12-13E.
Pittsburg County, OK

LOCATION

West-central part of the Arkoma Basin

PRIMARY PRODUCING RESERVOIR

Valley filling Hartshorne sandstone.

DEPOSITIONAL SETTING

The thick valley filling Hartshorne sandstone bodies represent sand that accumulated in a valley that eroded older Hartshorne deltaic and shallow marine deposits during a drop in sea level

DISTRIBUTION of RESERVOIRS

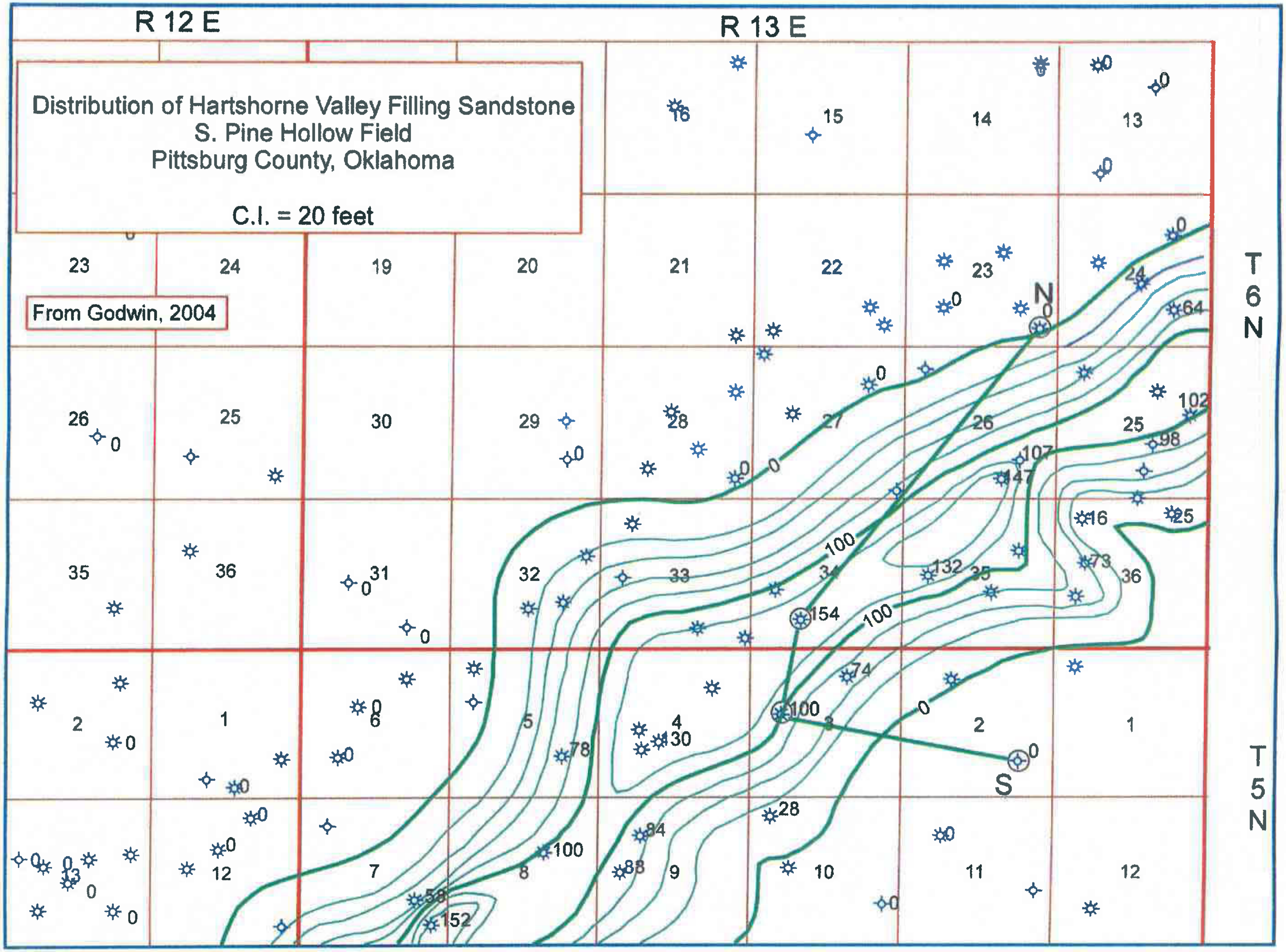
Reservoir trends are 2-3 miles wide and extend for tens of miles. Sandstone bodies near the axis of the incised valley may exceed 100 feet in thickness.

TRAPPING MECHANISM and TYPE of DRIVE

Stratigraphic and structural. Natural gas is produced where sandstone trends cross structural features. Reservoirs are water bearing down dip from gas accumulations.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

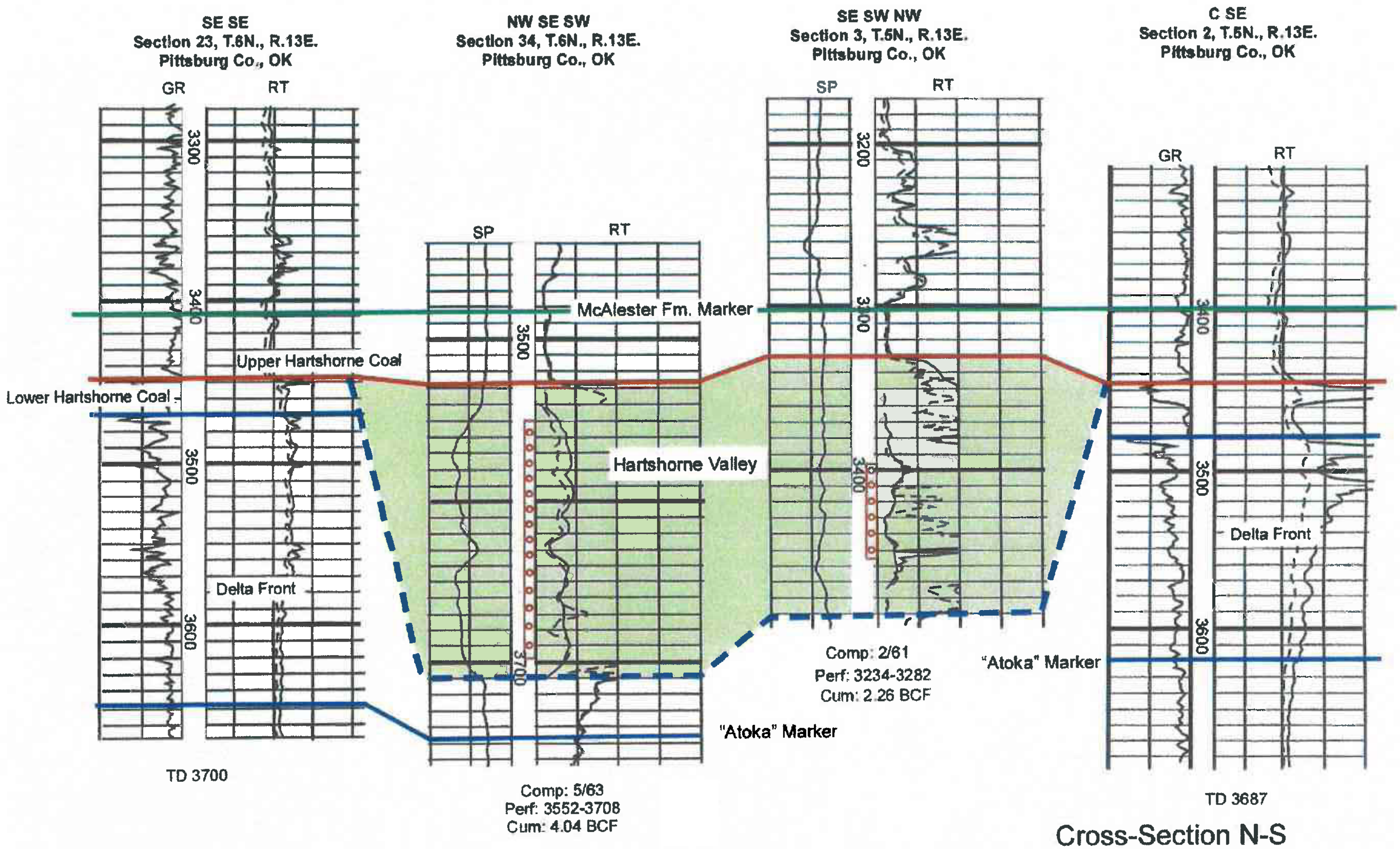
Better wells in the Hartshorne valley filling sandstone trend produce in excess of 4 BCF gas.



Distribution of Hartshorne Valley Filling Sandstone
S. Pine Hollow Field
Pittsburg County, Oklahoma

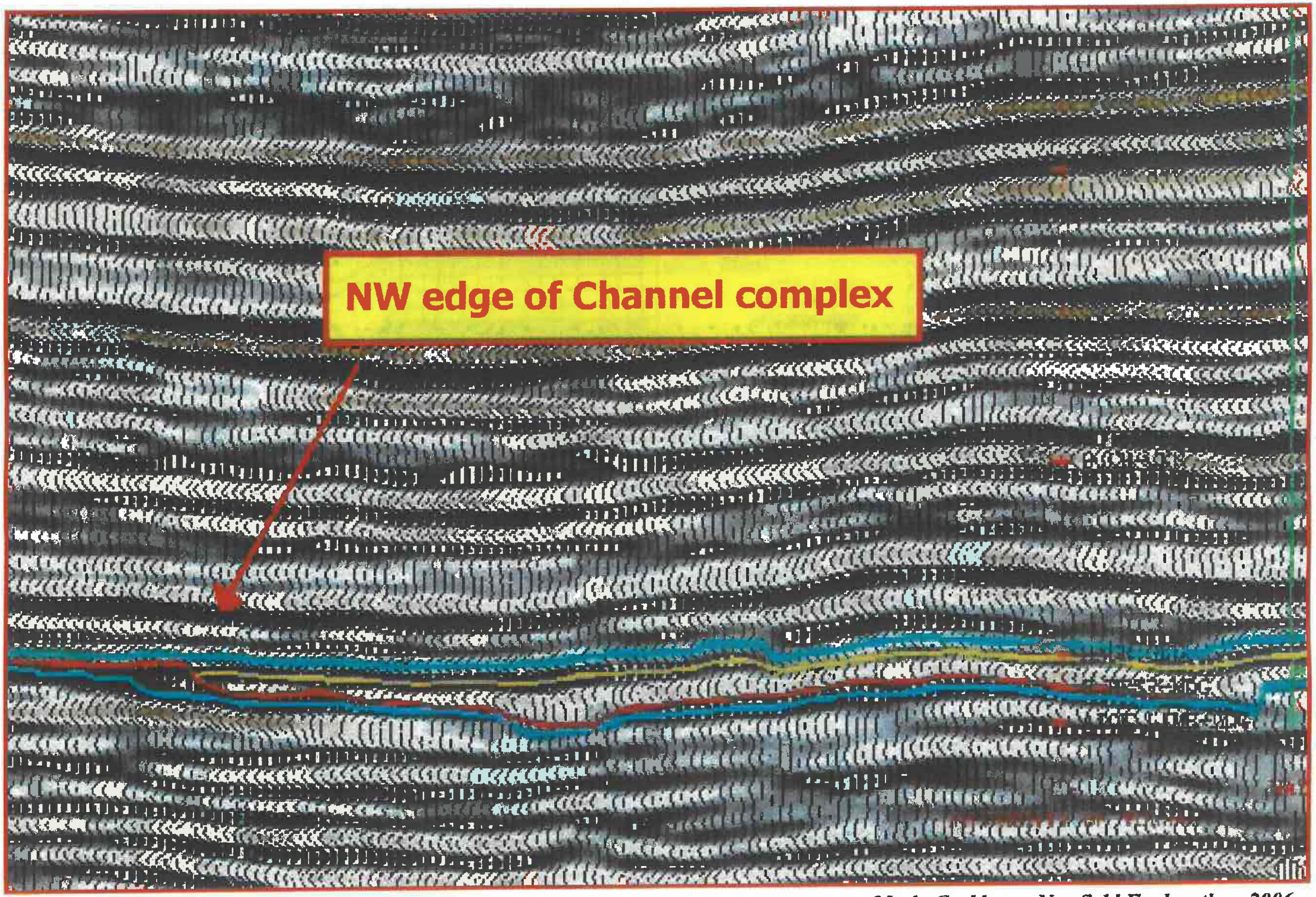
C.I. = 20 feet

From Godwin, 2004



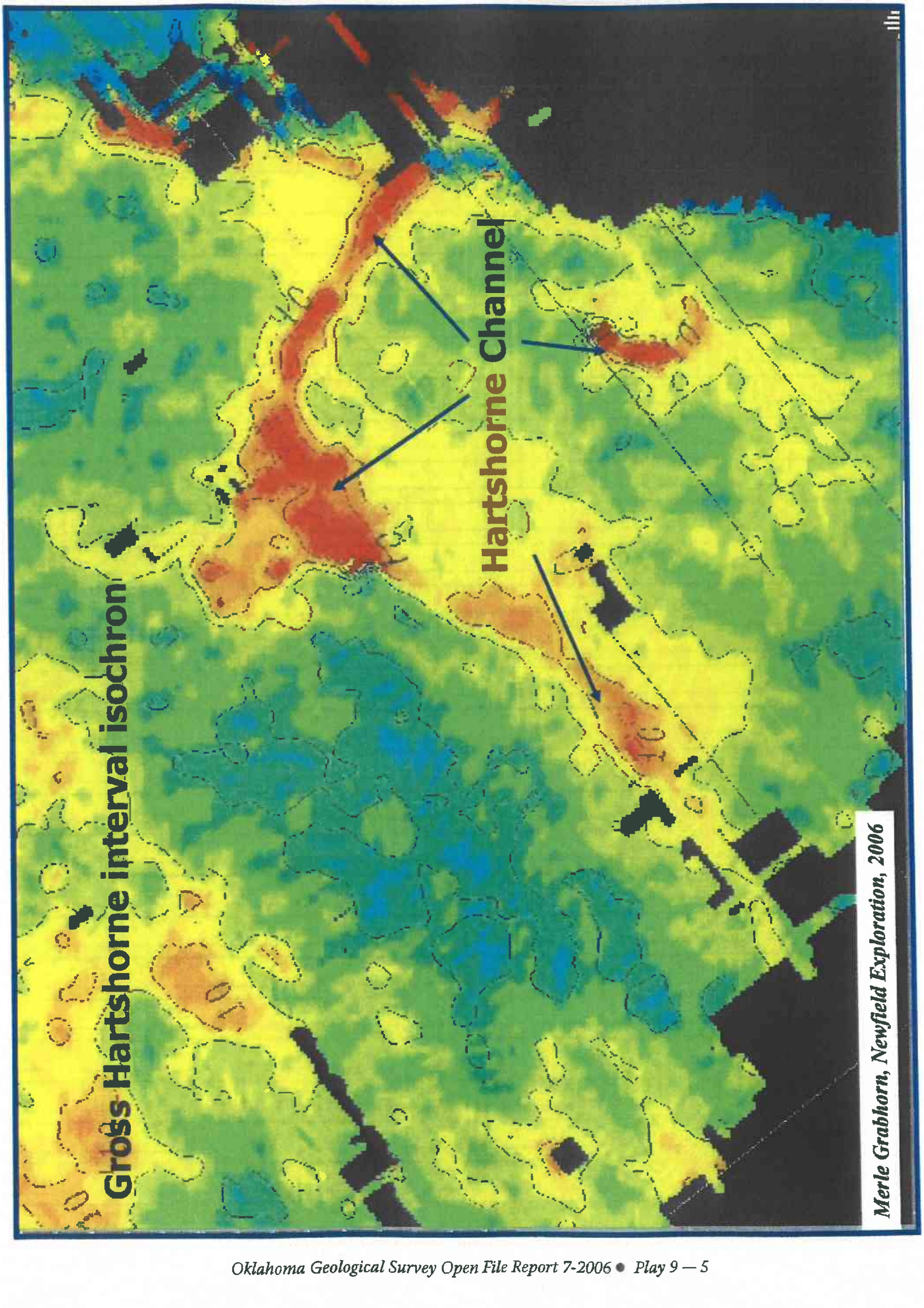
Cross-Section N-S
Hartshorne Sandstone
S. Pine Hollow Field
Pittsburg County, Oklahoma

From Godwin (2004)



Merle Grabhorn, Newfield Exploration, 2006

The extracted 3D seismic data from the Arkoma Basin defines a Hartshorne channel similar to the S. Pine Hollow Field. The isochron map shows the thickness and meandering nature of the channel.



Merle Grabhorn, Newfield Exploration, 2006

NOTES

FITTS FIELD
T.1-2N., R.7-8E.
Pontotoc County, OK

LOCATION

Franks Graben, western Arkoma Basin

PRIMARY PRODUCING RESERVOIRS

Hunton Group limestone, Viola Group limestone, Simpson (Bromide) sandstones and Pennsylvanian (Cromwell) sandstone

DEPOSITIONAL SETTING

All reservoirs listed above formed from sediments that were deposited in shallow marine settings.

DISTRIBUTION of RESERVOIRS

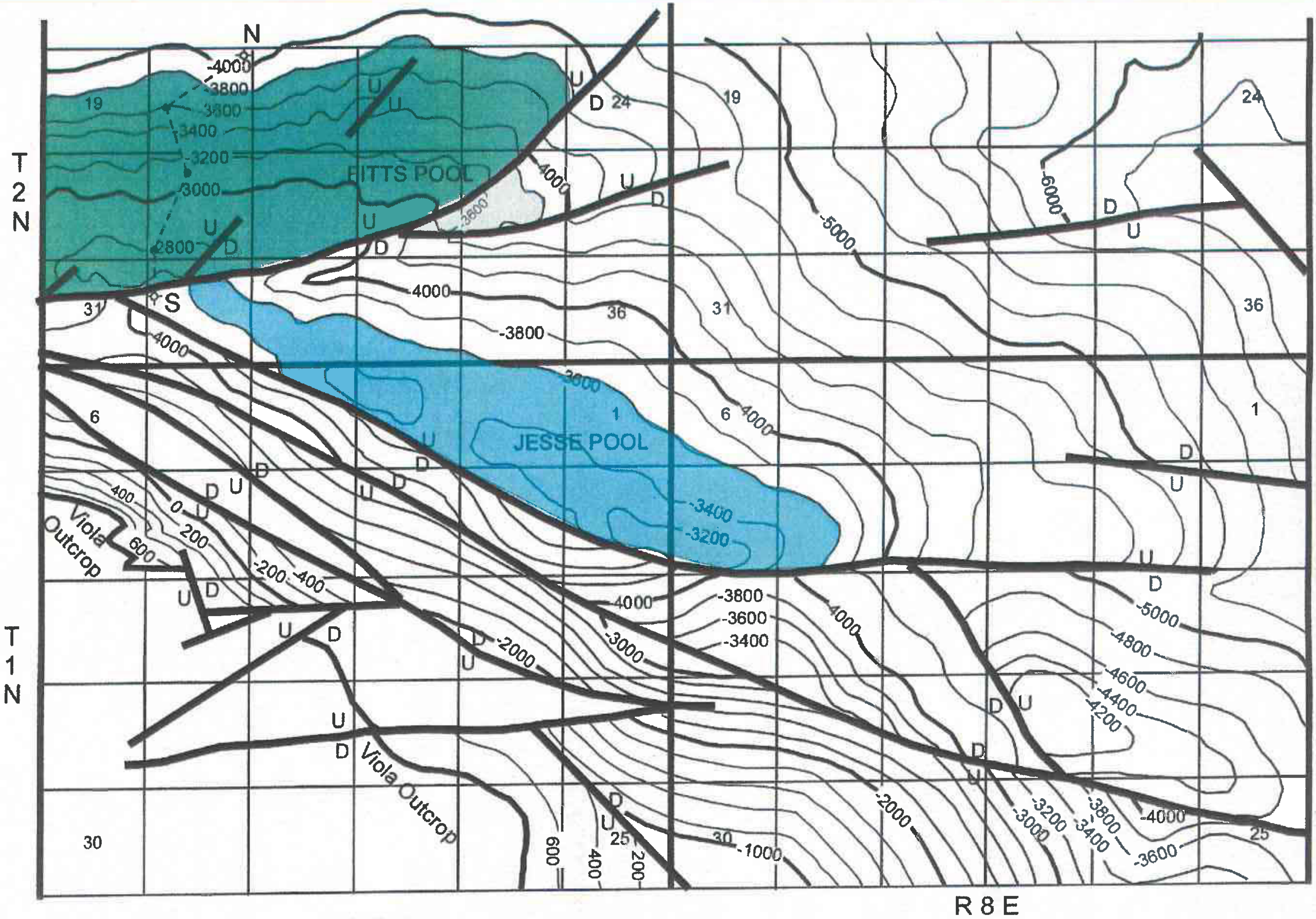
The reservoirs are distributed across the Fitts and adjacent anticlinal folds.

TRAPPING MECHANISM and TYPE of DRIVE

Structural trapping is responsible for accumulations in the Simpson, Viola and Hunton Groups. Interestingly, the oil-water contact on the Fitts anticline is relatively flat and crosses stratigraphy. The Cromwell Sandstone is productive on the Fitts and Jesse anticlines, but will produce in adjacent areas where stratigraphic controls dominate.

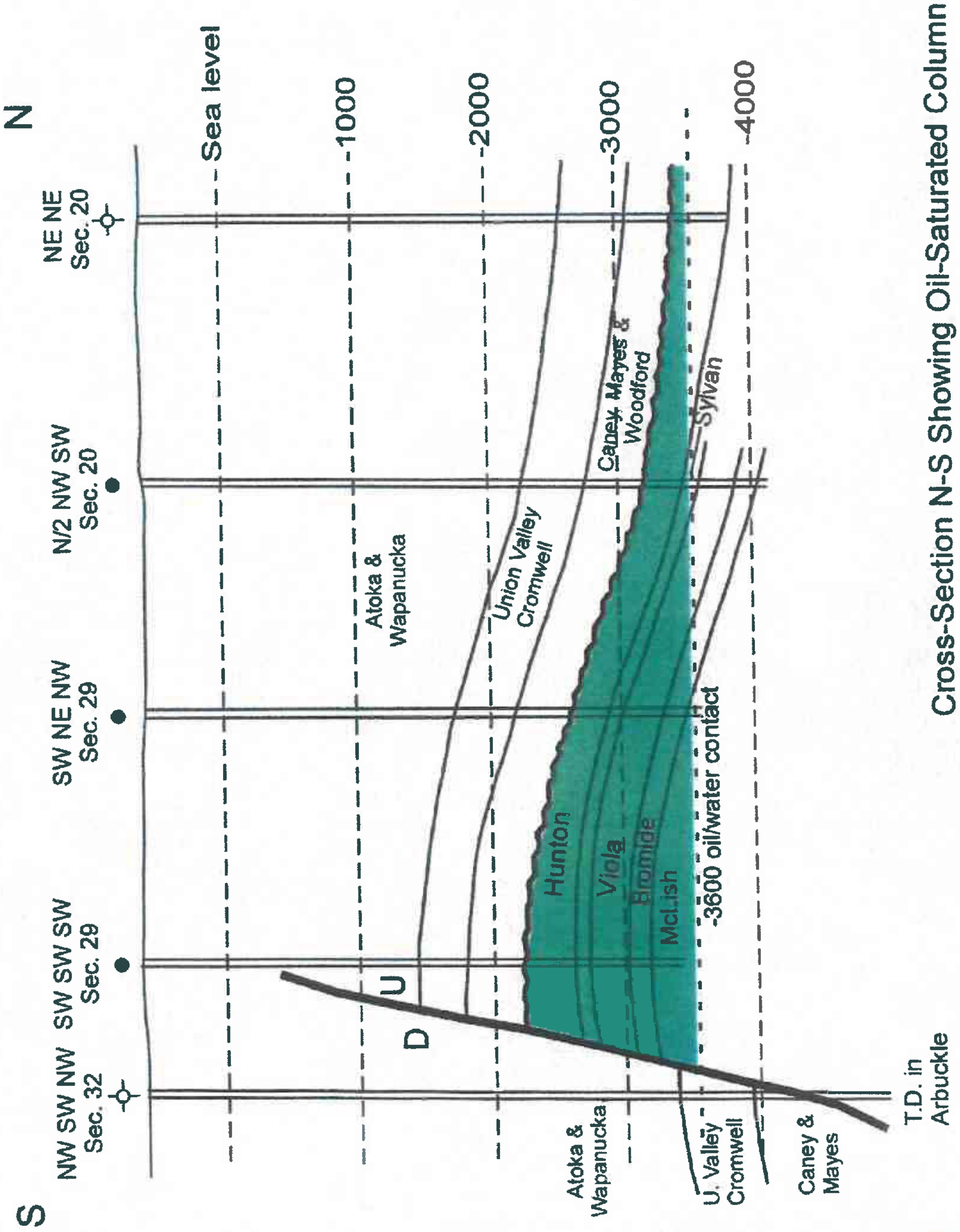
RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Individual well production is difficult to determine due to the age of the field and numerous pays. The Fitts pool has produced in excess of 200 million barrels of oil. The Jesse pool has produced over 10 million barrels of oil from Hunton and Cromwell reservoirs.



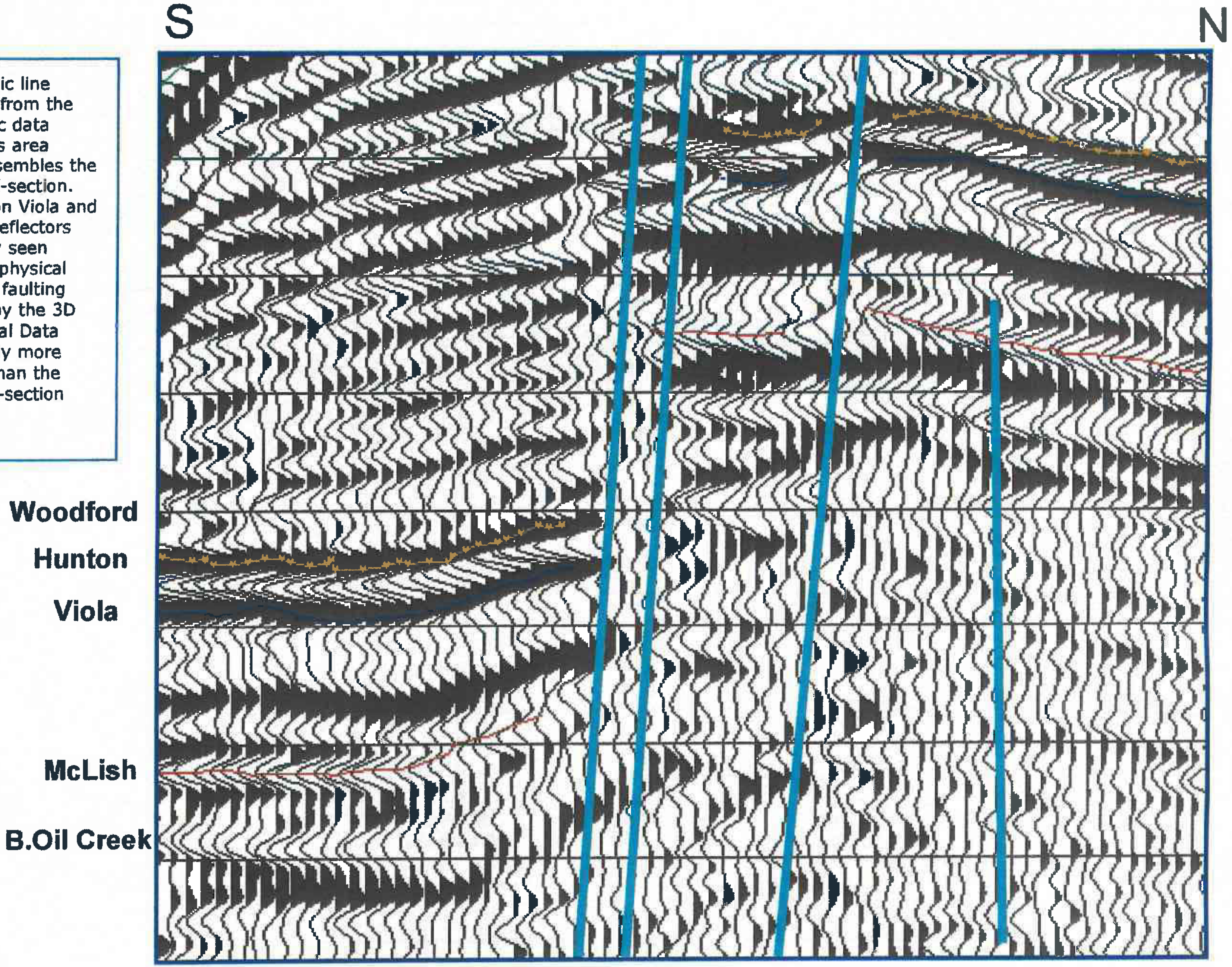
C.I. = 200 feet

Structural Contour Map on Top of Viola Group
Fitts and Jesse Pools
Pontotoc County, Oklahoma



Cross-Section N-S Showing Oil-Saturated Column
Fitts Pool
Pontotoc County, Oklahoma

After Puckette and others (2000)



The seismic line extracted from the 3D seismic data in the Fitts area closely resembles the geologic X-section. The Hunton Viola and Simpson reflectors are clearly seen in the geophysical Data. The faulting detected by the 3D Geophysical Data is obviously more complex than the geologic x-section illustrates.

Springman, 2006

NOTES

NOTES

WILBURTON FIELD
T.4-6N., R.17-19E.
Latimer County, OK

LOCATION

Central Arkoma Basin

PRIMARY PRODUCING RESERVOIRS

The Spiro Sandstone and carbonates (dolomite) of the Arbuckle Group

DEPOSITIONAL SETTING

All reservoirs listed above formed from sediments that were deposited in shallow marine settings.

DISTRIBUTION of RESERVOIRS

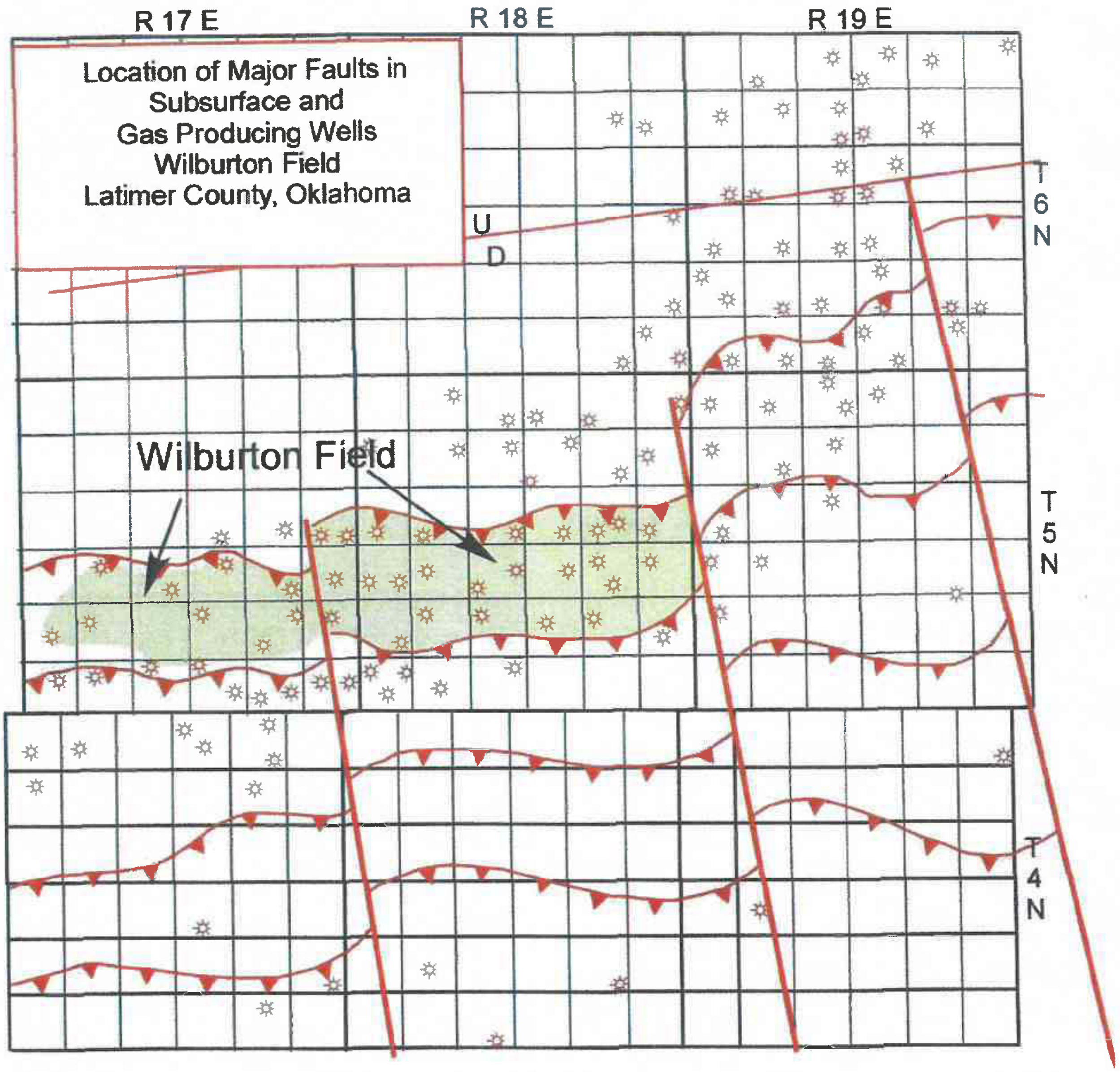
The Spiro Sandstone reservoir is located in thrust sheet immediately above the major detachment surface. Shallower thrust sheets contain Spiro from a more distal setting in the depositional basin that is too low porosity and permeability to produce because it is cemented. Cemented Spiro lacks chamosite or glauconite grain coatings. The Arbuckle dolomite reservoir is widely distributed throughout the field.

TRAPPING MECHANISM and TYPE of DRIVE

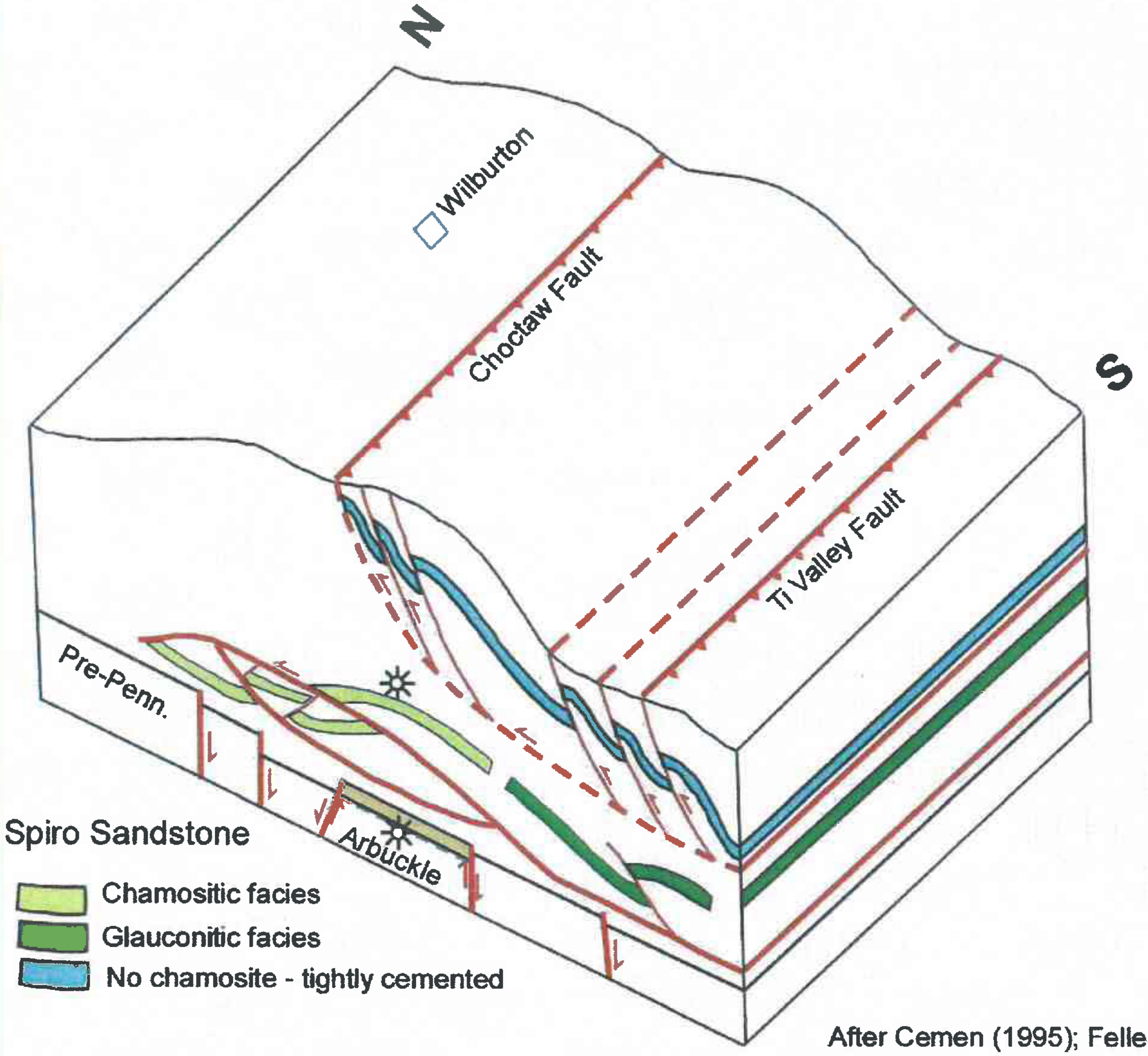
Structural trapping is responsible for the trapping of natural gas in the Arbuckle Group on the Wilburton Field horst block. Spiro sandstone reservoirs produce natural gas where chamosite/glauconite-bearing sandstone is thrusted and folded to form structural traps.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Average gas production for the Wilburton area exceeds 4 BCF per well. Many individual Spiro wells are projected to produce in excess of 6-10 BCF gas. Ultimate recovery for Arbuckle dolomite wells is expected to exceed 10 BCF per well.

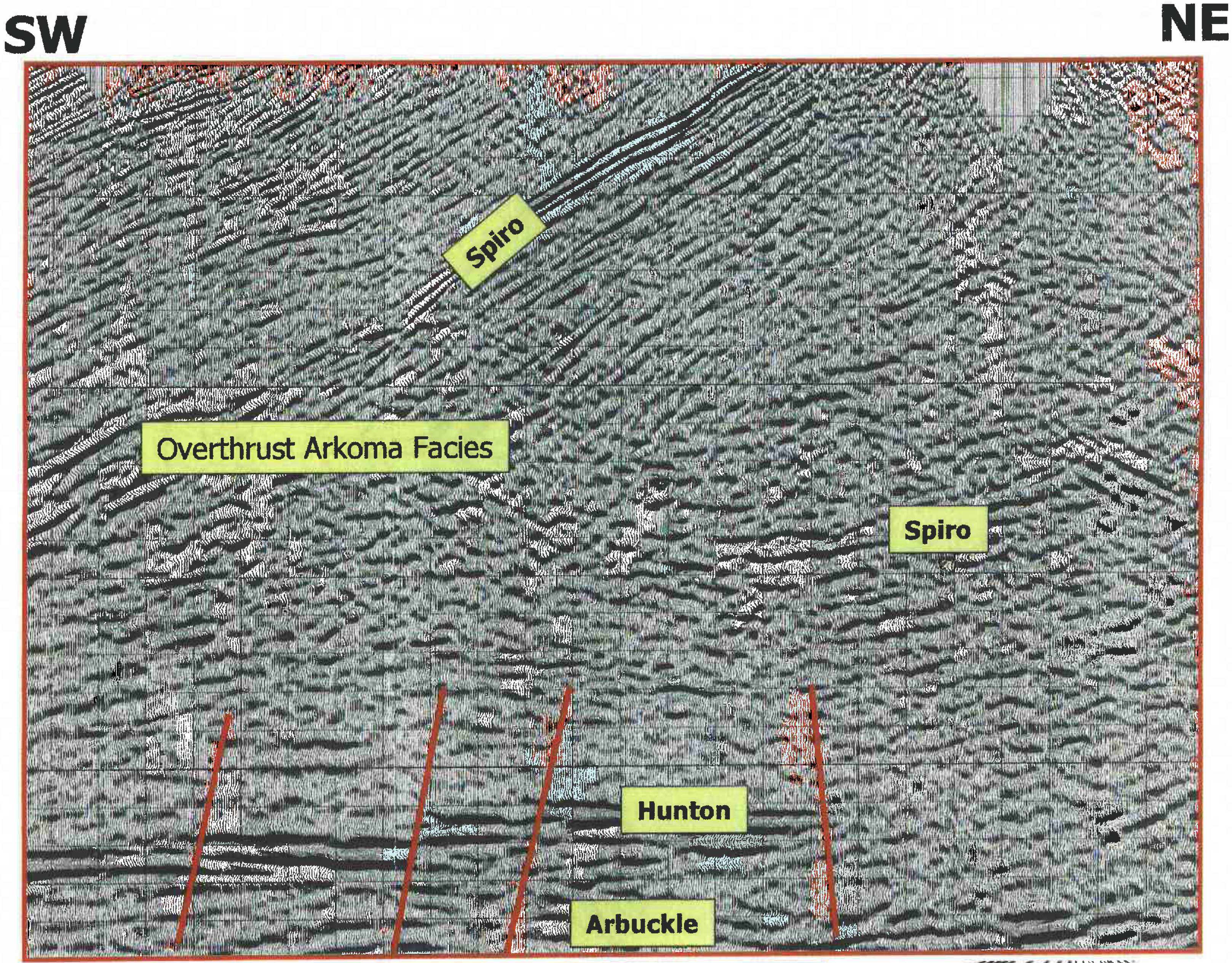


After Feller (1993)



After Cemen (1995); Feller (1995)

Block Diagram of the Wilburton Field Area
Spiro Gas Production is Controlled by Structure and Cementing Patterns
Arbuckle Gas Production is Subthrust and Fault Controlled



The thrusted Spiro-Wapanucka reflectors are mappable with the 3D seismic. The Hunton through Arbuckle tensional fault blocks, similar to the Wilburton Field can be confidently mapped.

WILSON Geophysical, Incorporated

NOTES

NOTES

BUFFALO MOUNTAIN FIELD
T.3-4N., R.20-21E.
Latimer County, OK

LOCATION

Ouachita Overthrust

PRIMARY PRODUCING RESERVOIR

The Jackfork sandstone

DEPOSITIONAL SETTING

Deeper marine sandstones formed from sand-rich gravity flows (turbidites) in the Ouachita depositional basin.

DISTRIBUTION of RESERVOIRS

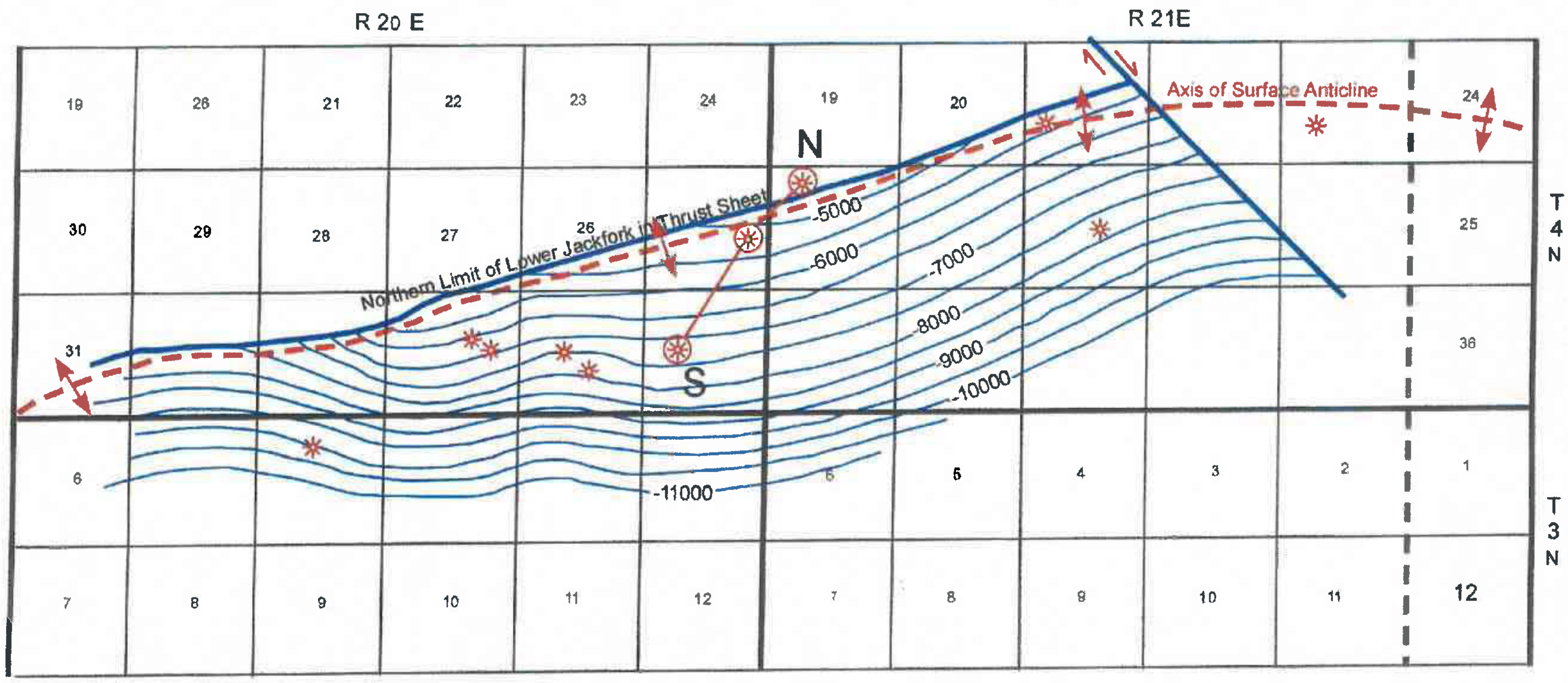
The Jackfork Sandstone is distributed across the field area.

TRAPPING MECHANISM and TYPE of DRIVE

Structural trapping is responsible for the trapping of natural gas in the lower and upper Jackfork sandstones. The lower Jackfork is primarily productive in a thrust sheet that is folded into an anticline. The northern limit of the principal productive area is defined by the bounding thrust fault.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Production for individual wells varies greatly due reservoir quality. Matrix porosity is highly variable and the sandstones are fractured. Estimated recovery on an individual well basis is 2.0 to 7.6 BCF per well (Montgomery, 1996).

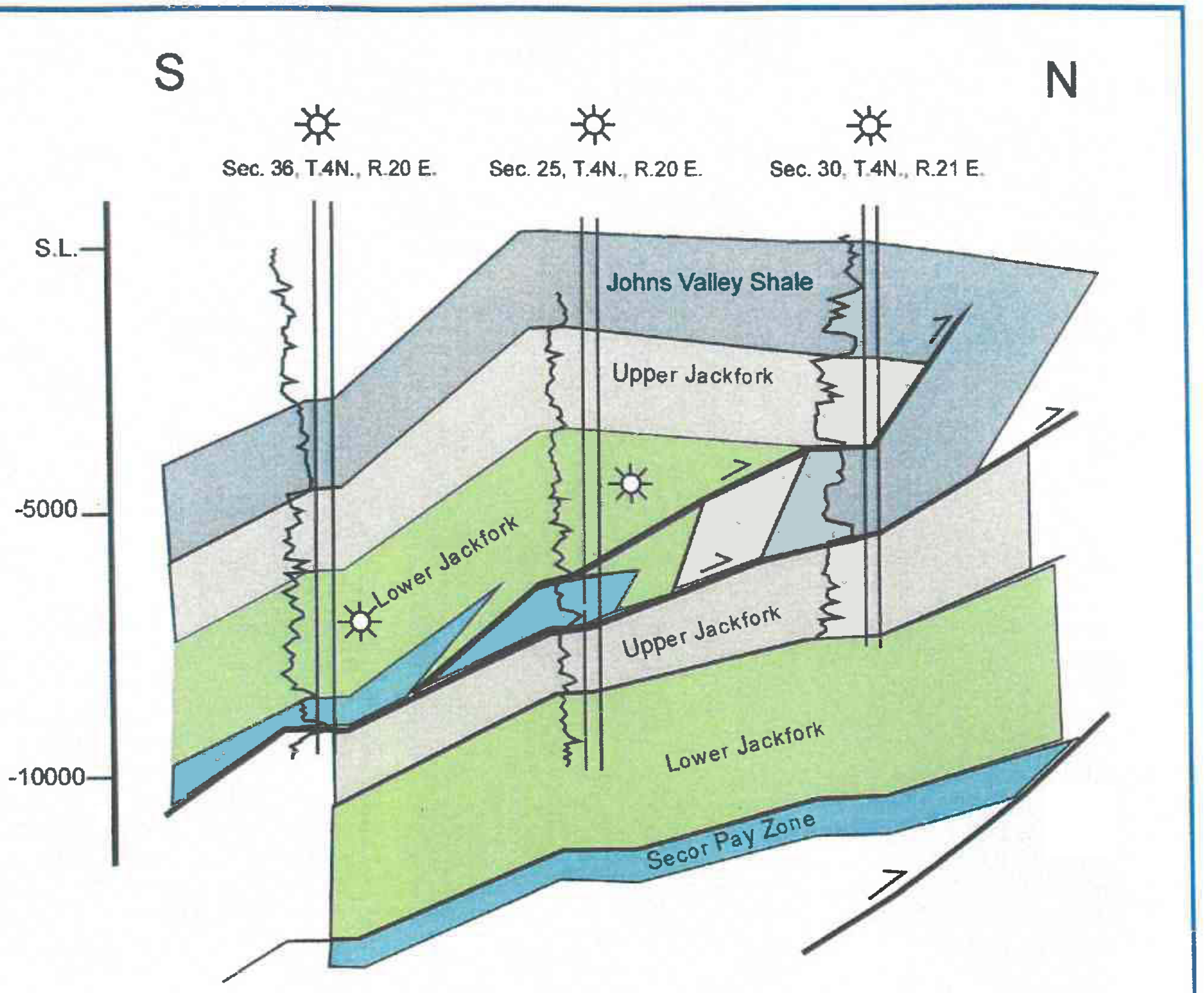


Structure Map of Thrusted Lower Jackfork Sandstone
Buffalo Mtn. Field
Latimer County, OK

C.I. = 500 feet

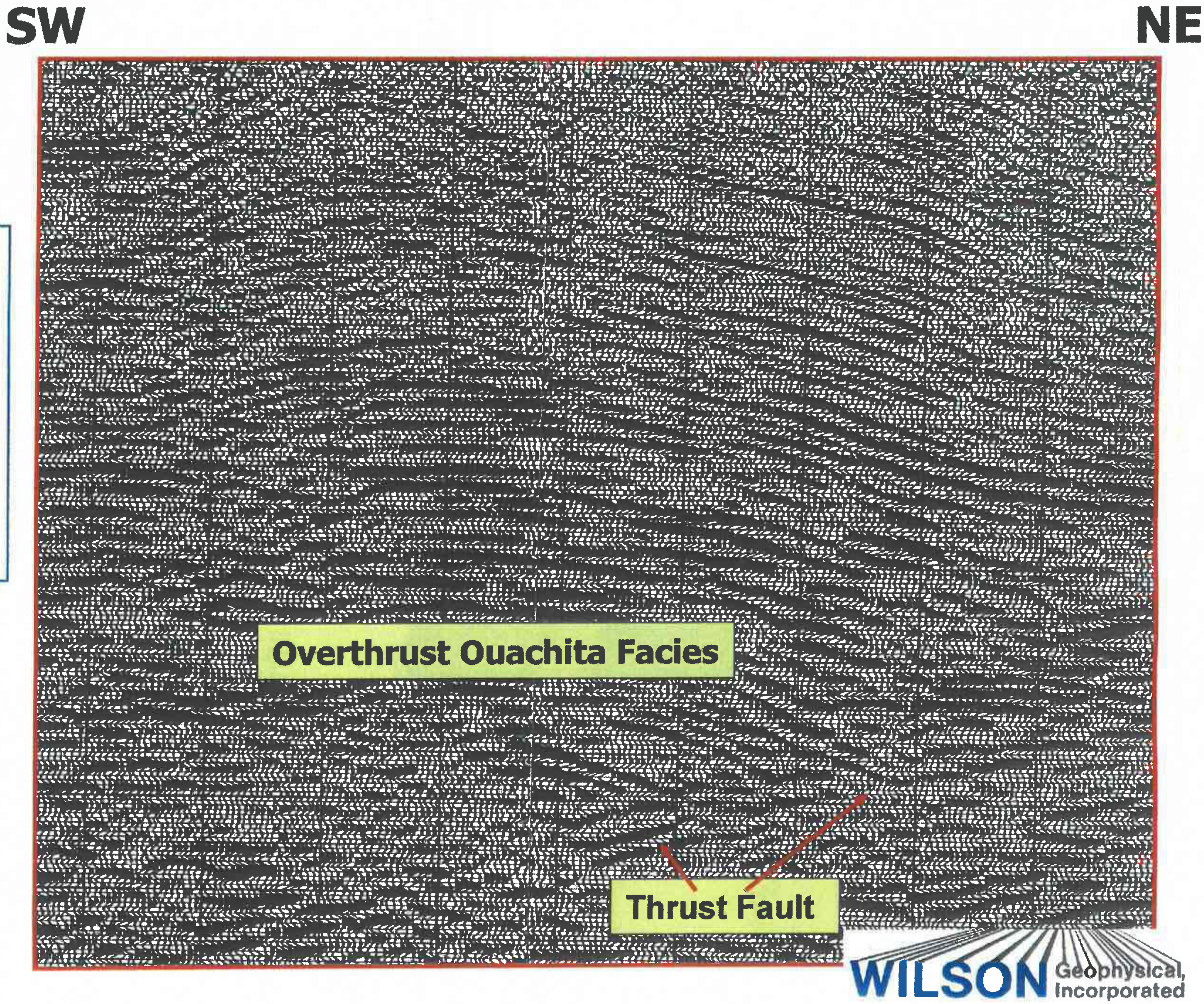
0 1 mi
Scale
C.I. = 500 ft

After Montgomery (1996)



After Montgomery (1996)

Cross-Section N-S
Buffalo Mtn. Field
Latimer County, Oklahoma



The Ouachita facies rocks are not continuous enough for regional structural mapping but, major thrust faults and anticlines can be identified.

NOTES

NOTES

WEST WHITEBEAD FIELD
T.3N., R.1W.
Garvin County, OK

LOCATION

Pauls Valley Uplift

PRIMARY PRODUCING RESERVOIRS

Oil Creek and Bromide sandstones, Simpson Group; Viola Group dolomite and limestone

DEPOSITIONAL SETTING

Shallow marine for both the Simpson and Viola Groups

DISTRIBUTION of RESERVOIRS

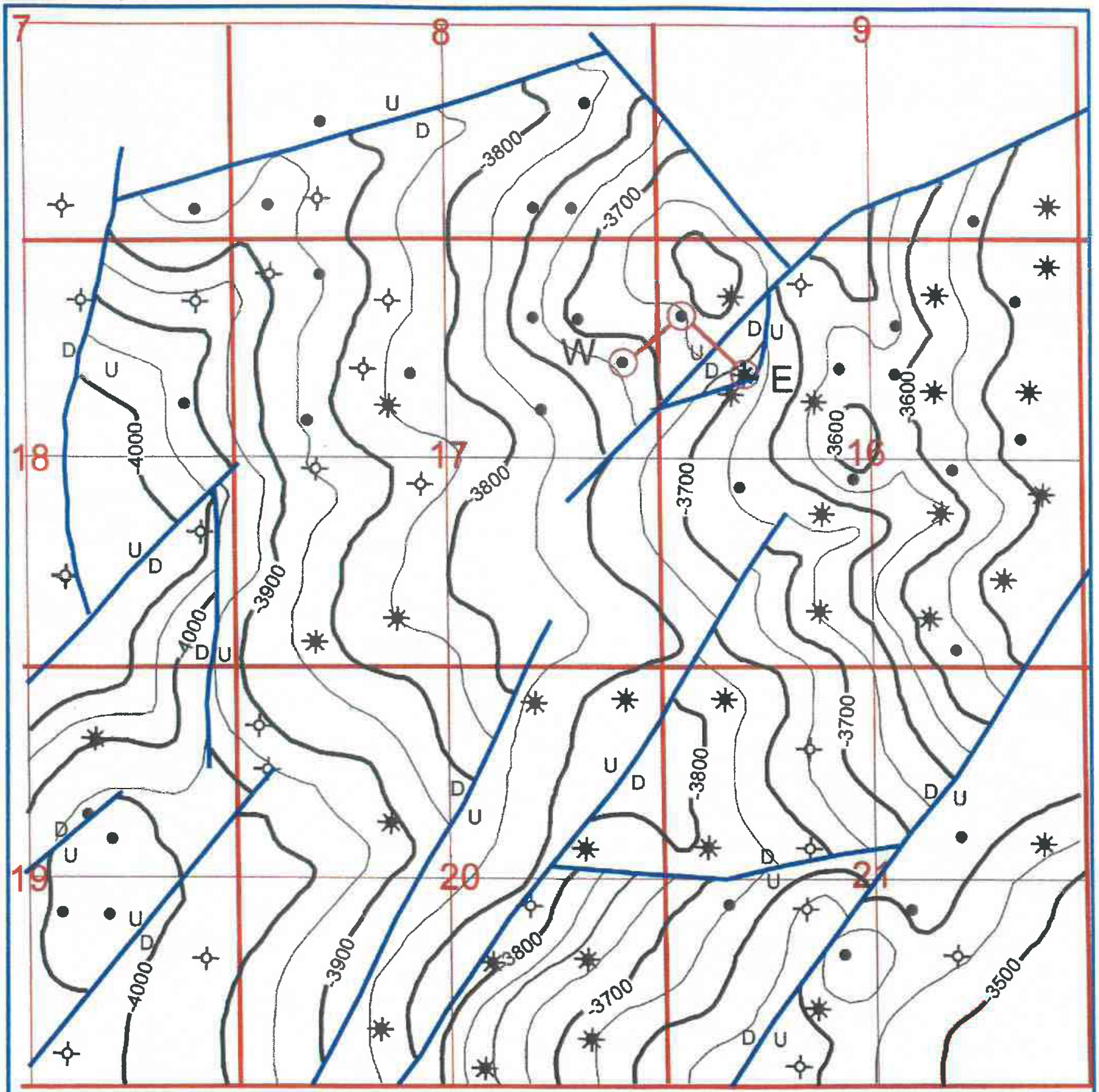
The sandstones of the Simpson Group are widely distributed across the area. The Viola is absent where it was eroded beneath the basal Pennsylvanian unconformity.

TRAPPING MECHANISM and TYPE of DRIVE

Structural trapping is responsible for the accumulation of oil and gas in the Simpson sandstones. Variable thickness of these sandstones contributes to trapping. All Simpson sandstones have a strong water drive that contributes to their high productivity. Viola production is partially controlled by structure. It is also influenced by the development of reservoir facies in the Viola beneath the pre-Pennsylvanian unconformity.

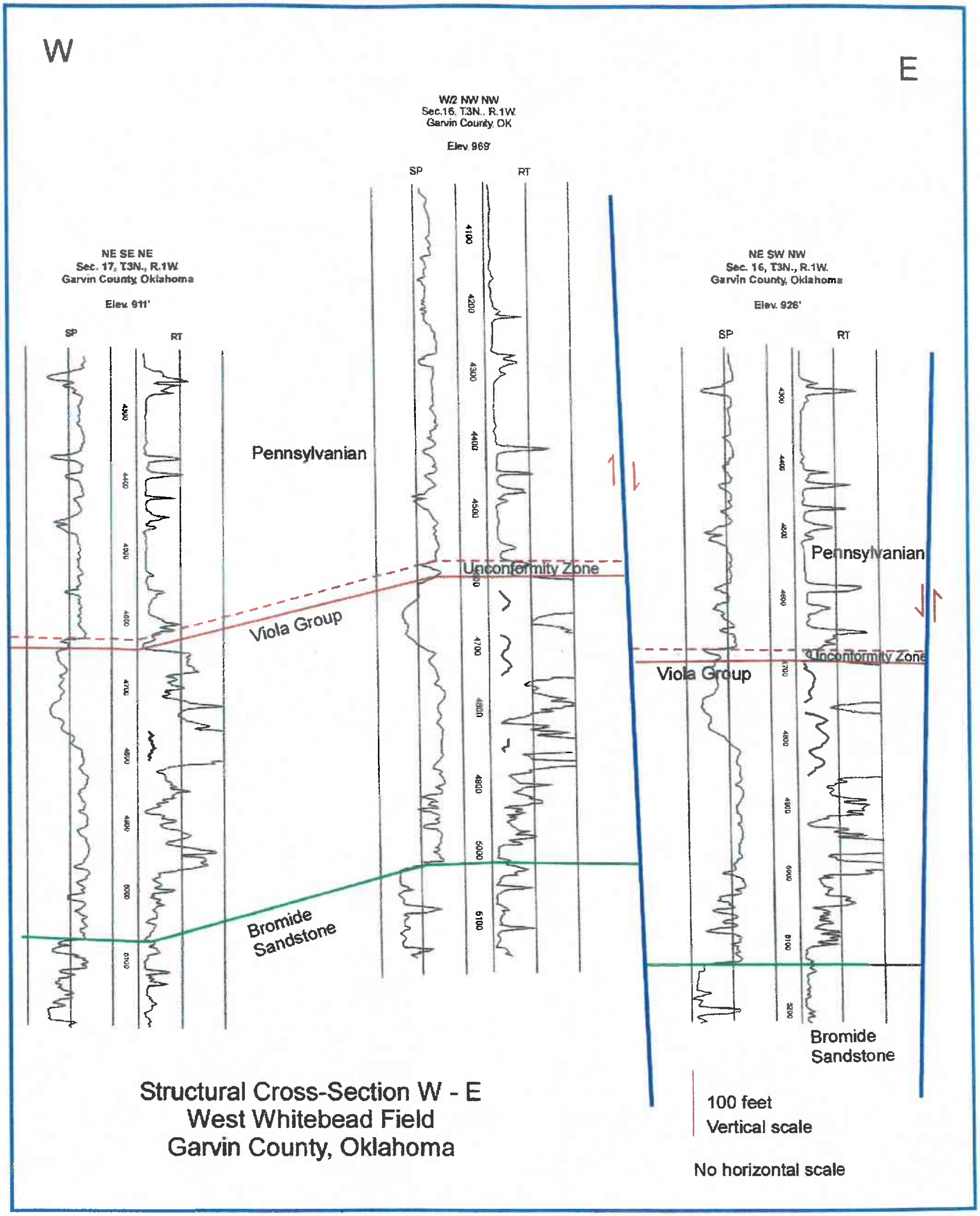
RESERVOIR PROPERTIES and AVERAGE PRODUCTION

Average Oil Creek sandstone production in Section 17 exceeds 800 thousand barrels of oil per well. Commingled Oil Creek and Bromide sandstone producers in Section 16 have cumulated 340 thousand barrels of oil per well (Springman and others, 1999).

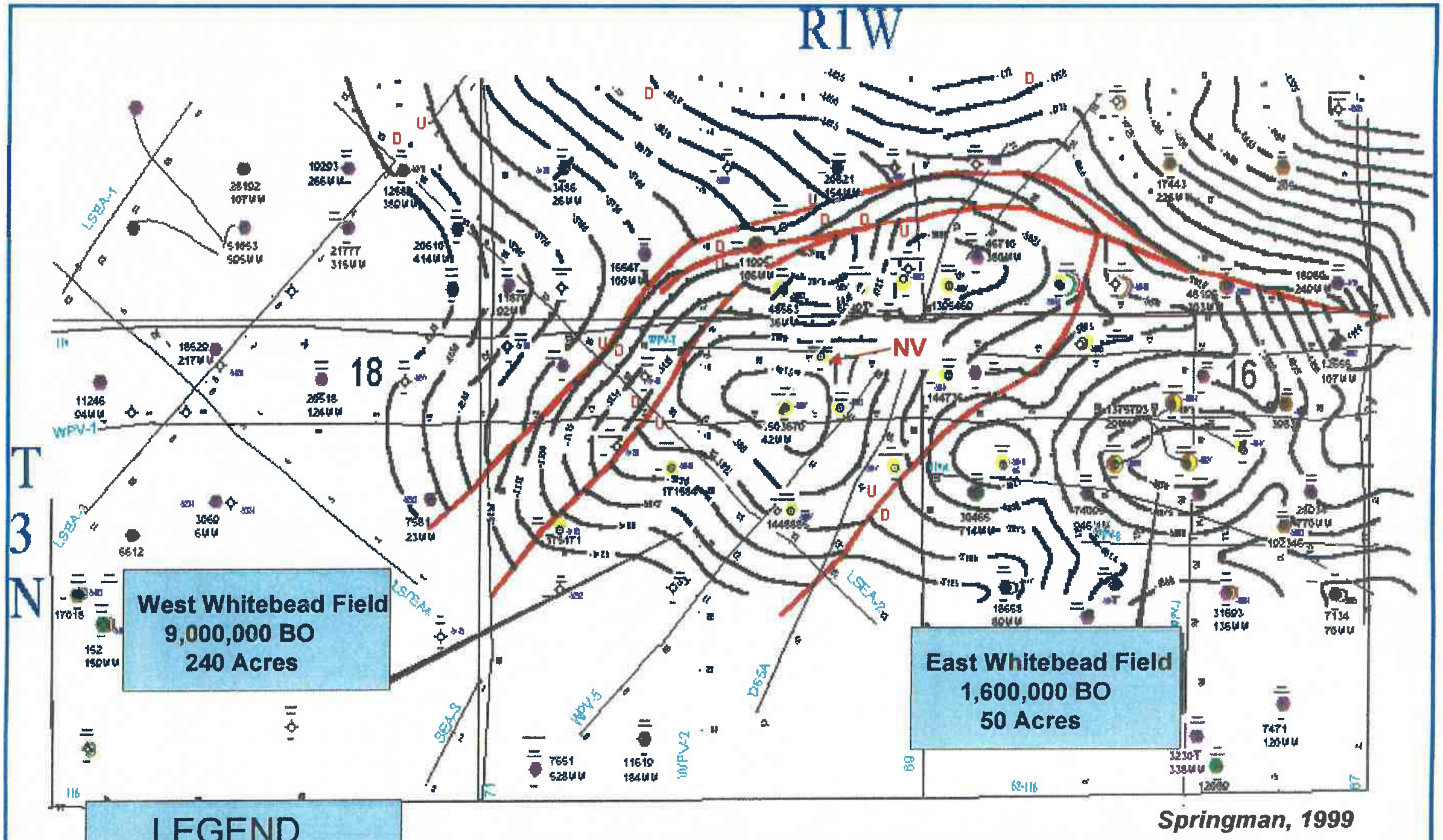


C.I. = 25 feet

Structural Contour Map
Top of Viola Group/Pennsylvanian Base
W. Whitebead Area
T.3N., R.1W.
Garvin County, Oklahoma



Structural Cross-Section W - E
West Whitebead Field
Garvin County, Oklahoma



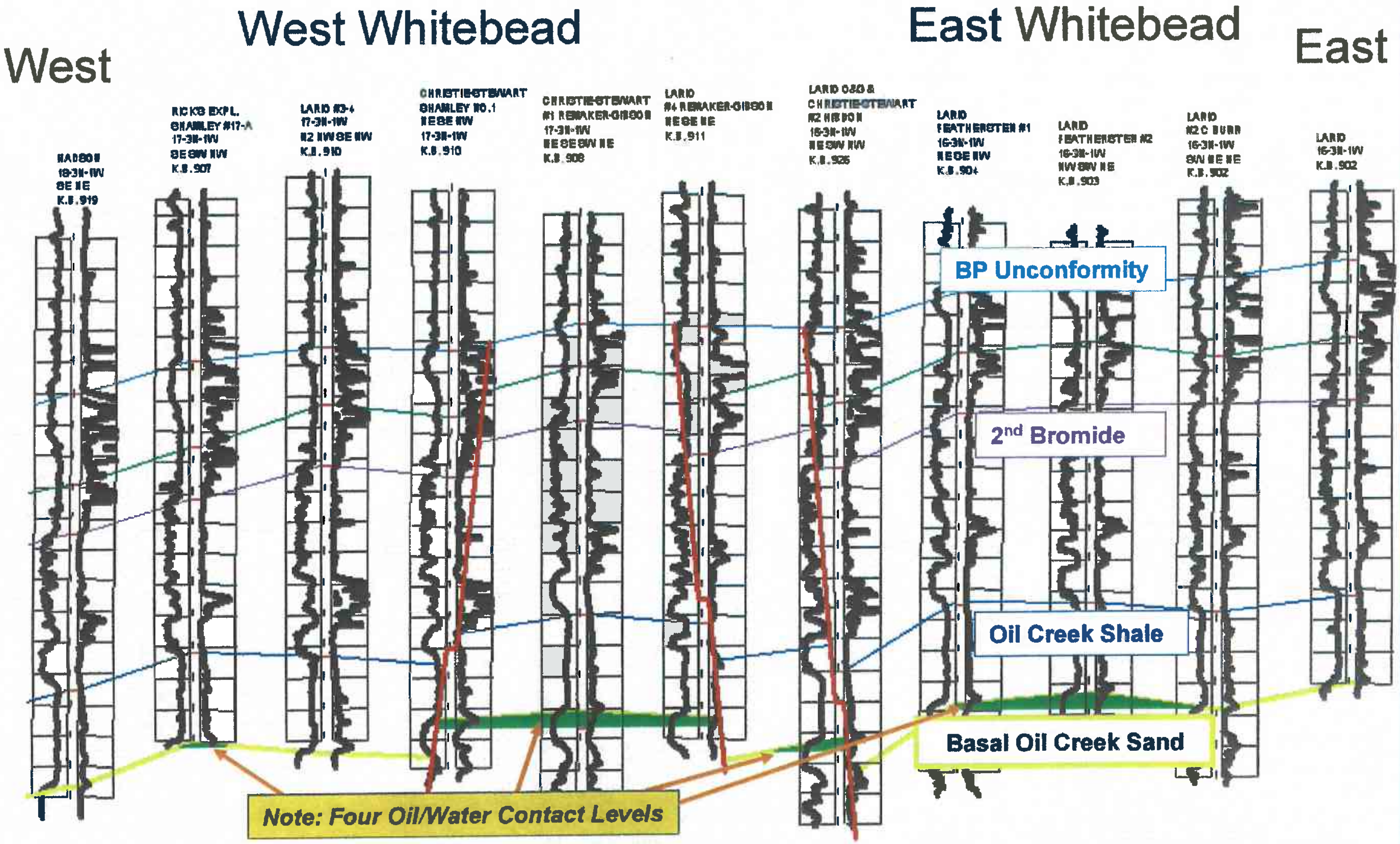
LEGEND

Producing Formations

- 🟢 Penn
- 🟣 Viola
- 🟤 1st Bromide
- 🔴 2nd Bromide
- 🟡 Basal Oil Creek Sd.

Basal Oil Creek Structure

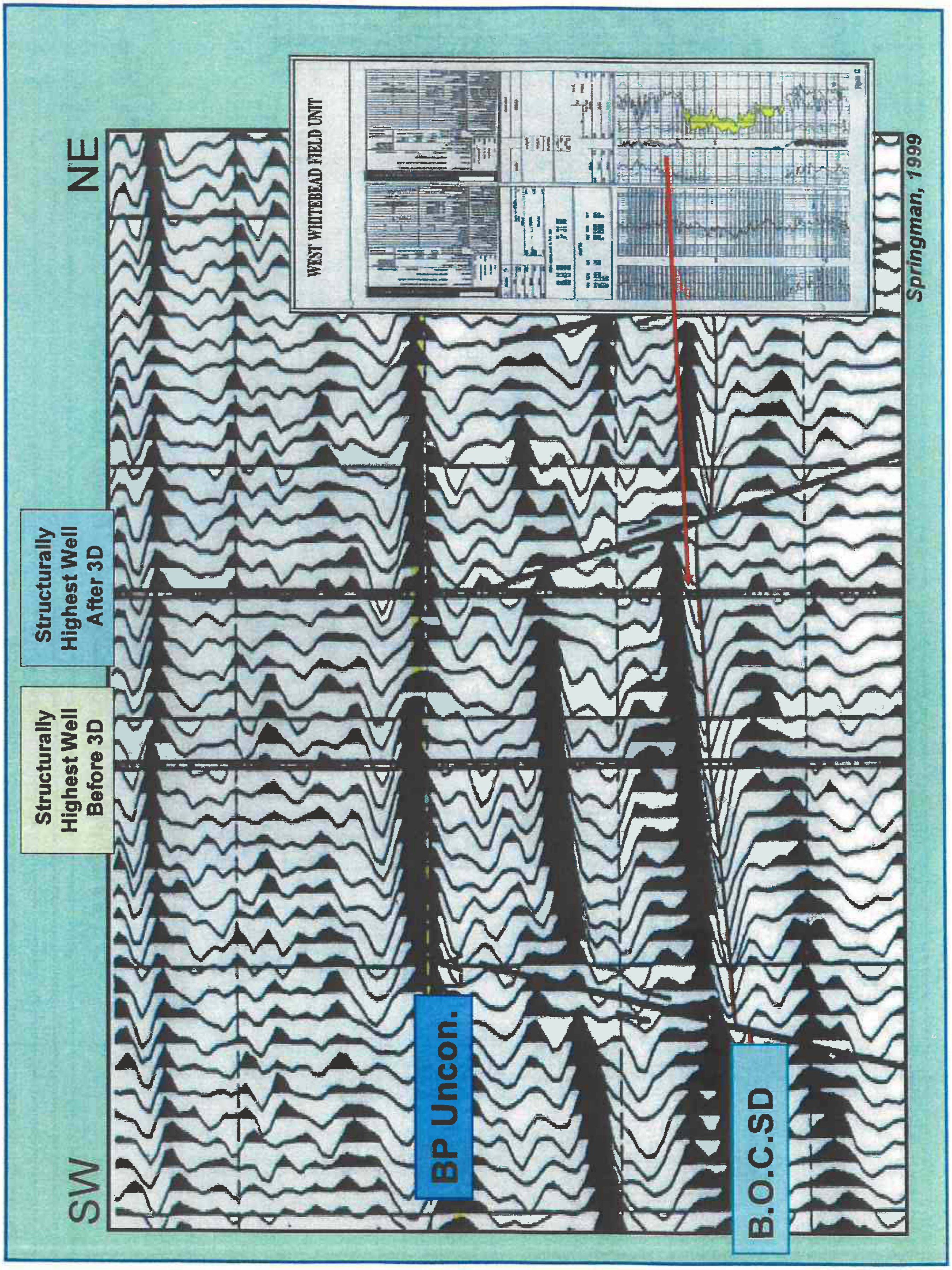
Data source: 2D seismic and subsurface



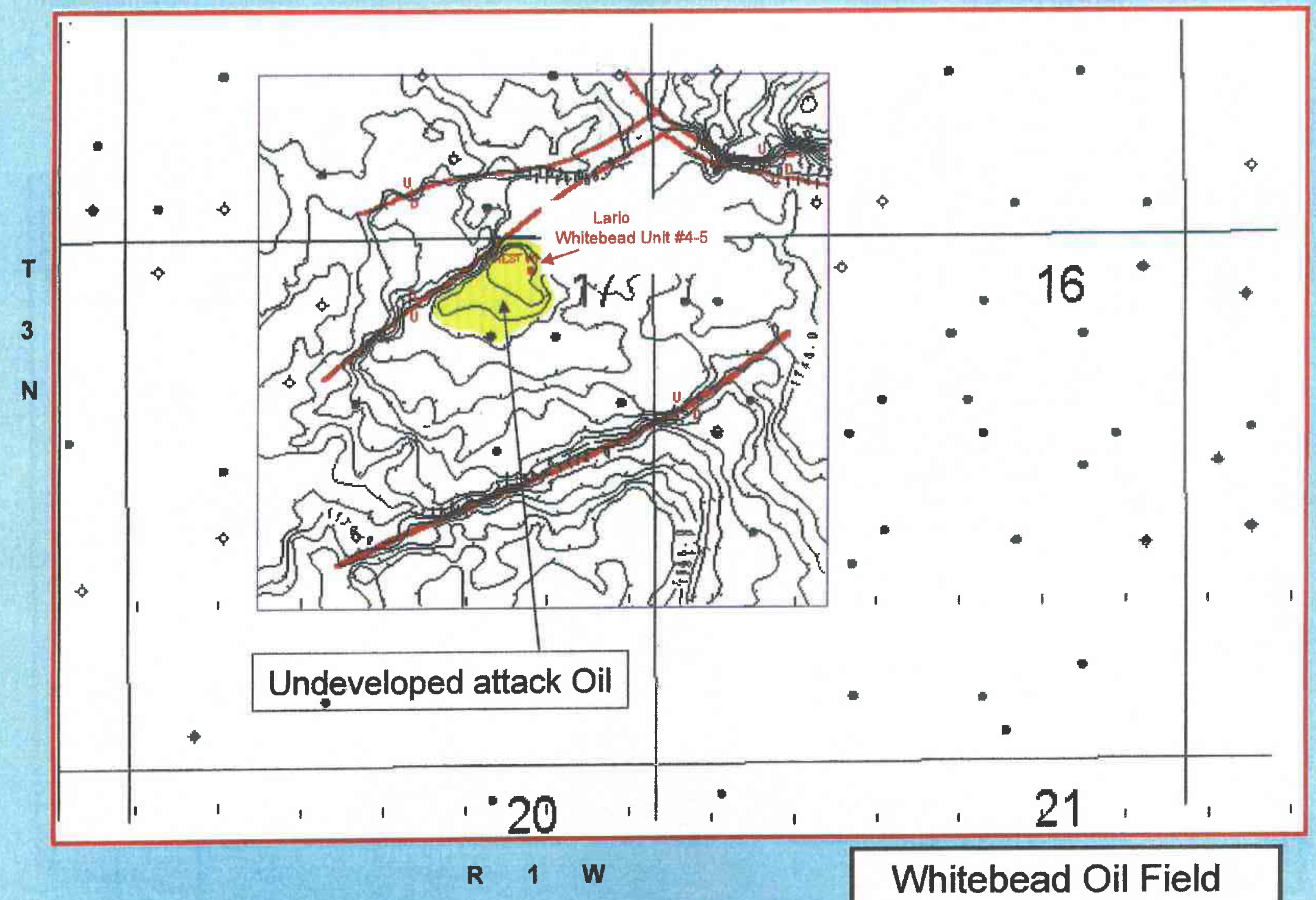
Whitebead Structural Cross Section

Springman, 1999

The prolific Simpson sands of the Seminole area can be accurately mapped as proven at the W. Whitebead field in Garvin Co., Ok. The 3D seismic data is excellent quality and the Simpson sands are good seismic reflectors.



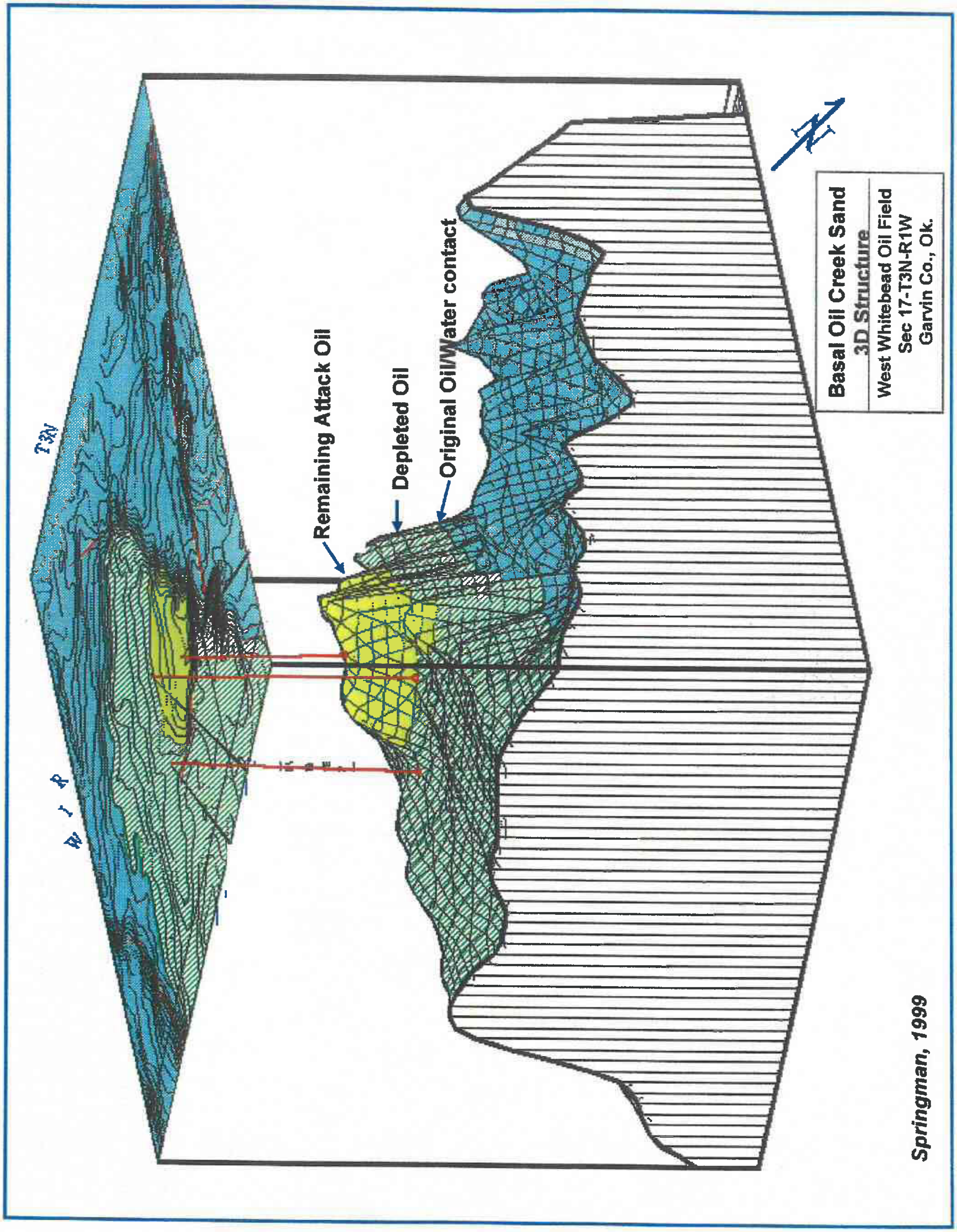
Springman, 1999



Whitebead Oil Field

Basal Oil Creek Sand
Time Structure
C.I. = 4ms. (approx. 25Ft.)

Springman, 1999



Basal Oil Creek Sand

3D Structure

West Whitebead Oil Field
Sec 17-T3N-R1W
Garvin Co., Ok.

Springman, 1999

NOTES

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CUMBERLAND FIELD
T.5S., R.7E.
Marshall and Bryan Counties, OK

LOCATION

Ardmore Basin

PRIMARY PRODUCING RESERVOIRS

Oil Creek, McLish and Bromide sandstones, Simpson Group

DEPOSITIONAL SETTING

Shallow marine for all Simpson Group sandstones

DISTRIBUTION of RESERVOIRS

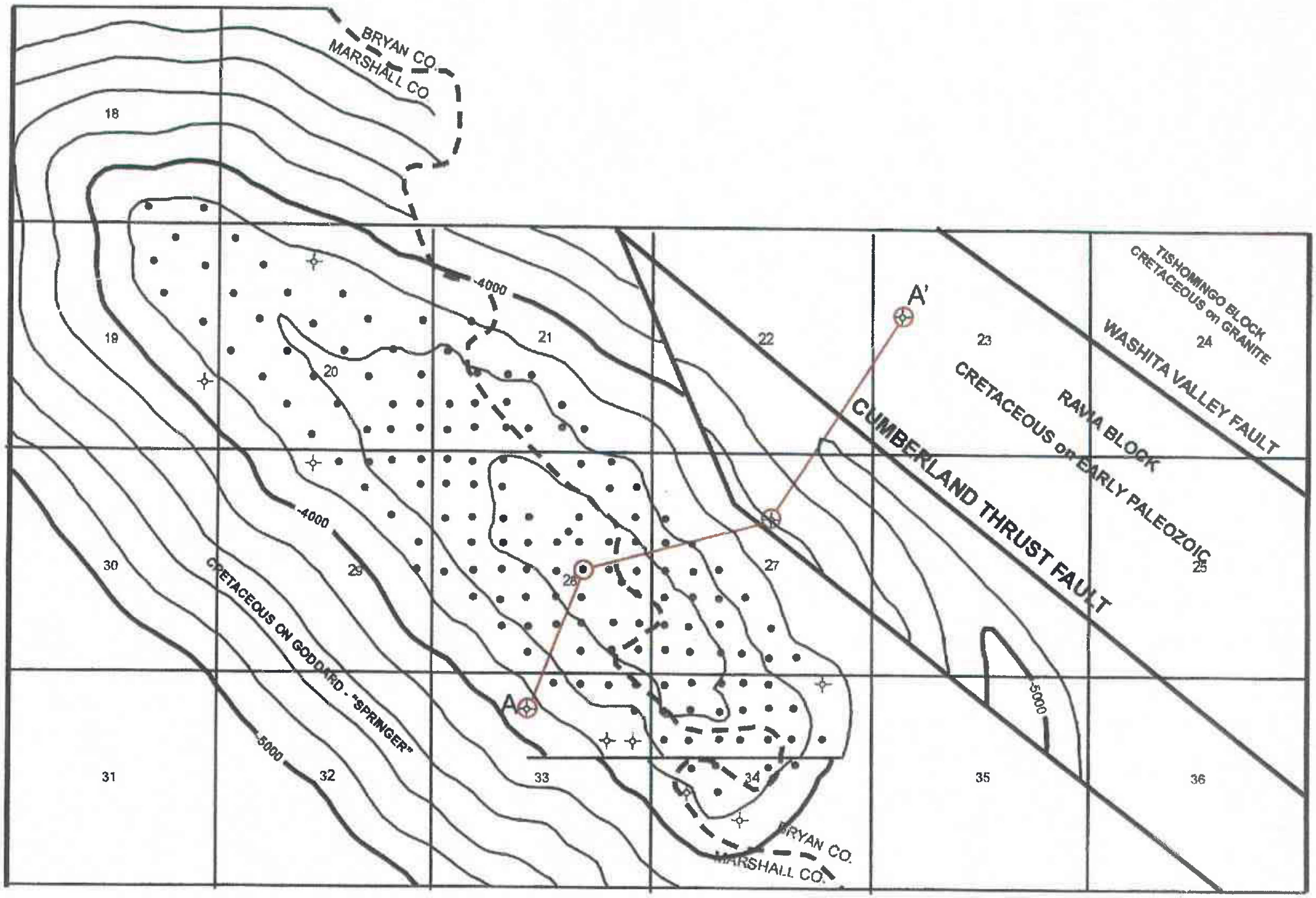
The sandstones of the Simpson Group are widely distributed across the area. The productive area is approximately 3 miles long and 1 mile wide.

TRAPPING MECHANISM and TYPE of DRIVE

Structural trapping is responsible for the trapping of oil and gas in the Simpson sandstones. Variable thickness of these sandstones contributes to trapping. All Simpson sandstones have a strong water drive that contributes to their high productivity. The Simpson sandstones produce on the antilcinal fold beneath the Cumberland thrust sheet.

RESERVOIR PROPERTIES and AVERAGE PRODUCTION

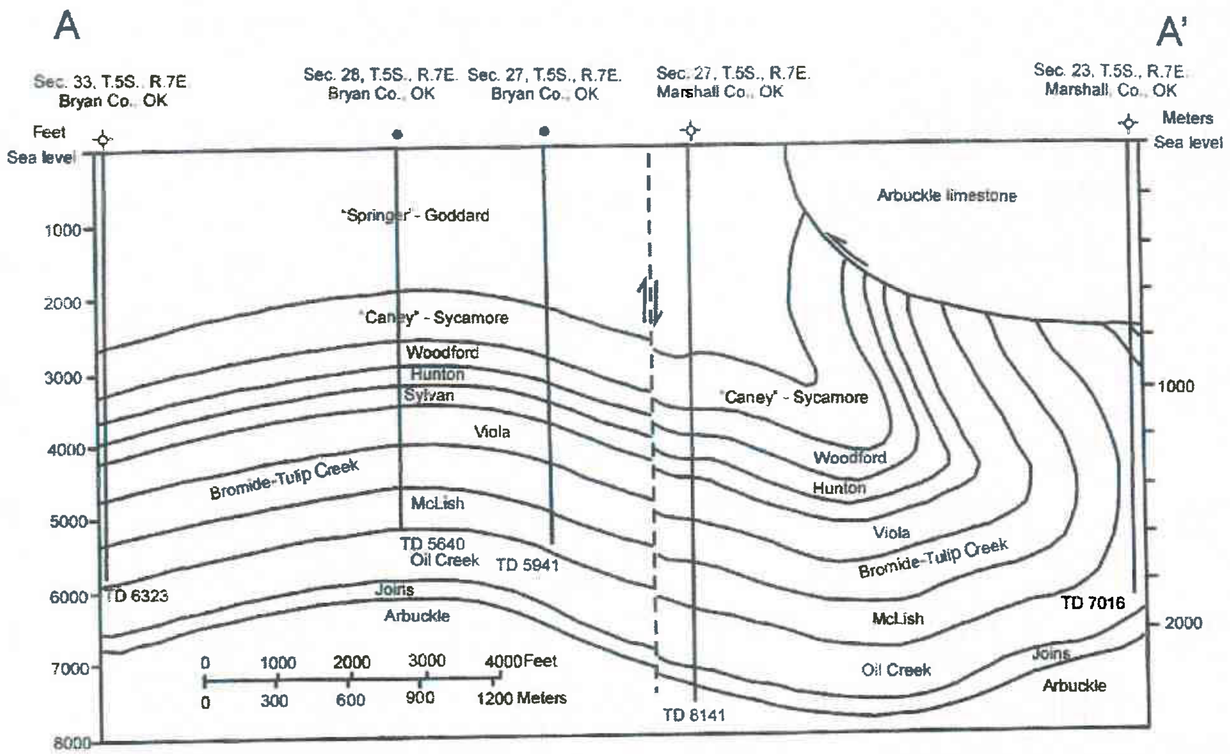
The average production per well on the Cumberland anticline is in excess of 400 thousand barrels of oil.



Structure Contour Map on Top of Viola Group
Cumberland Field
Marshall and Bryan Counties, Oklahoma

C.I. = 200 feet

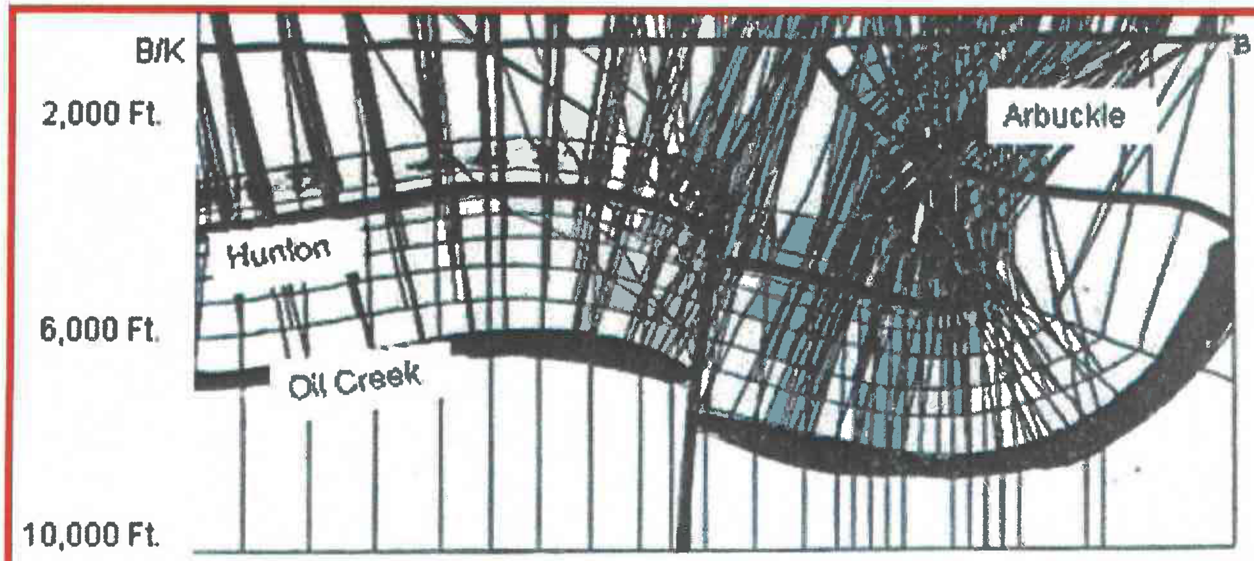
After Huffman and others (1987)



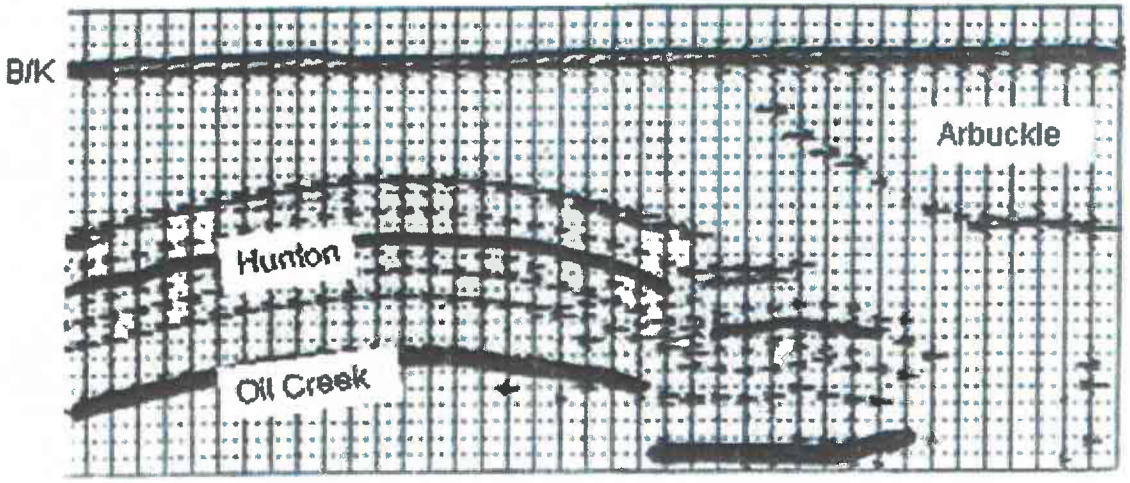
After Huffman and others (1987)

Cross Section of Cumberland Field
Marshall and Bryan Counties, OK

The ray trace and 2D synthetic model show the Hunton through Simpson reflectors should be mappable events in front of the thrust. The data recorded beneath the thrusted Arbuckle would be a highly distorted subsurface picture.

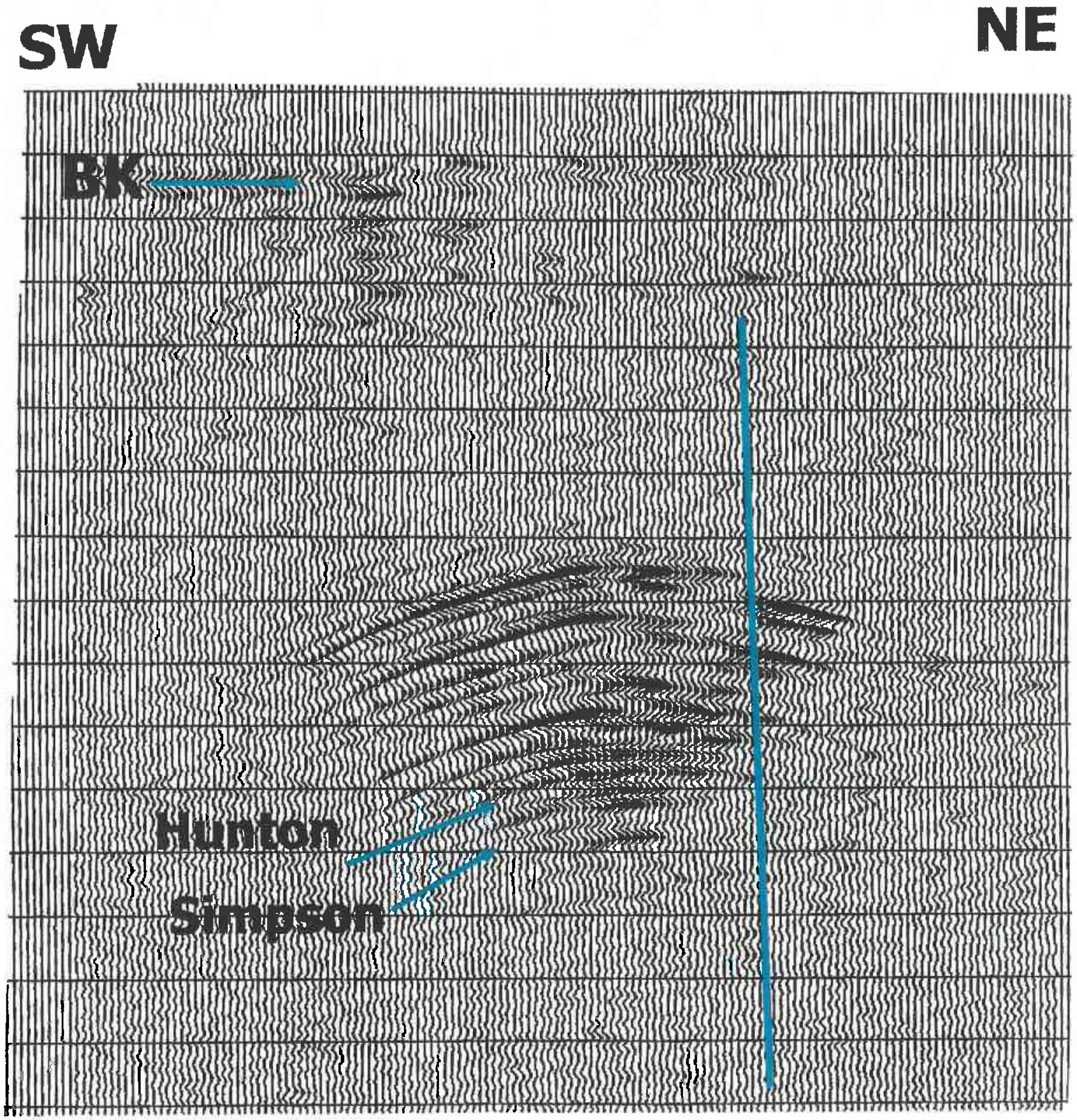


Cumberland Ray Trace Model



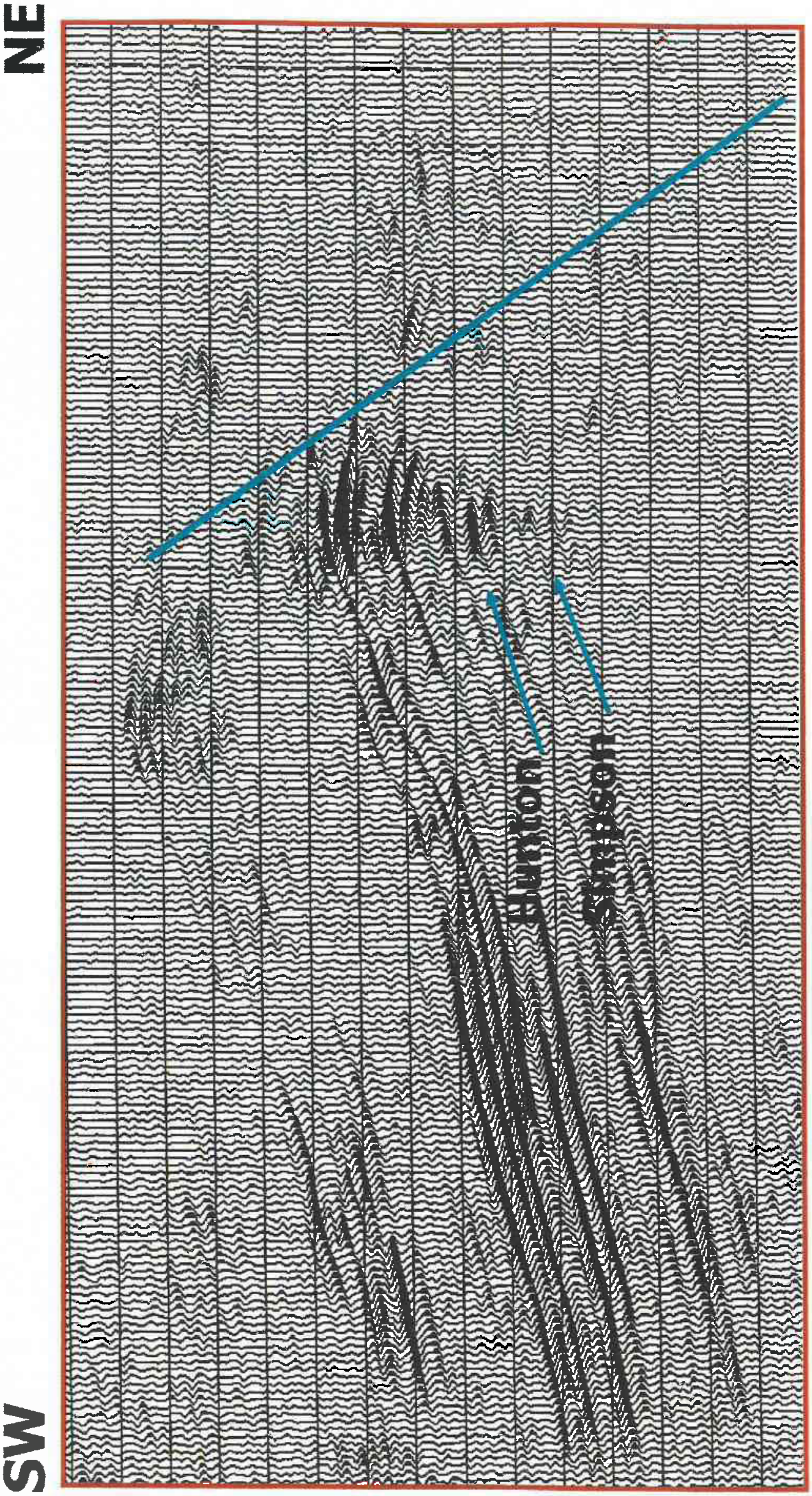
Synthetic Model

Springman, 1985



Springman, 2005

The 3D seismic data recorded across the Cumberland Field shows the Hunton through Simpson good for structural mapping as the model results predicted.



Springman, 2005

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