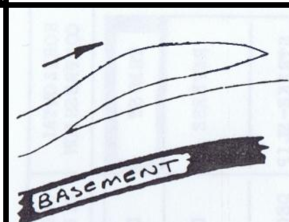
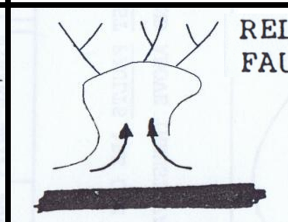
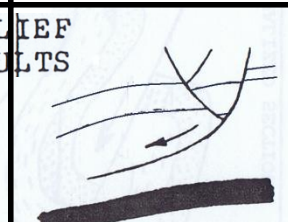
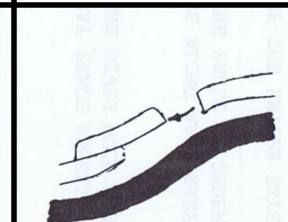
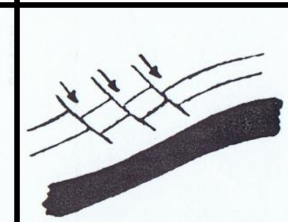
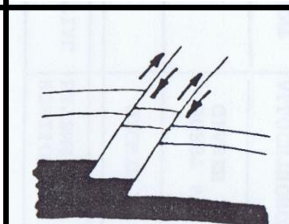
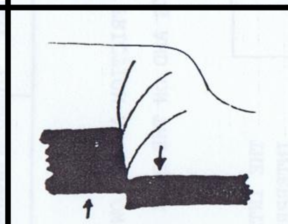
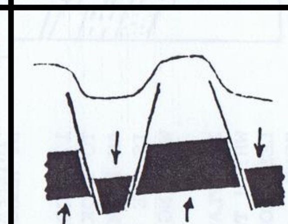
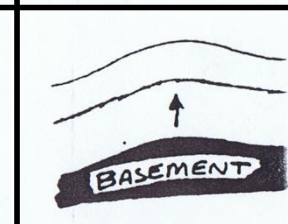
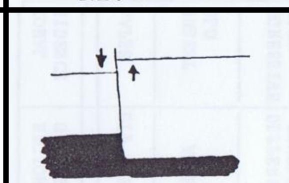
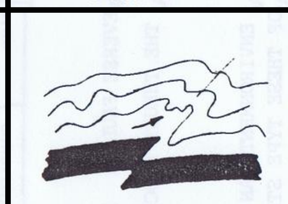
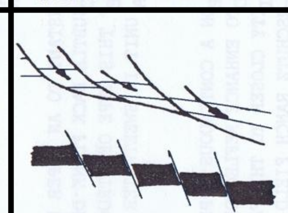
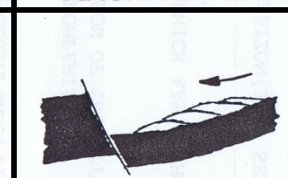
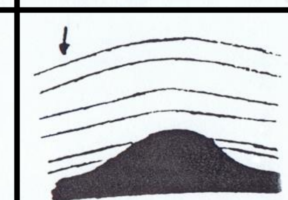
Seismic Interpretation Principles and Workflow

H. Roice Nelson, Jr.

Day 2 Session 3

- Structural interpretation
  - Fault interpretation
  - Fracture interpretation
  - Anisotropy interpretation
- Stratigraphic interpretation
  - Sequence interpretation
    - Divergent
    - Convergent (thinning)
    - Parallel
    - Semi Layer-Cake to Layer Cake
    - Chaotic
  - Geochronostratigraphic reconstruction
- Integrating other data into the interpretation
- Salt and fault shadow interpretation
- Exploration interpretation
- Reservoir characterization
- Project Documentation
- Display Concepts and Interpretation Procedures

Structural Styles Chart

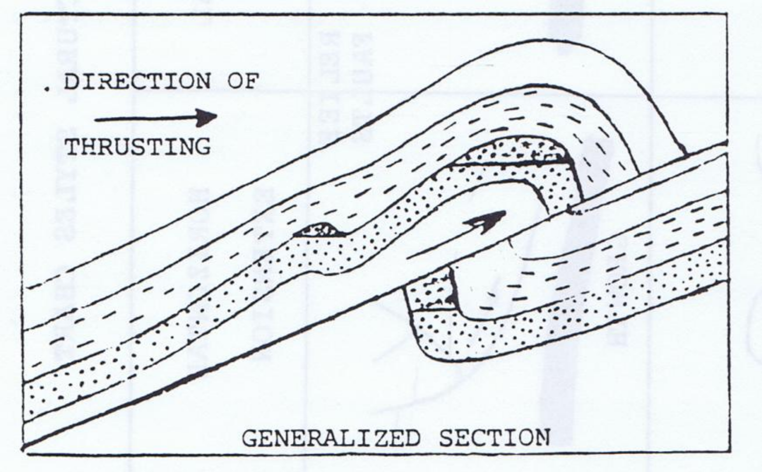
Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	 THRUST	 RELIEF FAULTS SALT DOME	 GROWTH	 COLLAPSE	 DIP & FAULT
Involved	 REVERSE	 DRAPE	 HORST & GRABEN	 RECUMBENT FOLD	 ARCH
Weak	 STRIKE-SLIP (INVERTED EXTENSIONAL)	 DECOLLEMENT	 ALLOCHTHONOUS	 BASAL TRANSGRESSIVE SAND	 DIFFERENTIAL COMPACTION

Information on this and related charts was compiled from several sources, including a talk by W.O. Abbott, Occidental, and from **PennWell Maps Oil & Gas Field Classifier**, 2nd Edition, Compiled by Norman J. Hyne.

Drag Folds on Thrust Faults

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

DRAG Folds on THRUST FAULTS are due to friction along low angle reverse faults. Drag Fold form below and above thrust faults and on the back flank of the thrust block as illustrated below.



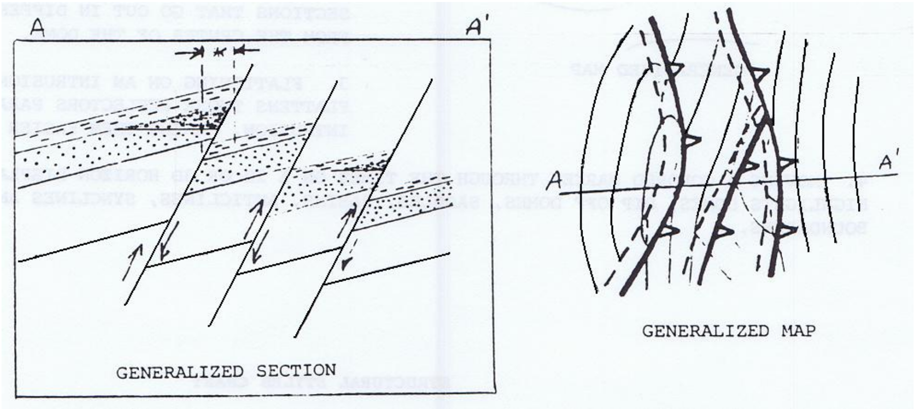
The Interactive environment can aid interpretation of these types of structures by allowing the interpreter to:

1. Add a constant to an upper horizon to look for subtle back flank drag folds. An example of this type of structure is the Brady Unit in Sweetwater County, WY.
2. Flatten on a continuous upper horizon, which tends to enhance reflectors with less continuity closer to the fault zone. The Anschutz Ranch Field is an example.
3. Do iterative ray trace modeling and side by side or overlaid comparison of synthetic and stacked sections gives much more confidence of this type of structure.
4. Select sections along arbitrary lines from a 3D data volume, which are orthogonal to the strike of the fault in order to show the faulting better.
5. Map displays of the entire extent of a horizon using shadow horizon(s). See point 3 of REVERSE FAULT TRAPS.

Reverse Fault Traps

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

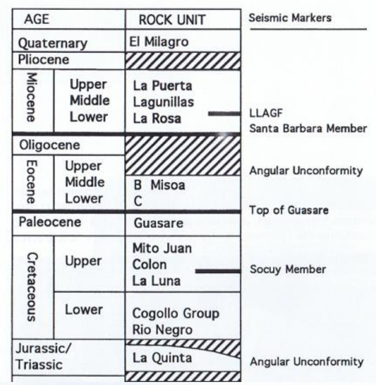
REVERSE FAULT TRAPS are due to compressional forces. In order to form traps, the faults must cut dipping rocks and be curved or at the junction of two faults. Offshore California has several major fields with these type of complicated structures.



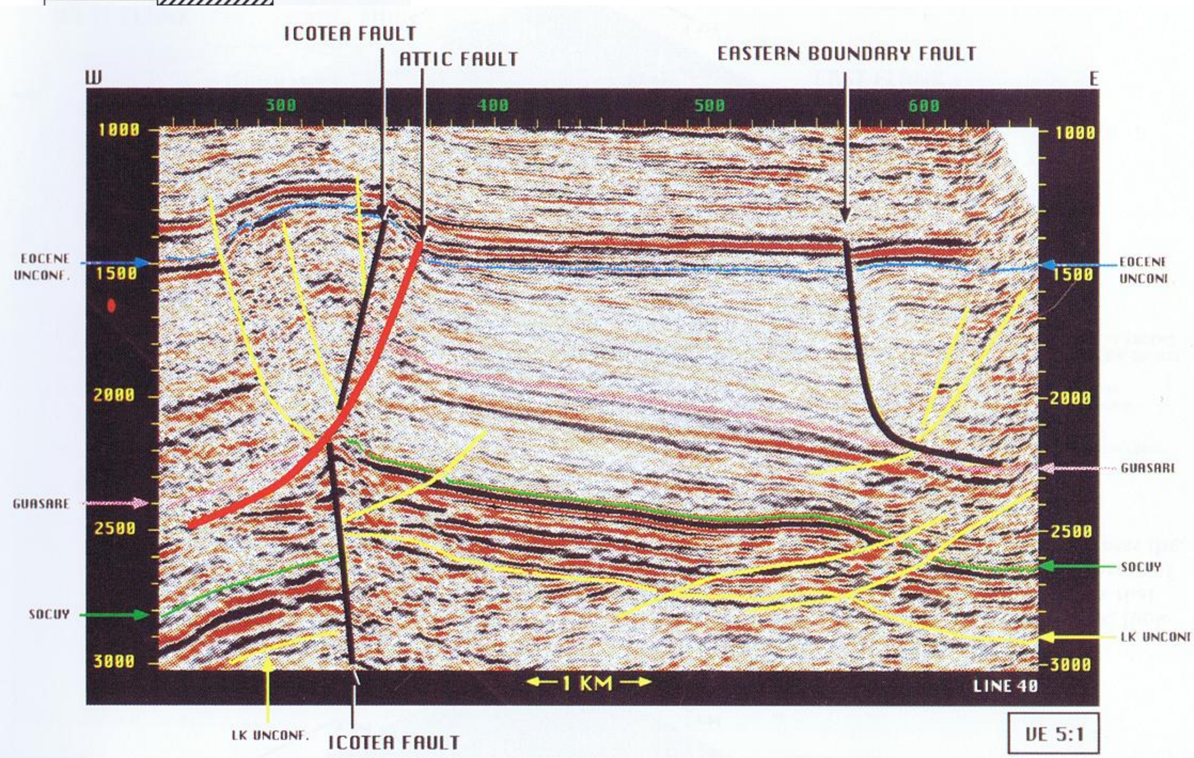
The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

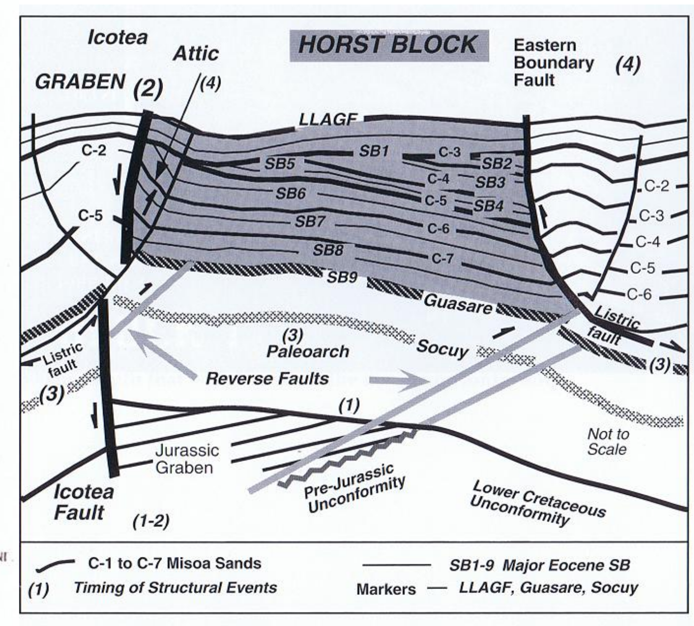
1. Enhance fault cuts by changing the seismic display scales. Shrinking the horizontal scale by decimation of seismic traces makes the faults more vertical, enhancing breaks in the reflectors.
2. Reconstruct pre-fault structure using the polygon fault correlation window.

3. Build map displays that show the entire extent of a horizon. Note most mapping packages contour single valued surfaces. Ith the workstation, shadow horizon(s) can be interpreted under thrust blocks (*) and displayed as contours over a 3D survey's density map display.



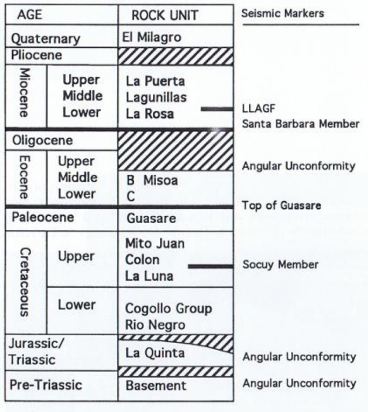
3-D Reverse Fault Structural Interpretation

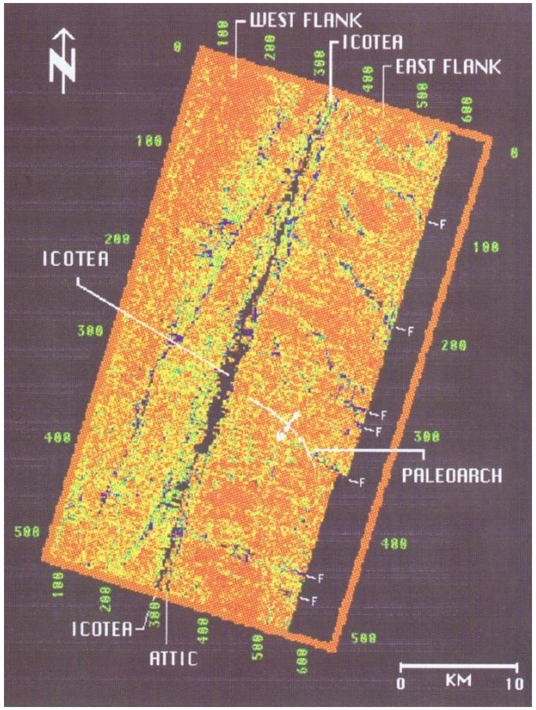


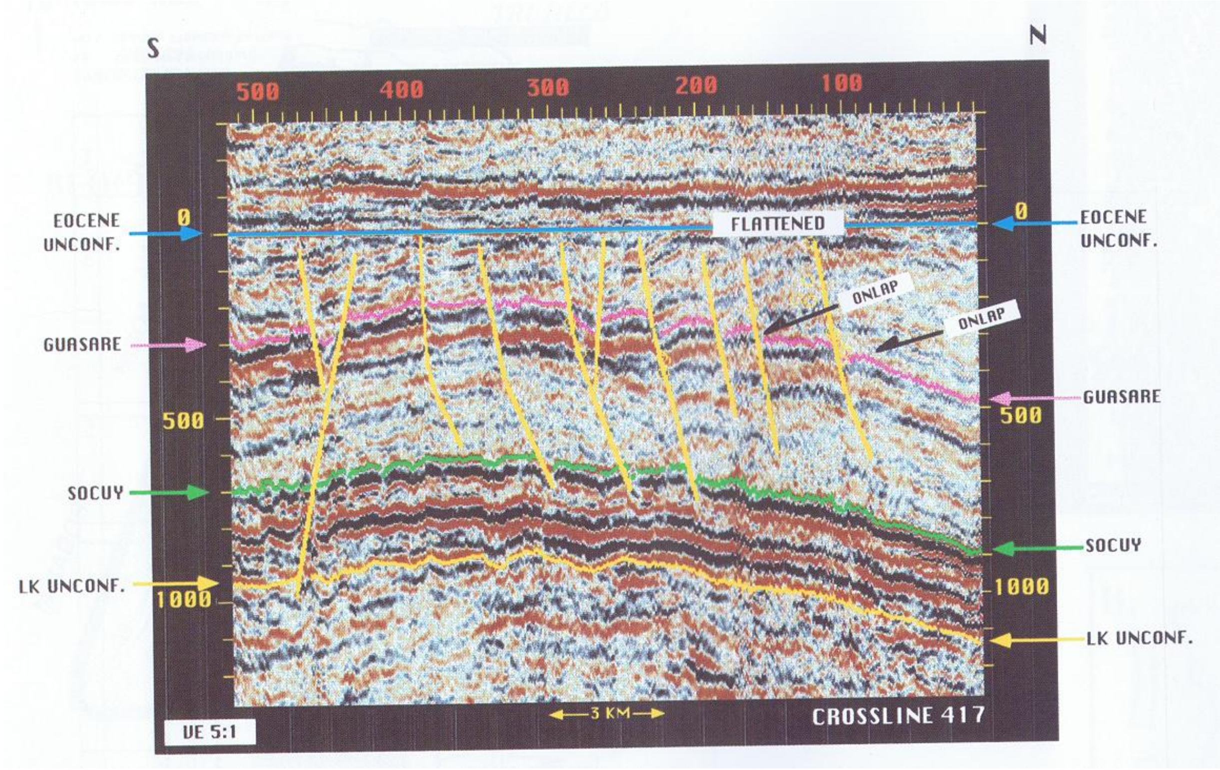


Martin H. Link, et. al. in **Application of 3-D Seismic Data to Exploration and Production**, page 75, data from Maraven from Central Lake Maracaibo, Venezuela.

Flattening on Eocene to Enhance Small Guasare Faults





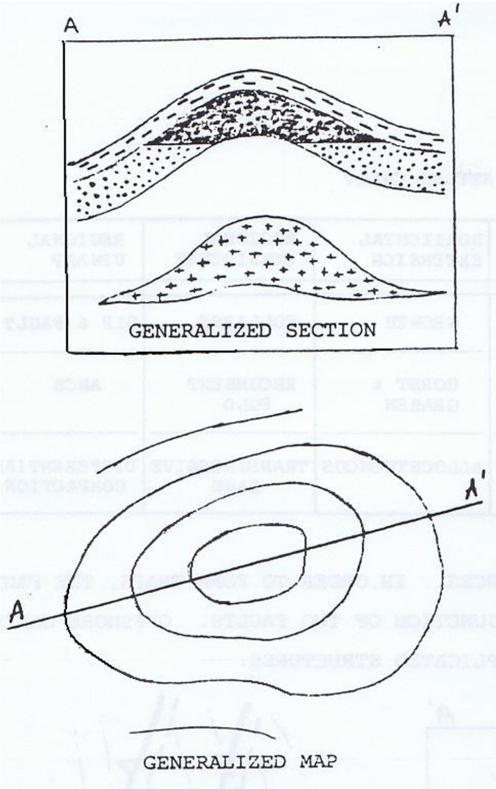


<- First Derivative Map Top of Guasare

Martin H. Link, et. al. in **Application of 3-D Seismic Data to Exploration and Production**, pages 74, 76, data from Maraven from Central Lake Maracaibo, Venezuela.

Igneous, Salt, and Shale Domes

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction



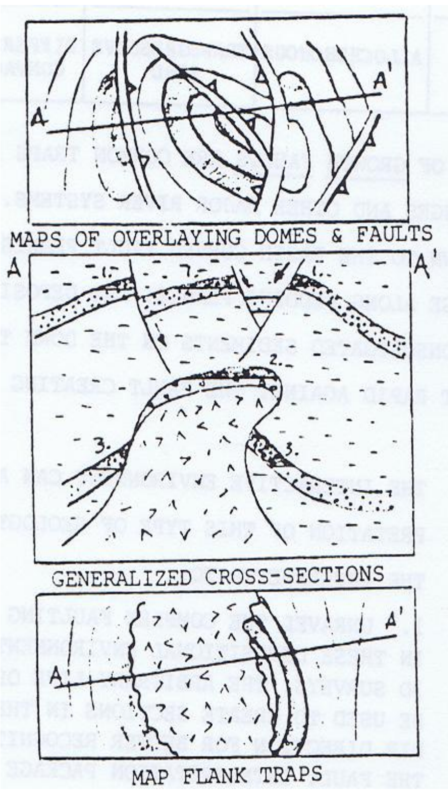
IGNEOUS, SALT and SHALE DOMES are a result of intrusions, either volcanic in origin or gravity induced movement of low density materials. Domes, circular or elliptical anticlines, are one of the most widespread types of hydrocarbon traps.

The Interactive environment can aid interpretation of dome type structures by allowing the interpreter to:

1. Easily select sections to best evaluate critical closure on the flank of the structure. Dip sections are retrieved from a 3D survey using the arbitrary line option. For 2D surveys, those portions of the 2D lines zigzagging across the structure are easily retrieved without finding and folding paper sections.
2. Once a possible dome is located, it can be easily confirmed by selecting several sections that go out in different directions from the center of the dome.
3. Flattening on an intrusion horizon also flattens those reflectors parallel to the intrusion, making them easier to see.
4. Moving a colored marker through the times on a 3D or 3D horizon display dramatically highlights domes, dip off domes, saddles, basins, anticlines, synclines and fault boundaries.

Salt Domes

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction



<u>SALT DOMES</u>, particularly, have additional traps, which are due to a combination of structure and stratigraphy. These traps include (1) overlaying domes and faults, (2) strat traps, and (3) flank traps. Uplifted overlaying sediments often form traps, which can be faulted separating the reservoirs into numerous pools. Fractures and vugs in the cap rock create reservoir rock. Flank traps tend to have thick pay zones due to dip.

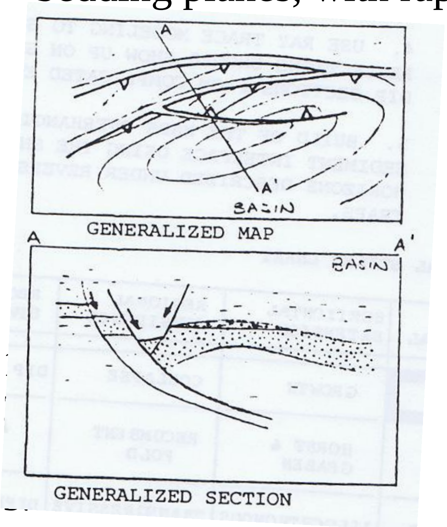
The Interactive environment can aid interpretation of salt dome by allowing:

1. Rapid building and revising surfaces to test the location of the salt-sediment interface and to study fault patterns.
2. Use the polygonal drag window to correlate horizons across fault blocks and on different sides of the dome.
3. Flatten horizons to study pre-salt or pre-fault depositional patterns and to reconstruct the depositional and tectonic history.
4. Use ray trace modeling to study where reflections should show up on specific dip sections from complicated events.
5. Build maps of overhanging salt-sediment interface using the shadow horizons described under reverse fault traps.

Annealment Structures

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

ANNEALMENT STRUCTURES on the downthrown side of GROWTH FAULTS are common traps at the mouths of major river systems. At depth movement of curved fault planes often starts along bedding planes, with rapid growth against the fault, creating broad anticlines on the basin side.



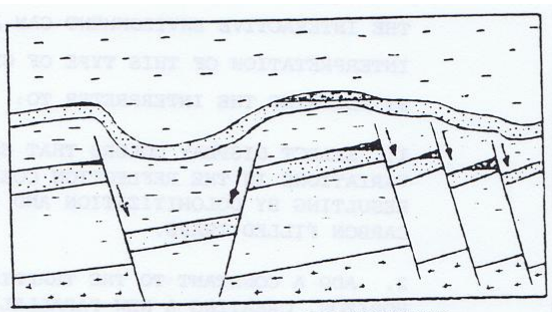
The Interactive environment can aid interpretation of these types of geology by allowing the interpreter to:

1. Unravel the complex faulting occurring in these depositional environments. With 3D surveys, the arbitrary line can be used to create sections in the fault dip direction for better recognition. The fault interpretation package can be used to pick faults on a few critical 2D or 3D sections, labeling the same fault from map displays, build fault plane surfaces, evaluate with map or 3D displays, and bring up other sections cutting the fault plane to check and modify fault locations.
2. Make drag windows with different vertical scales and use these to correlate similar rock layers across the growth faults.
3. Flatten on key horizons keeping growth consistent within different fault blocks.
4. Build map displays showing the structure of a key horizon overlain with an isochron contour map to evaluate growth or expected trap closure.
5. Tie in modeling results, well log synthetics, and VSP data to confirm the interpretation.

Tilted Fault Blocks

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

<u>TILTED FAULT BLOCKS</u> are large, structural blocks, often miles across, broken and tilted by normal faulting. These large structures are formed in areas of rifting like the North Sea, Andaman Sea, Labrador Sea, and U.S. Great Basin, and when covered with sediments, can form giant fields.

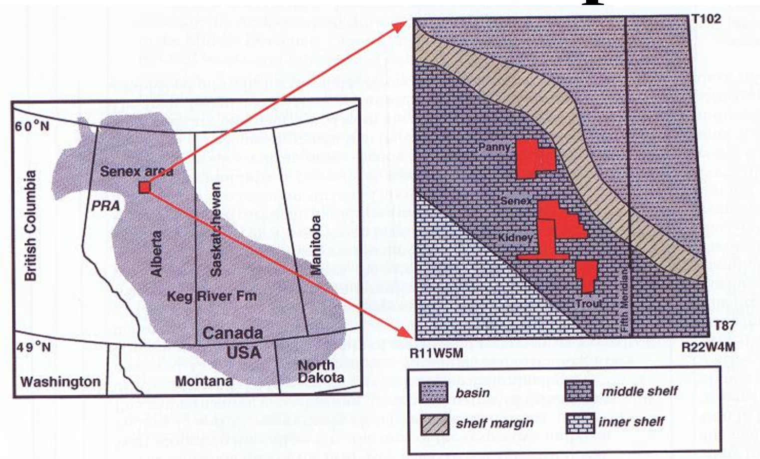


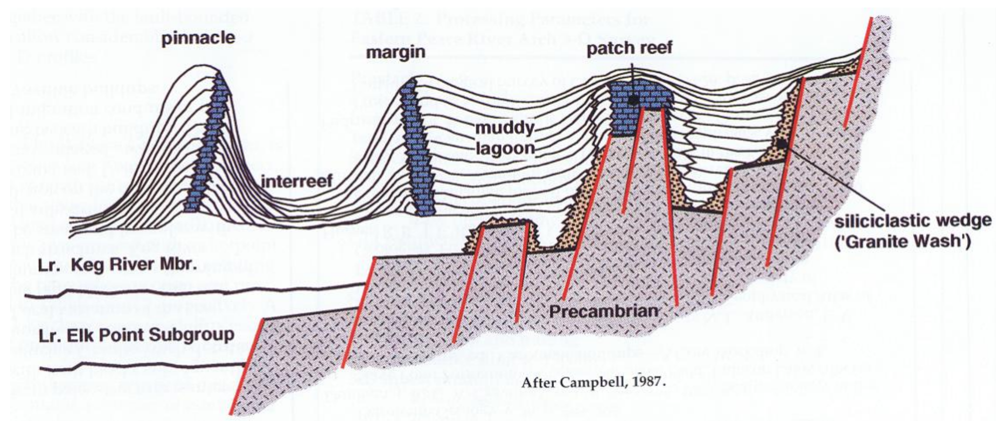
GENERALIZED CROSS-SECTIONS

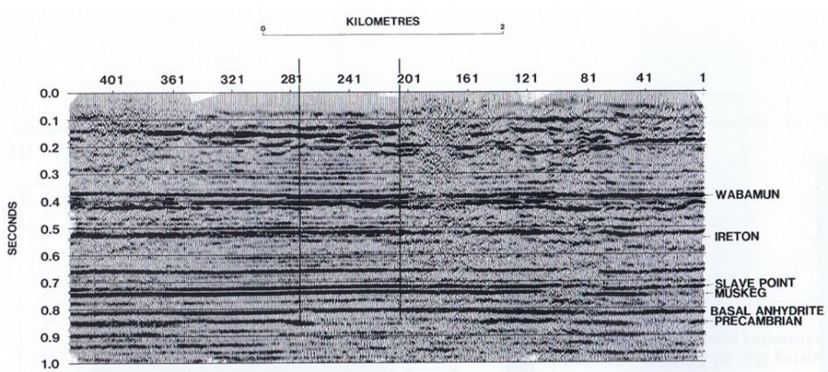
The Interactive environment can aid interpretation of this type of geology by allowing the interpreter to:

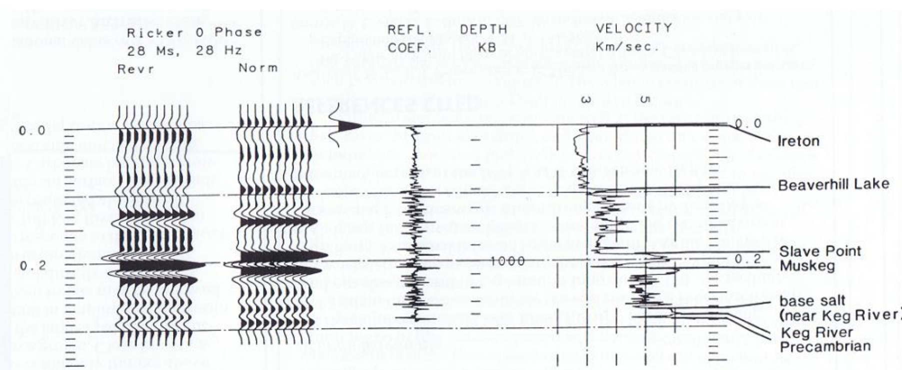
1. Overview 30 KM regional lines by rescaling.
2. Use trace and sample interpolation to allow detailed analysis of anomalies, including wiggle trace evaluation of the waveform variations.
3. Enhance fault cuts by changing the display scale. The more vertical the faults are made by stretching the vertical scale or shrinking the horizontal scale, the more the breaks in continuity are enhanced.
4. Choose the proper color assignment for the seismic display to enhance no data areas due to faulting, as well as reflection continuity and similar reflection sequences across faults.
5. Use horizon computations to create a new horizon by adding a constant to a picked horizon, which can create seed horizons through no reflection areas which can be easily adjusted by changing the picking options.

Tectonic Controls on Devonian Reef Development, Alberta, Canada



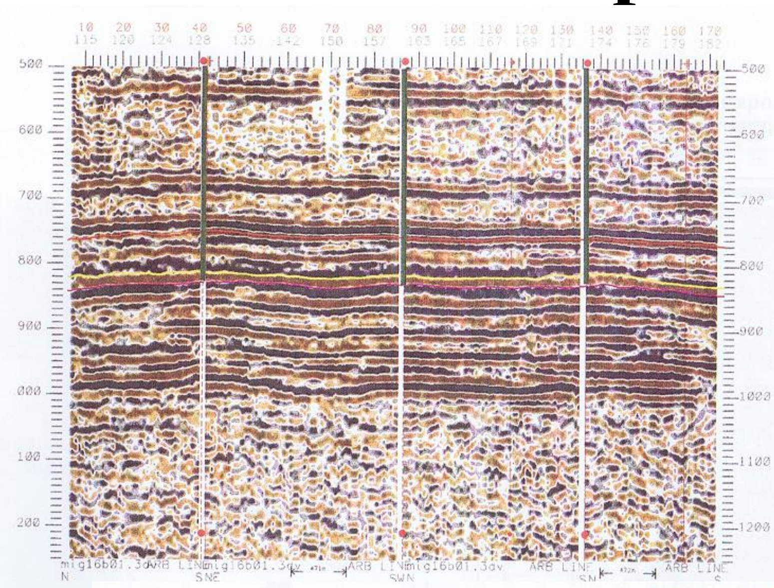


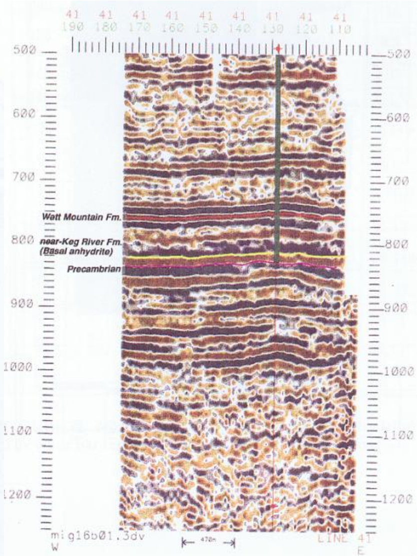


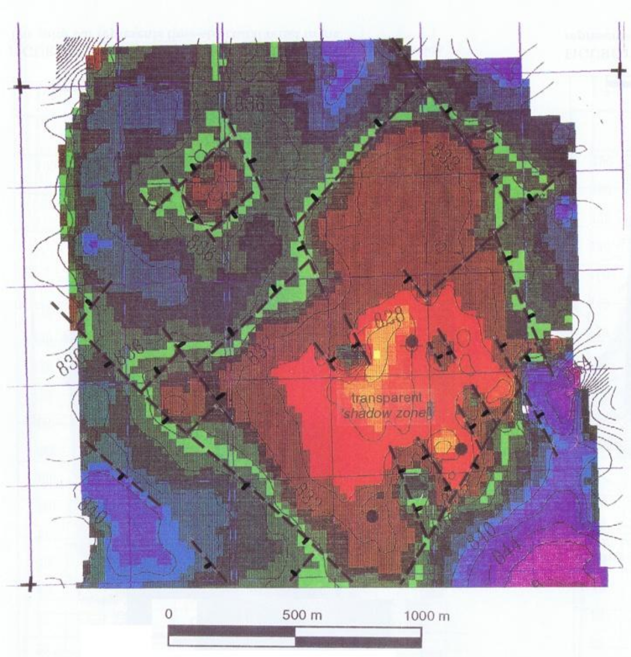


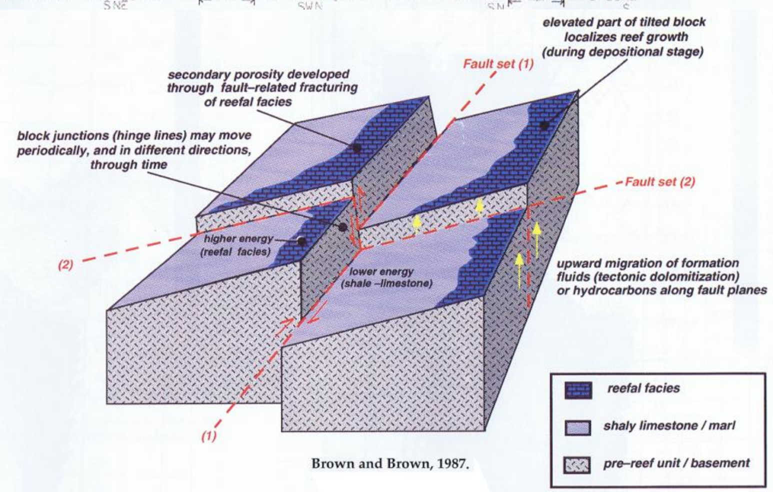
Darrin J. Edwards in **Application of 3-D Seismic Data to Exploration and Production**, pages 192-192, 196, data from Colin Energy Corp. from Senex Area, Alberta, Canada.

Tectonic Controls on Devonian Reef Development, Alberta, Canada









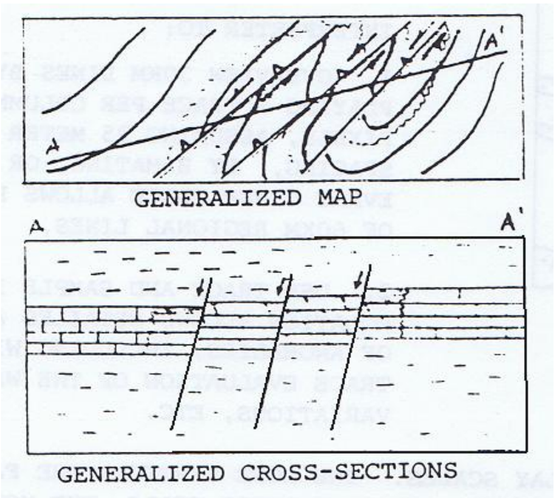
Brown and Brown, 1987.

Darrin J. Edwards in **Application of 3-D Seismic Data to Exploration and Production**, pages 192-192, 196, data from Colin Energy Corp. from Senex Area, Alberta, Canada.

Secondary or Tectonic Dolomite

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

SECONDARY or TECTONIC DOLOMITE traps are typically the result of water percolating along fractures turning impermeable limestone into dolomite. The stratigraphic changes typically follow the orientation of the fractures, forming fault controlled combination traps. Examples are the oil fields that started production in the late 1880's near Findley, Ohio, and the giant Arun gas field in Sumatra.



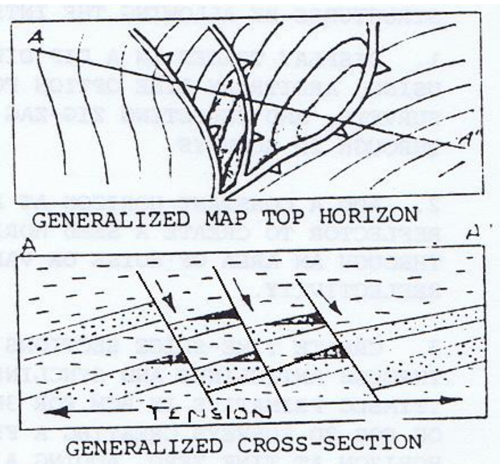
The Interactive environment can aid interpretation of this type of geology by allowing the interpreter to:

1. Select display colors to enhance variations in the reflection coefficient resulting from dolomitization and hydrocarbon filled traps.
2. Add a constant to the trapping horizon, creating a parallel horizon at a reflector within the limestone layer showing where there has been velocity induced distortions to the layer.
3. Build fault maps to determine expected areal extent and trends of dolomitization.
4. Extract seismic reflection amplitudes at horizons where there are amplitude variations associated with hydrocarbons and display the results on 2D or 3D map displays to see the areal extent of variations.
5. Make animation files to study subtle changes in amplitude, reflection character, reflector dip, or fault trends.

Normal Fault Traps

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

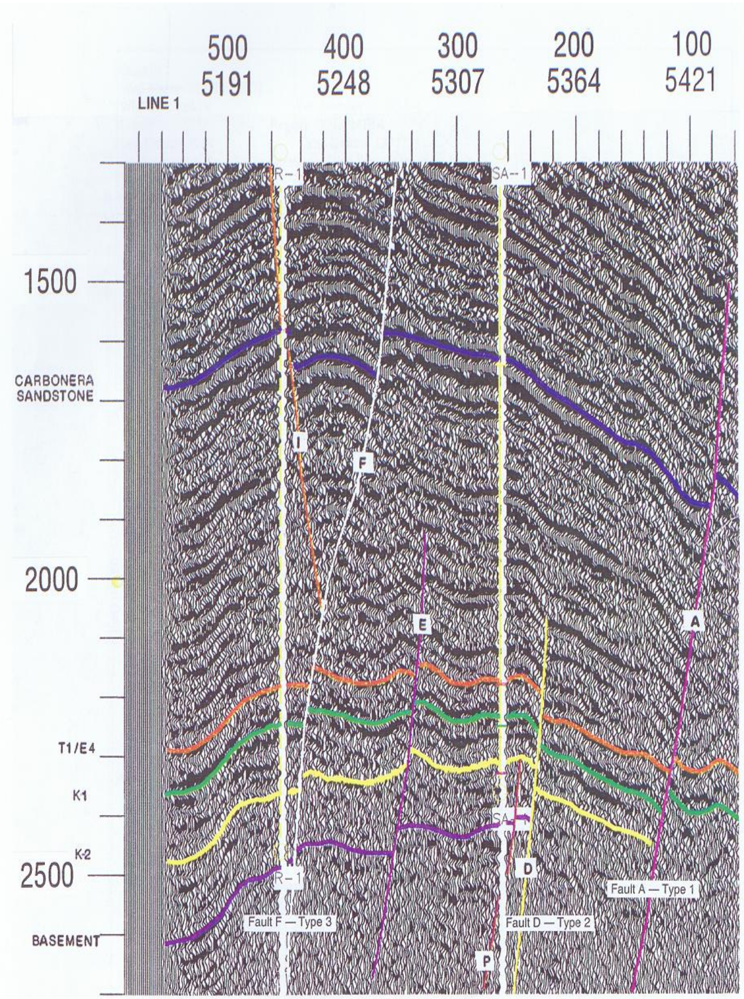
NORMAL FAULT TRAPS are structural traps resulting from tectonic forces. To form hydrocarbon traps, faults must cut dipping rocks and must either be curved or at the junction of two faults. Normal faults are associated with domes, growth basins, and other tensional tectonic movements.

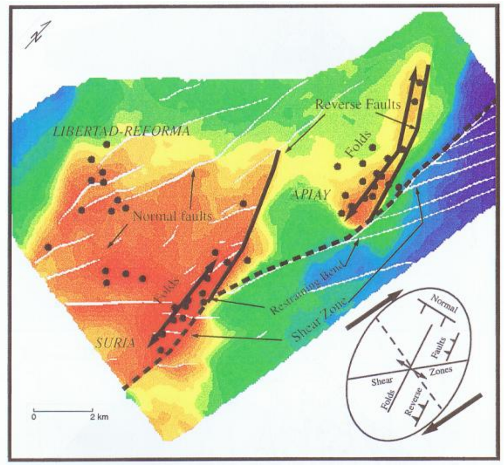


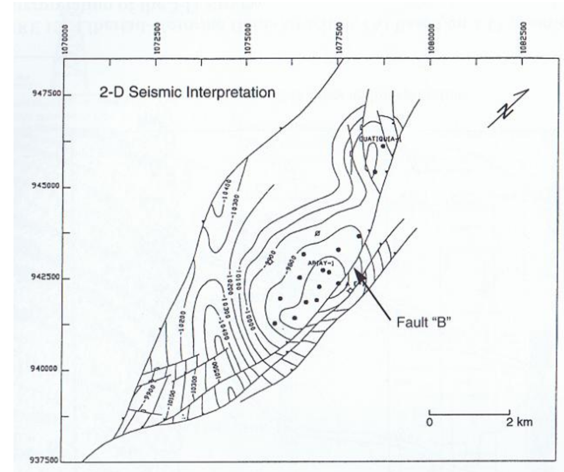
The Interactive environment can aid the interpretation of these types of structures by allowing the interpreter to:

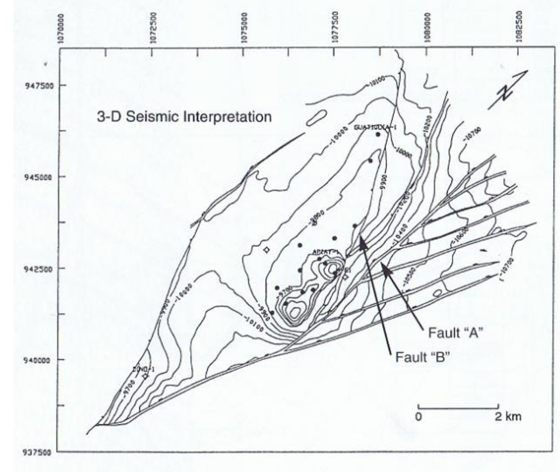
1. Use the polygonal fault correlation window to reconstruct geology prior to faulting.
2. Build fault plane maps to understand complex fault trends.
3. Instantly enhance reflection continuity by adjusting the color look-up tables to give an AGC appearance to the seismic data.
4. Instantly change the color look-up tables to enhance strong amplitude events (bright spots), reverse the apparent polarity, or coloring specific amplitude ranges associated with sands or interest yellow while decreasing other amplitudes.
5. Flatten seismic relative to horizon picks. If picks are not made down fault scarps, there will be gaps in the flattened seismic section showing the trace location of faults at the horizons used for flattening.
6. Reconstruct the fault history by building picture or animation files of seismic data flattened starting with deep horizons and moving up through depositional history. These steps can be tied to hydrocarbon migration times.

2-D vs. 3-D Structural Interpretation







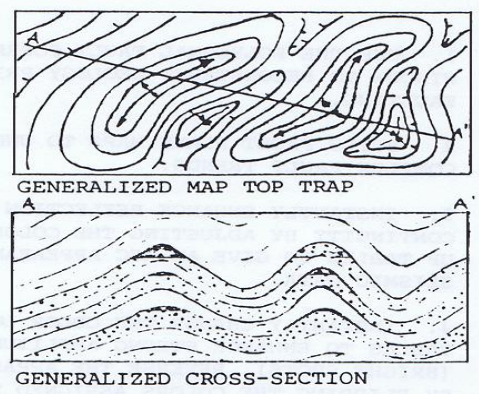


Mario Gutierrez, et. al. in **Application of 3-D Seismic Data to Exploration and Production**, pages 64-65, data from Ecopetrol from Llanos Basin, Columbia.

Anticlines

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

ANTICLINES are large, upward arches often formed in areas of compression. These structures can have multiple producing zones. Anticlines are found with many different types of structural styles and are widely distributed geographically as hydrocarbon traps. Typical examples are found in the Oklahoma Mountains, which consist of elongated domes of basement rock.



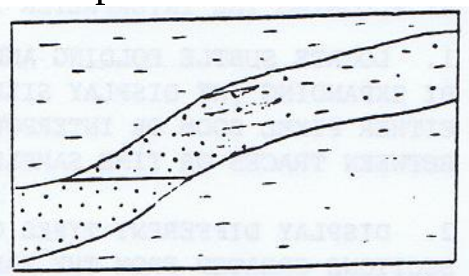
The Interactive environment can aid the interpretation of these types of structures by allowing the interpreter to:

1. Display traces in a dip direction using arbitrary line options for 3-D surveys and zig-zag lines through 2-D surveys.
2. Add a constant horizon at a good reflector to create a seed horizon through an area of noise or variable reflectivity.
3. Create time-slice sections to step through anticlines and synclines. For a 2-D survey create a flat horizon at time zero, add (a) constant(s) to the times or horizons of interest and extract 2-D time-slices or horizon slices.
4. Look at animations through 3-D time-slice files for detail study of structure expansion (anticlines), linear trends (faults), subtle patterns in noisy data, and horizon crossing events that can be related to hydrocarbon / water contacts, saddle points, etc.
5. Reconstruct paleogeology by flattening vertical sections to specific horizons or by making horizon-slices.
6. Work with horizon map displays to do detailed evaluation of anomalies and guide the sections to display next.

Updip Facies Changes

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

UPDIP FACIES CHANGES form combination traps when the reservoir rock is porous and permeable downdip and changes to an impermeable facies in the updip direction. These reservoirs would be classified stratigraphic if sands were deposited downdip and shales updip during the same geologic sequence, but structural if the impermeable facies were due to later uplift. These traps tend to form small fields.



GENERALIZED CROSS-SECTION

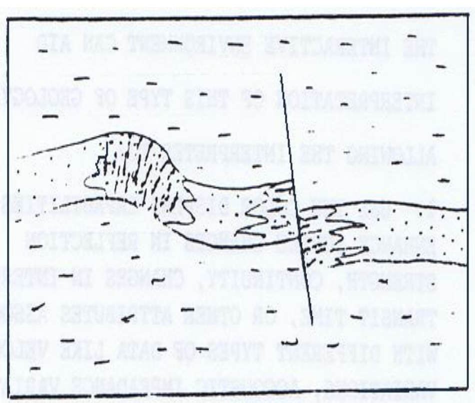
The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

1. Use the color display capabilities to enhance subtle changes in reflection strength, continuity, changes in interval transit time, or other attributes associated with different types of data like velocity variations, acoustic impedance variations, etc.
2. Flatten seismic relative to specified horizons to reconstruct geologic history and determine the depositional environment and whether an anomaly is structurally or statigraphically controlled.
3. Extract attributes at and parallel to a horizon to look for spatial variations which can be related to.
4. Work back and forth between map and section displays to quickly and accurately determine the spatial size, orientation, and relationship between anomalies.
5. Look for anomalies which can be related to hydrocarbons; like flat gas/water contacts, gas induced velocity pushdowns, bright spots or dim spots, etc.

Fractured Reservoirs

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

FRACTURED RESERVOIRS occur in fine grained rocks that have some porosity but need additional porosity and permeability to be hydrocarbon reservoirs. These rocks can produce hydrocarbons from fractures caused by folding or faulting. The Austin Chalk plays in Central Texas and many of the new resource plays are examples of this type of structural trap.

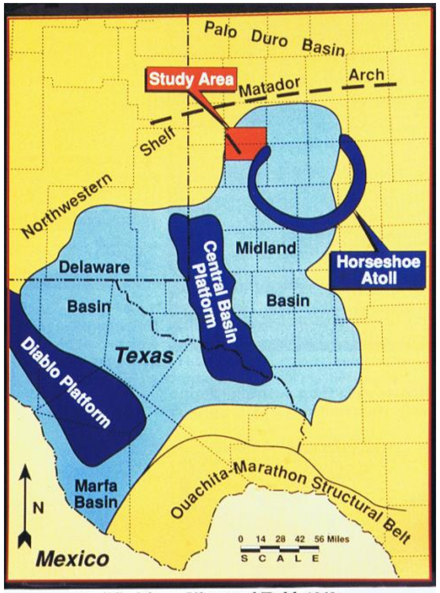


GENERALIZED CROSS-SECTION

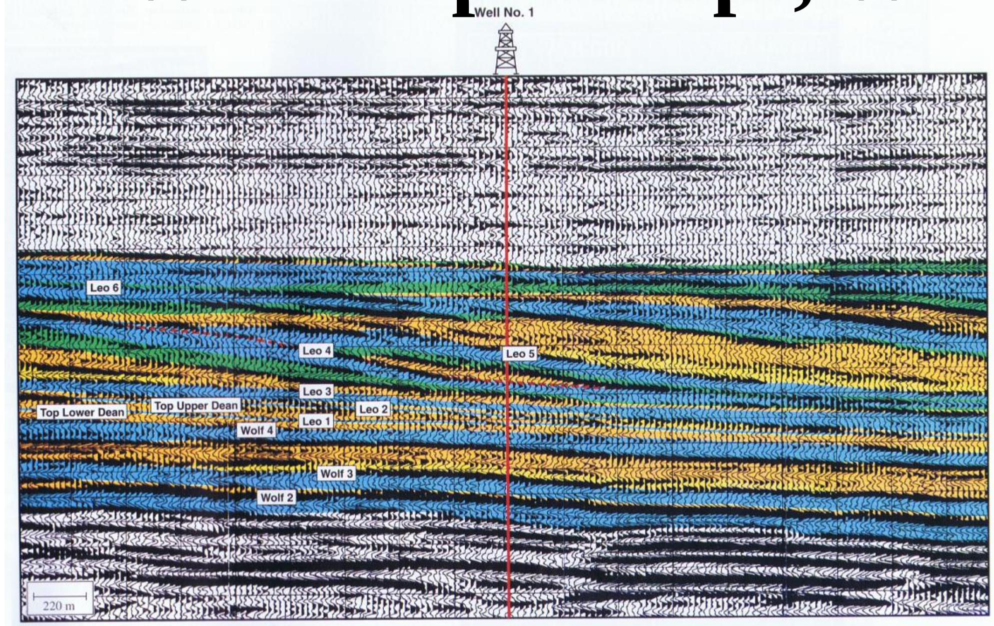
The Interactive environment can aid the interpretation of this types of geology by allowing the interpreter to:

1. Locate subtle folding and faulting by expanding the display size with either pixel zoom or interpolation between traces or time samples.
2. Display different types of sections created from the same seismic traces; such as instantaneous phase to enhance reflection continuity; instantaneous frequency to look for frequency tuning or absorption; reflection strength to look for amplitude anomalies; stacking velocity to look for velocity anomalies; acoustic impedance to look for temporal or spatial lithologic changes; synthetic sections to compare a derived geologic model with actual seismic data; etc.
3. Create paleo-time-slices to evaluate spatial variations in the different types of data described in 2 above. These sections are created by extracting the attributes from vertical sections at specific horizon times and mapping.
4. Use softcopy color options to enhance subtle differences in the data, making large displays for detailed study.

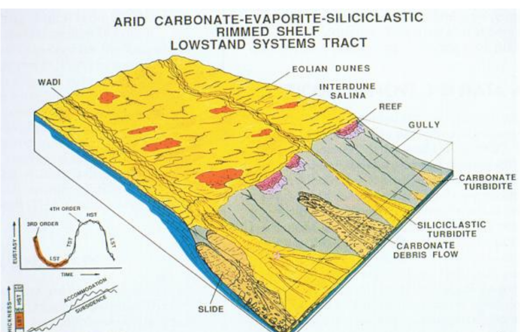
Porous Carbonate Debris Flows in Leonard and Wolfcamp Groups, West Texas



Modified from Silver and Todd, 1969.



Yellow = lowstand fan
Orange = lowstand prograding complex
Green = transgressive systems tract
Blue = highstand systems tract



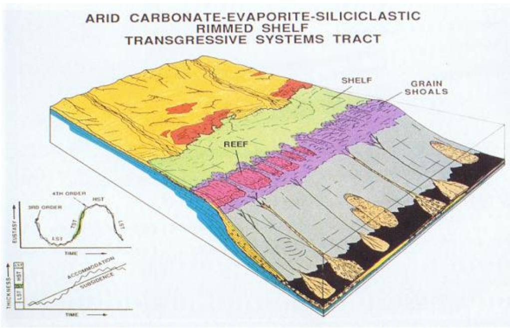
From Handford and Loucks, 1994.

Lowstand Systems Tract.

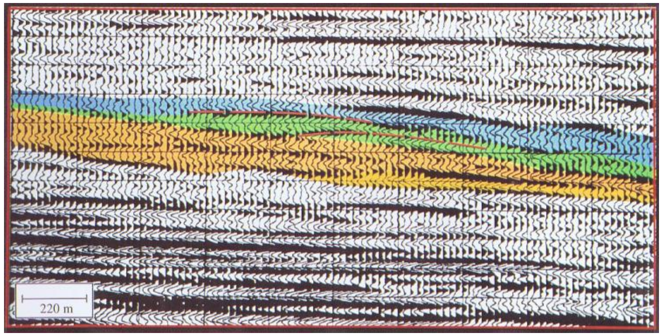
Submarine Canyon.

Jory A. Pacht, et. al., in **Application of 3-D Seismic Data to Exploration and Production**, pages 165-169, data from Heyco Producing Co. and Ranck Exploration from Midland Basin, West Texas.

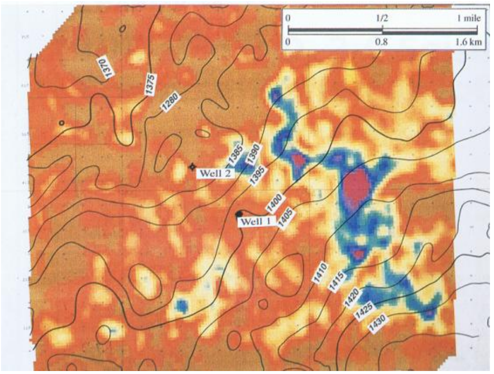
Porous Carbonate Debris Flows in Leonard and Wolfcamp Groups, West Texas



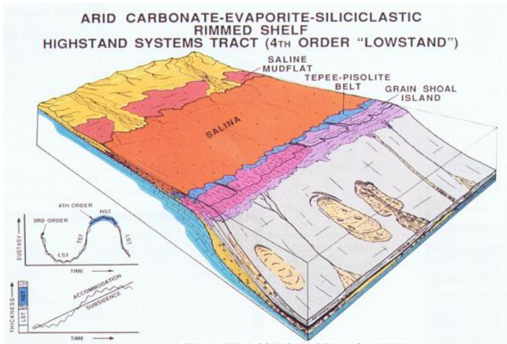
Transgressive Systems Tract.



TST Backstepping Mounds.

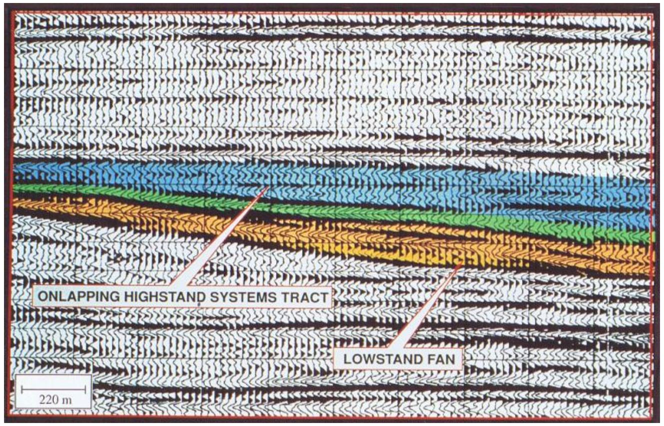


Average Weighted Frequency Map.



From Handford and Loucks, 1994.

Highstand Systems Tract.



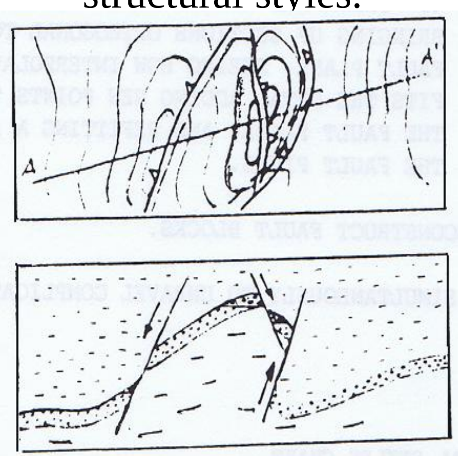
HST Catch-Up Deposition.

Jory A. Pacht, et. al., in **Application of 3-D Seismic Data to Exploration and Production**, pages 165-169, data from Heyco Producing Co. and Ranck Exploration from Midland Basin, West Texas.

Faulted Anticlines

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

<u>FAULTED ANTICLINES</u> are often associated with faulting due to original folding. These faults frequently form impermeable barriers which divide a structure into separate reservoir pools. Faulted anticlines occur in a variety of geographic locations and within many different types of structural styles.

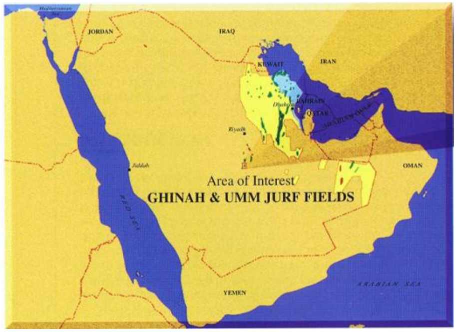


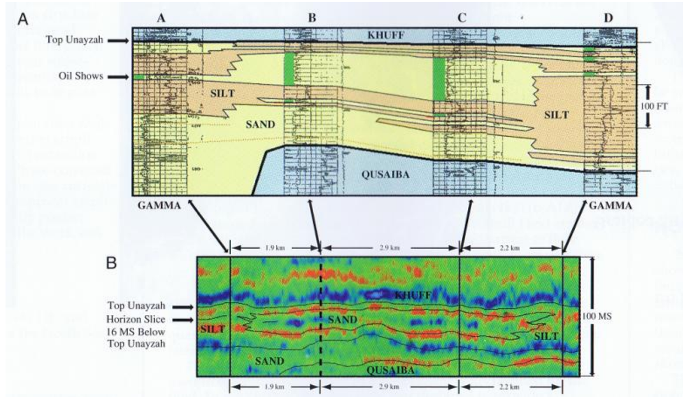
The Interactive environment can aid the interpretation of these types of structures by allowing the interpreter to:

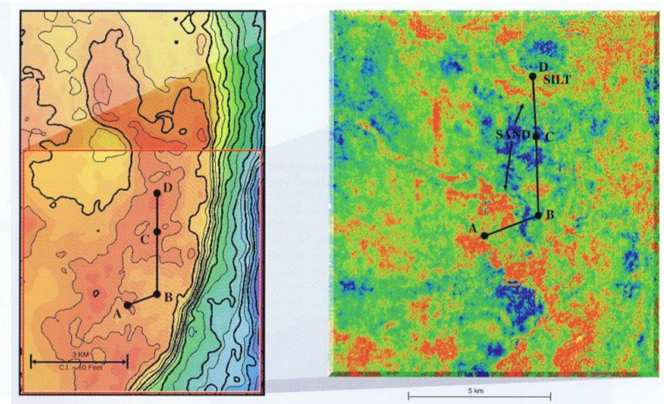
1. Select sections for display orthogonal to the fault heave.
2. Pick faults as a vector list whenever they are recognized on a section, then display all of the picks in the fault database in map view to allow the interpreter to interactively connect fault segments, build fault plane maps, generate fault plane surfaces, and fault heave polygons.
3. Use the fault correlation window to reconstruct geology along polygonal boundaries.
4. Use the drag window to move and correlate a third window of data across faults.
5. Flatten the seismic on specified horizons to check the relative throw in different fault blocks. If there are busts in fault blocks, the reflection packages will not tie.
6. Work back and forth with the horizon display and the seismic section display to identify fault trends, anticlinal plunge, dip direction, critical closures, etc.

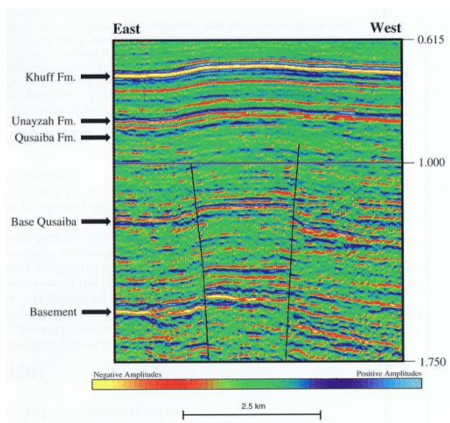
Interpretation of Ghinah Field

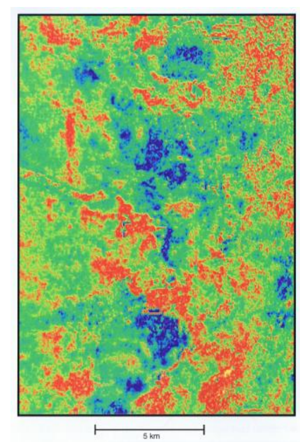
After Tying In Infill Drilling

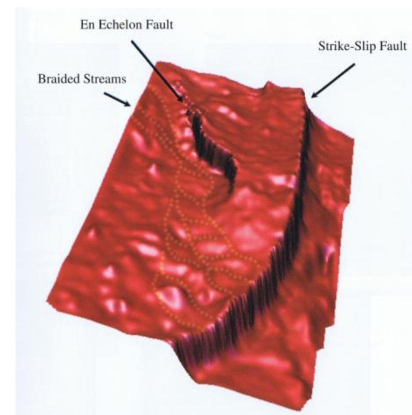












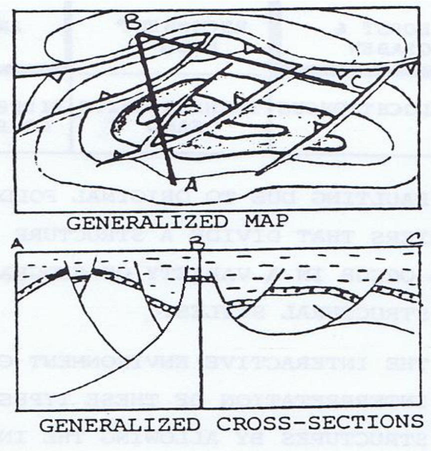
Satellite Image   Drape Across Faults   Amplitudes Unayzah+16ms   Unayzah Horizon

S. C. Simms in **Application of 3-D Seismic Data to Exploration and Production**, pages 104-106, data from Saudi Aramco.

Antithetic or Synthetic Faults

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

ANTITHETIC or SYNTHETIC FAULTS are tensional faults that cut rollover anticlines as they form, often dividing hydrocarbon reservoirs into numerous pools. These type of traps are particularly common among the growth faults and salt domes of the Gulf of Mexico and West Africa.

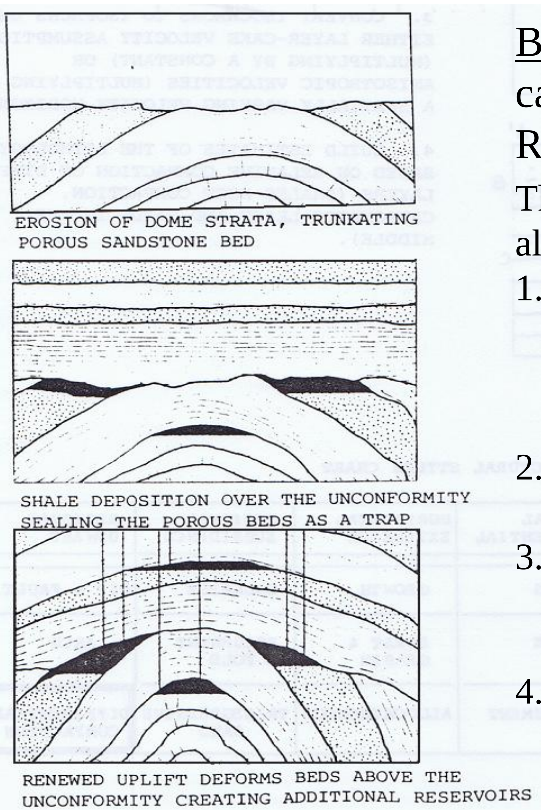


The Interactive environment can aid the interpretation of these types of structures by allowing the interpreter to:

1. Use the computer to build and keep track of the fault data base as described in FAULTED ANTICLINES.
2. Recognize antithetic vs. normal faults by moving a color marker through a map display of all fault times. On normal fault planes the marker will always move in the same direction, and it will move opposite on the first antithetic times and back in the normal fault direction on an ANTITHETIC FAULT ending into ANTITHETIC FAULT.
3. Create fault plane maps by identifying fault segments that belong to the same fault, labeling them as a specific fault, and fitting a surface to the specified points
4. Check and modify fault hypothesis by bring up sections orthogonal to the fault plane, seeing how interpolated faults fit the data, adding new points to improve the fault planes, and refitting a surface to the fault picks.
5. Use the polygon and drag windows to reconstruct fault blocks.
6. Work with both map and seismic displays simultaneously to unravel complicated geology.

Bald Headed Anticlines

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction



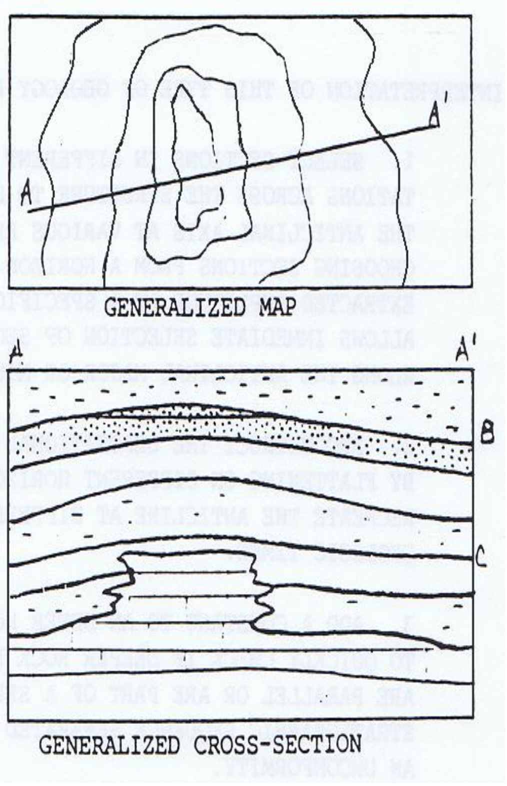
BALD HEADED ANTICLINES develop in stages, as shown in the cartoon below (from **Geological Evolution of North America**, p. 274, R.L. Carroll and T.H. Clark, Publisher John Wiley & Sons, 1979).

The Interactive environment can aid interpretation of this type of geology by allowing the interpreter to:

1. Select sections in different orientations across the structure to determine the anticlinal axis at various levels. Choosing sections from a horizon that is extracted amplitude at a specific time allows immediate selection of sections along the anticlinal major or minor axis.
2. Reconstruct the depositional history by flattening on different horizons to recreate the anticline at different geologic times.
3. Add a constant to an upper horizon to quickly check if deeper rock layers are parallel or are part of a separate stratigraphic sequence separated by an unconformity.
4. Display a shallower horizon as multiple contours on a surface (raster) display of a deeper horizon to study differences in the relative dip of the two horizons on a single display.

Compaction Anticlines

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

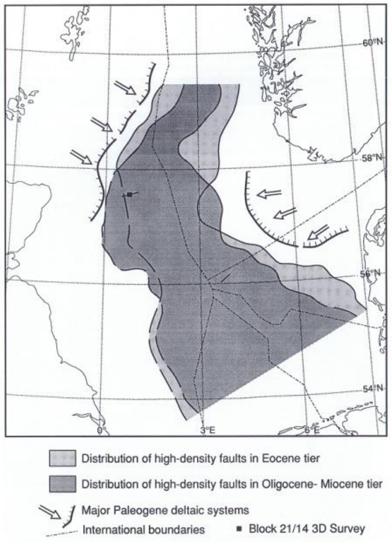


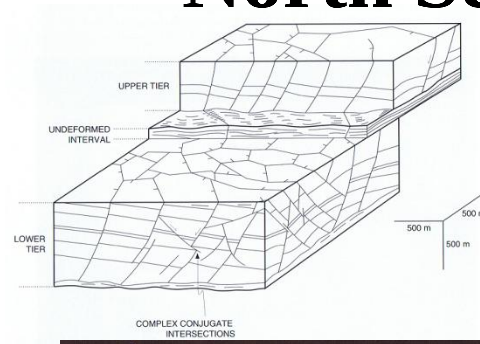
<u>COMPACTION ANTICLINES</u> are structures occurring over buried hills and reefs. The overlaying sediments compact more than the basement hills and limestone reefs creating anticlines. The sediments on the flanks of the controlling structure create additional compact. The generalized map below could be a time structure map showing dip off the anticline, or an isochron map showing thickening between reflectors from B and C off the structure. The Interactive environment can aid interpretation of this type of geology by allowing the interpreter to:

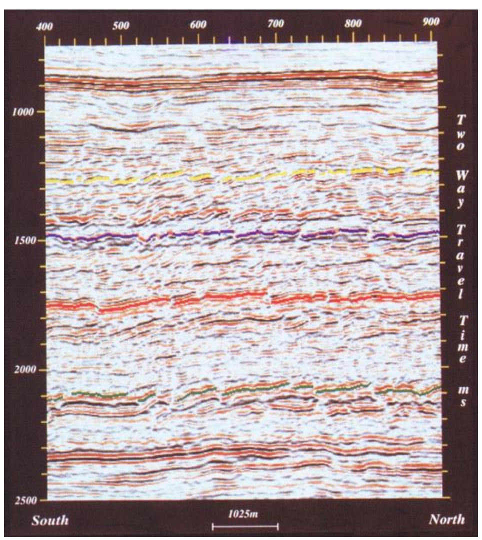
1. Study the relative amount of compaction during different geologic times by flattening on different horizons and measuring the time to a deeper reflector by using the show location option.
2. Use map displays with multiple contours on surface displays to study the relationship between different horizons, isochrons, and the amount of compaction.
3. Convert isochrons to isopachs with layer-cake or anisotropic velocity assumptions.
4. Build estimates of the lithology based on relative compaction of different layers (shales most compaction, carbonates least, and sands in the middle).

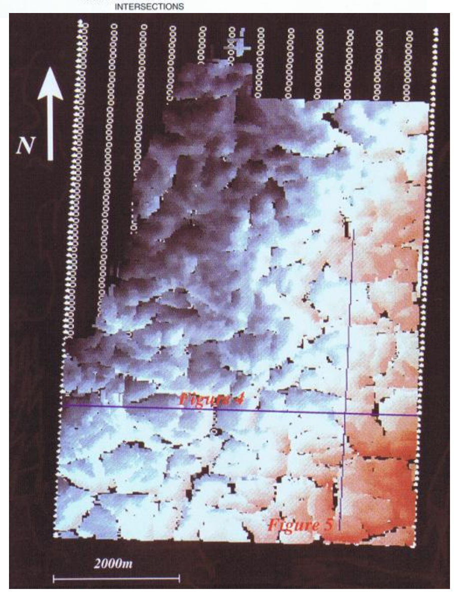
Polygonal Fault Systems

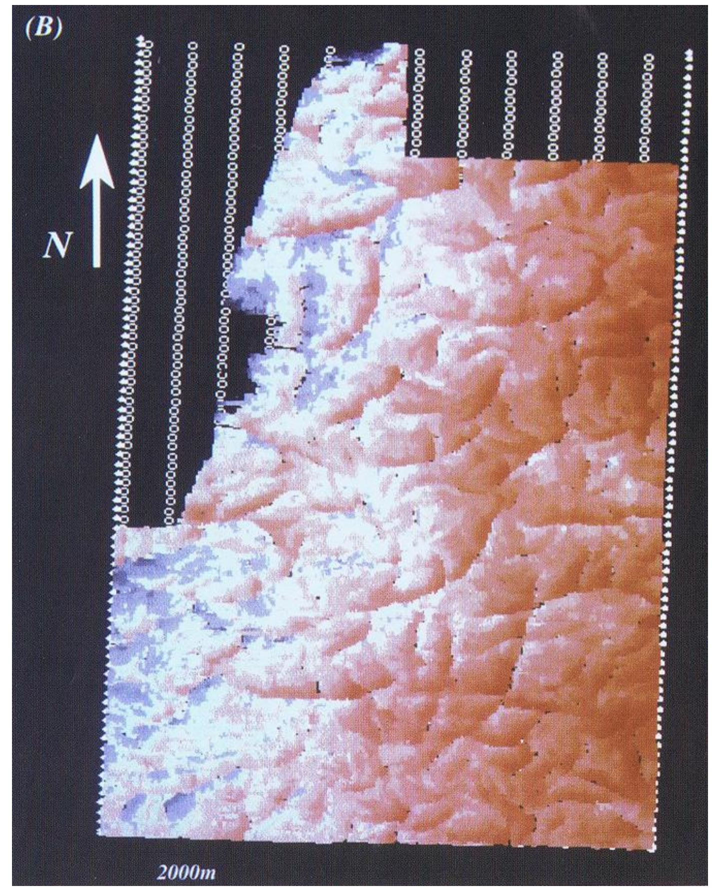
North Sea Basin









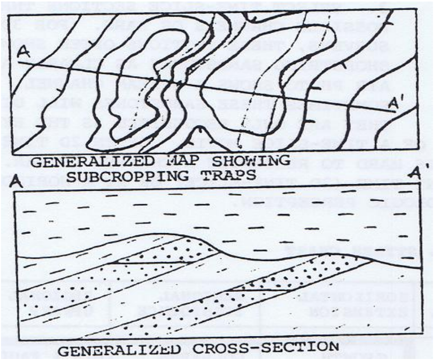


Joseph A. Cartwright in **Application of 3-D Seismic Data to Exploration and Production**, pages 227, 229-230, data from Fina Exploration Ltd., Texaco U.K. Ltd., Santa Fe Ltd., and Purbeck Oil & Gas Ltd. In Block 21 / 14b

Angular Unconformities

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

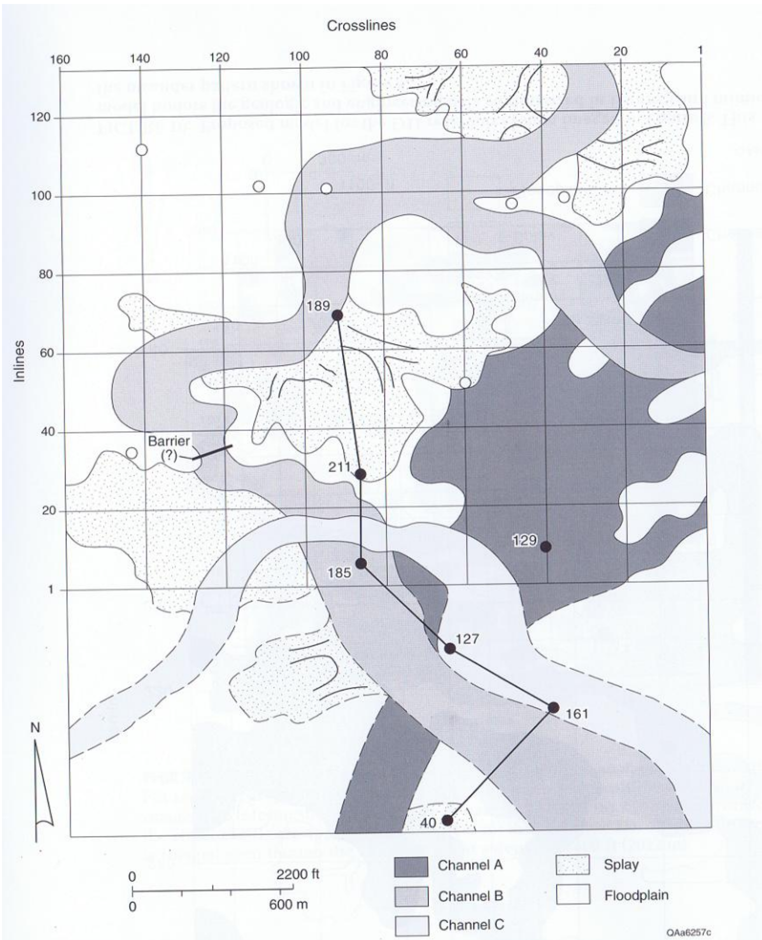
ANGULAR UNCONFORMITIES occur where dipping rocks come up against a buried erosional surface. This type of stratigraphic trap is very widespread and occurs in most basins around the world. Many of the giant North Sea fields are angular unconformities, where the Jurassic or Base Cretaceous is the trap. The Statfjord Field, located on the Norwegian/British demarcation is an example.

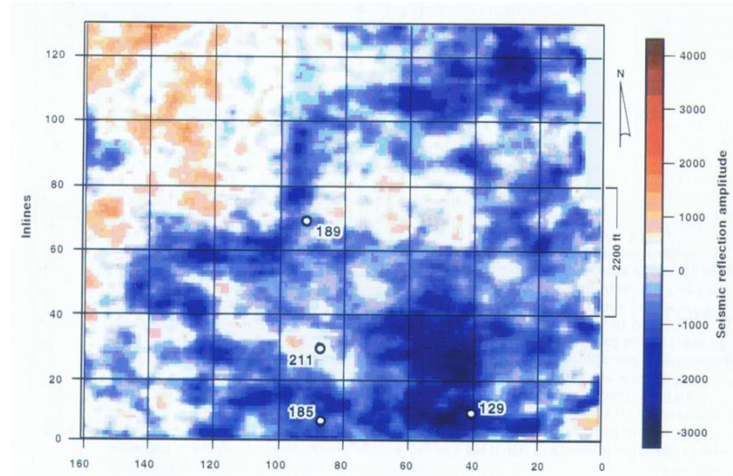


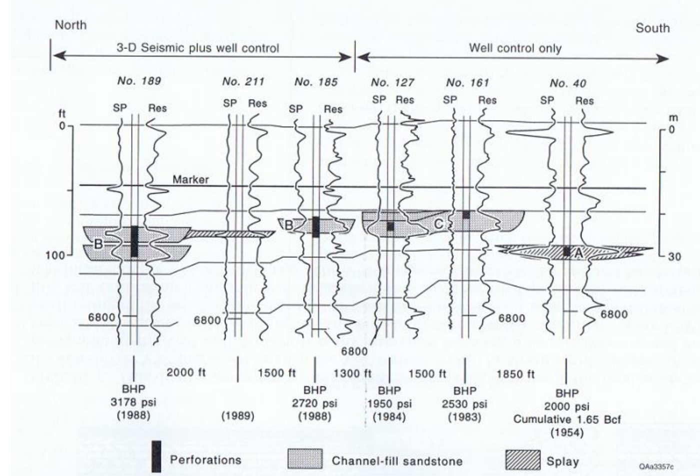
The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

1. Dynamically scale the data to enhance the strong reflector from the unconformity, or clip the strong reflector to enhance the weak trapping reflectors underneath.
2. Build instantaneous phase sections to increase reflector continuity and improve picking of weak reflectors.
3. Do post stack reprocessing to improve critical reflectors: such as predictive or spiking deconvolution to cut out multiples or interbed ringing, filtering to enhance a certain frequency range, or wavelet substitution to match different vintages of 2D data.
4. Use amplitude extraction to study subtle changes in reflection energy and thus the reflection coefficient at the unconformity horizon.
5. Add a constant to the unconformity and extract amplitudes to study subcropping events. Paleo-time-slice movies beneath an unconformity often show subcropping events better than regular time-slice animations.

Thin-Bed Fluvial Reservoir Interpretation





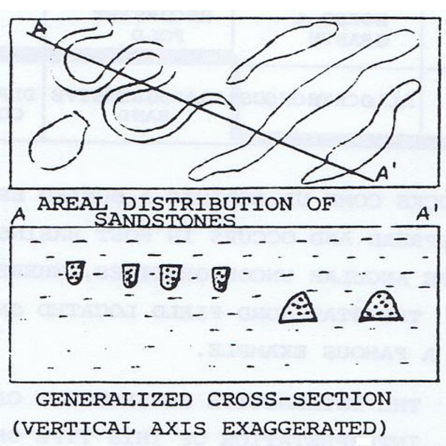


Bob A. Hardage, et. al. in **Application of 3-D Seismic Data to Exploration and Production**, pages 30-31, Stratton Seismic data from the Texas Bureau of Economic Geology.

Shoestring, Channel, Bar Sandstones

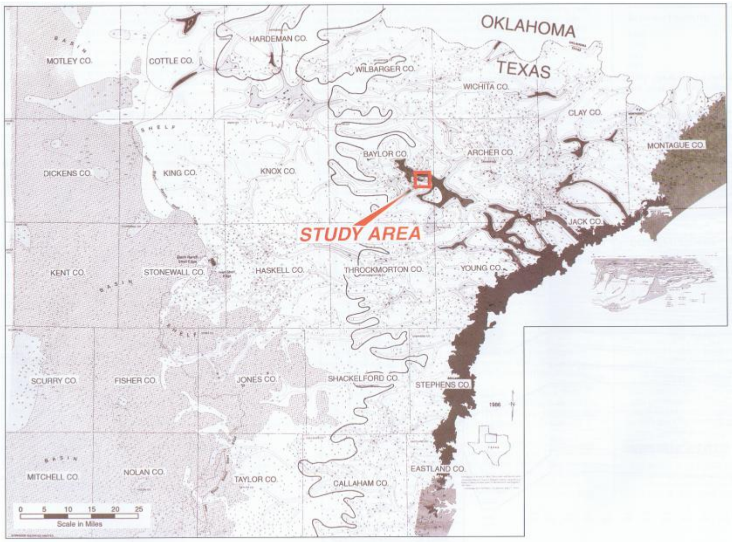
Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

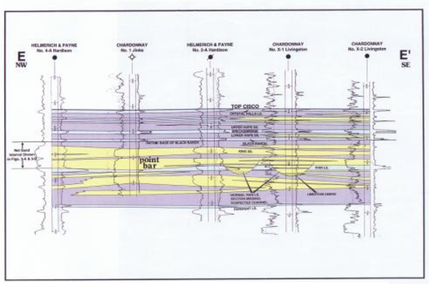
SHOESTRING SANDSTONES are long, narrow sand bodies formed by channels or bars. These stratigraphic traps are often encased in shale and filled with oil with no oil water contact. CHANNEL SANDSTONES are from meandering river channels or delta distributing channels. BAR SANDSTONES are from beaches or destructive deltas and the associated offshore bars. Bars are differentiated from channels in cross-section ( or ), orientation (parallel to the shoreline vs. perpendicular), and the vertical sequence (coarsening upward vs. channel filling upward) [After Dr. N. J. Hyne, **Oil & Gas Field Classifier**]. The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

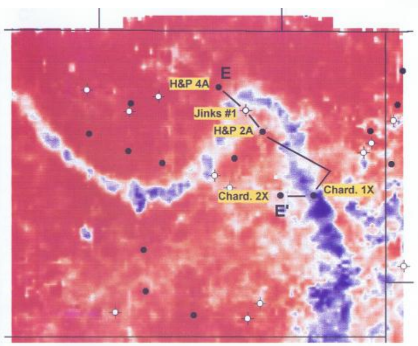


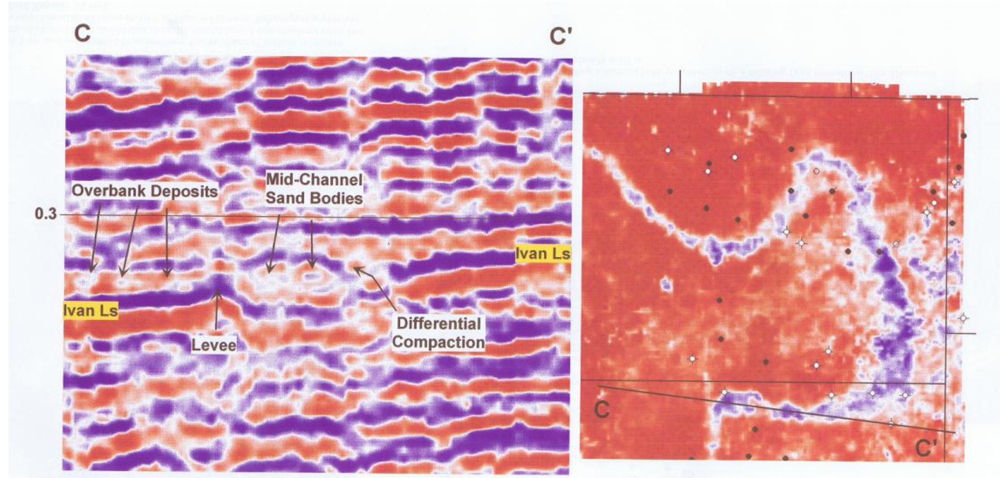
1. Manipulate the display colors so as to enhance diffractions or reflection continuity changes due to channel cuts or bar buildups of sandstones.
2. Select traces cutting through (dip) or following along (strike) SHOESTRING SANDSTONE or other elongated sandstone bodies.
3. Select time-slice sections through possible channels or bars. For 3-D surveys, these sections often show ancient shoestring sandstones as clearly as an air photo shows a stream channel. Sometimes these sandstones will dip and they are only recognized as the eye integrates animation frames. Often 2-D time-slices are spatially aliased making it hard to recognize a channel or bar. Gridding helps.

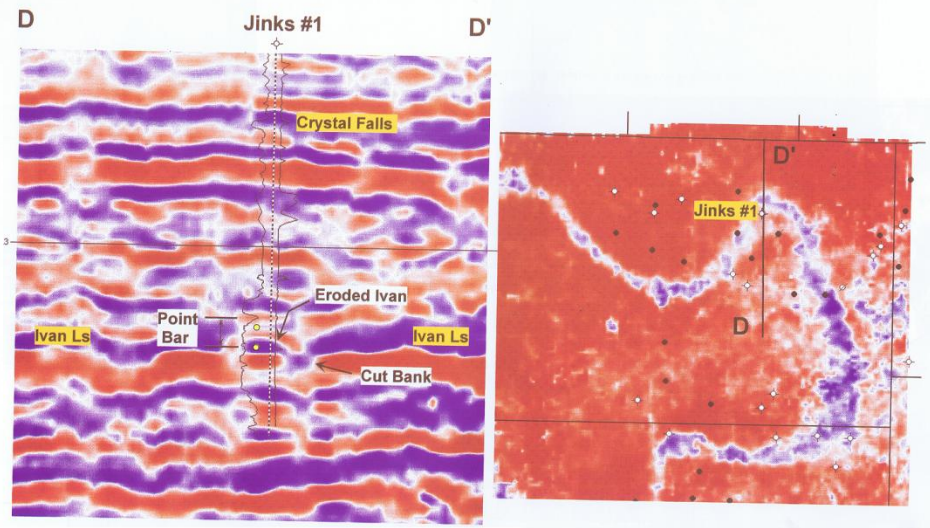
Overbank, Channels, and Point Bars











Mike Burnett in **Application of 3-D Seismic Data to Exploration and Production**, pages 48, 52-53, data from Baylor County, TX.

Stratal Slices

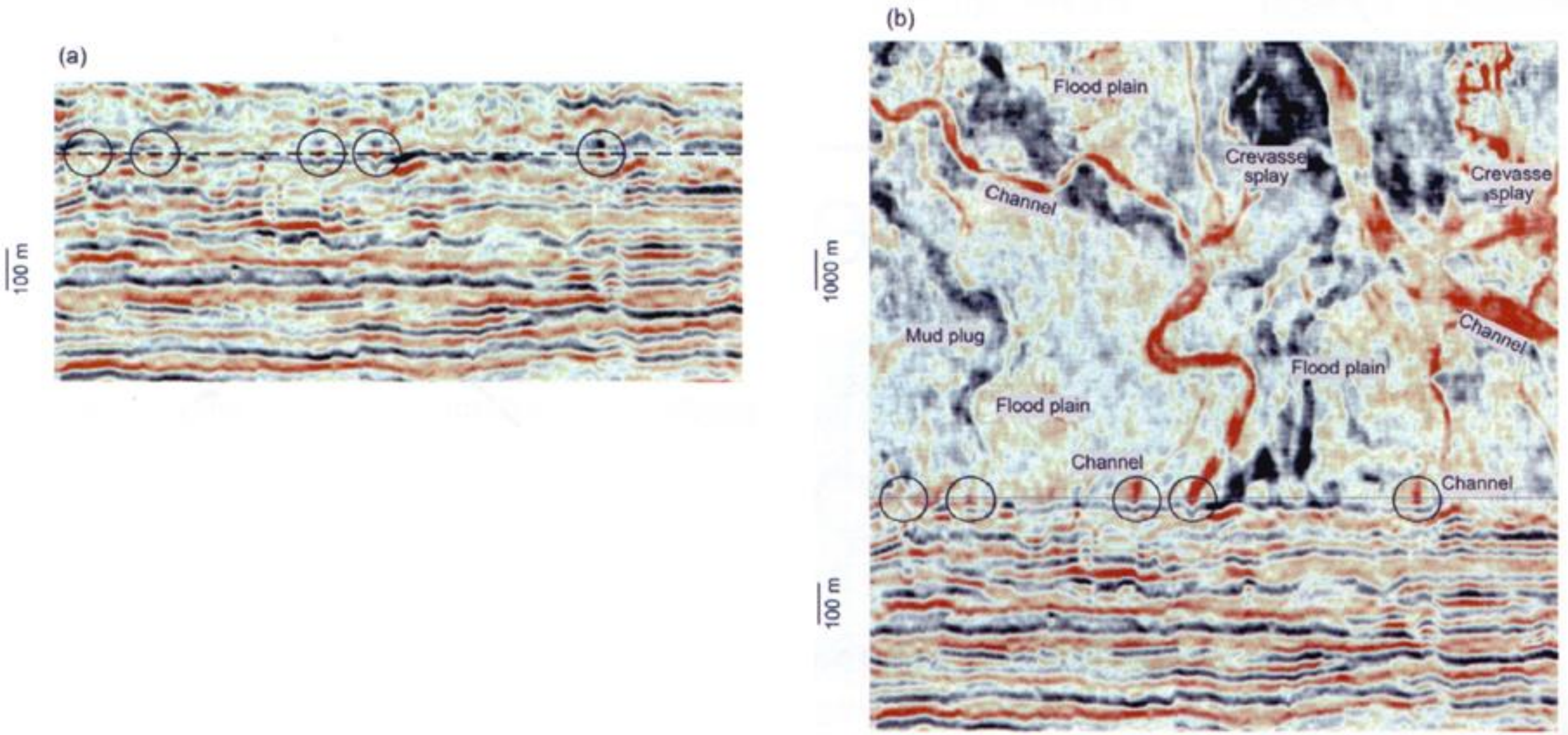


Figure 1. (a) Vertical section view of a fluvial environment (dash line and circled features); (b) Stratal slice showing small depositional features are better seen in horizontal view than in vertical view.

A. Hongliu Zeng, **The Bureau of Economics Geology (BEG)**, 1996, Stratal Slices.

Oolite Shoals

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

<u>OOLITE SHOALS</u> are made of sand-sized spheres of CaCo which has precipated out of shallow tropical seas and has been washed into elongated mounds by waves. These stratigraphic traps form small fields, and many shoals often parallel each other. N.S. Neidell has shown the value of color, acoustic impedance, and detailed velocity analysis to enhance recognition. [Neidell, et. al., Improve Prospect Picks with Move Out Velocity Analysis, **World Oil**, pages 129-142, January 1984.] The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

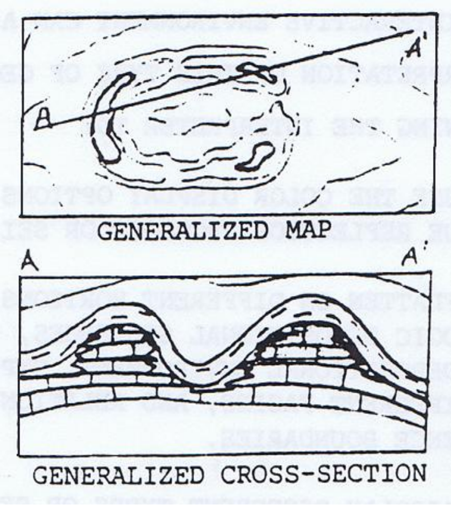
GENERALIZED CROSS-SECTIONS

1. Use the color display options to enhance unique reflection packages or seismic facies.
2. Flatten on different horizons to reconstruct geologic depositional sequences, estimate the depositional environments, types of sediments, and tie to sequence boundaries.
3. Display different types of sections to enhance an anomaly temporally and spatially, like Hilbert Transform attribute analysis, velocity, or acoustic impedance sections.
4. Use horizon display and map select options to study the relationship between similar anomalies, like parallel elongated mounds with similar reflection character.
5. Look for tel-tale anomalies associated with hydrocarbons, like flat spots associated with a gas/water contact, amplitude anomalies, etc. If these events are recognized, the basic steps of calculating net producible gas sands can be followed, i.e. make the data zero phase, pick a peak and trough through a bright spot, calculate isochrons, extract amplitudes, calculate composite amplitudes, smooth, calculate net gas sand isochrons and convert to isopachs.

Atolls

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

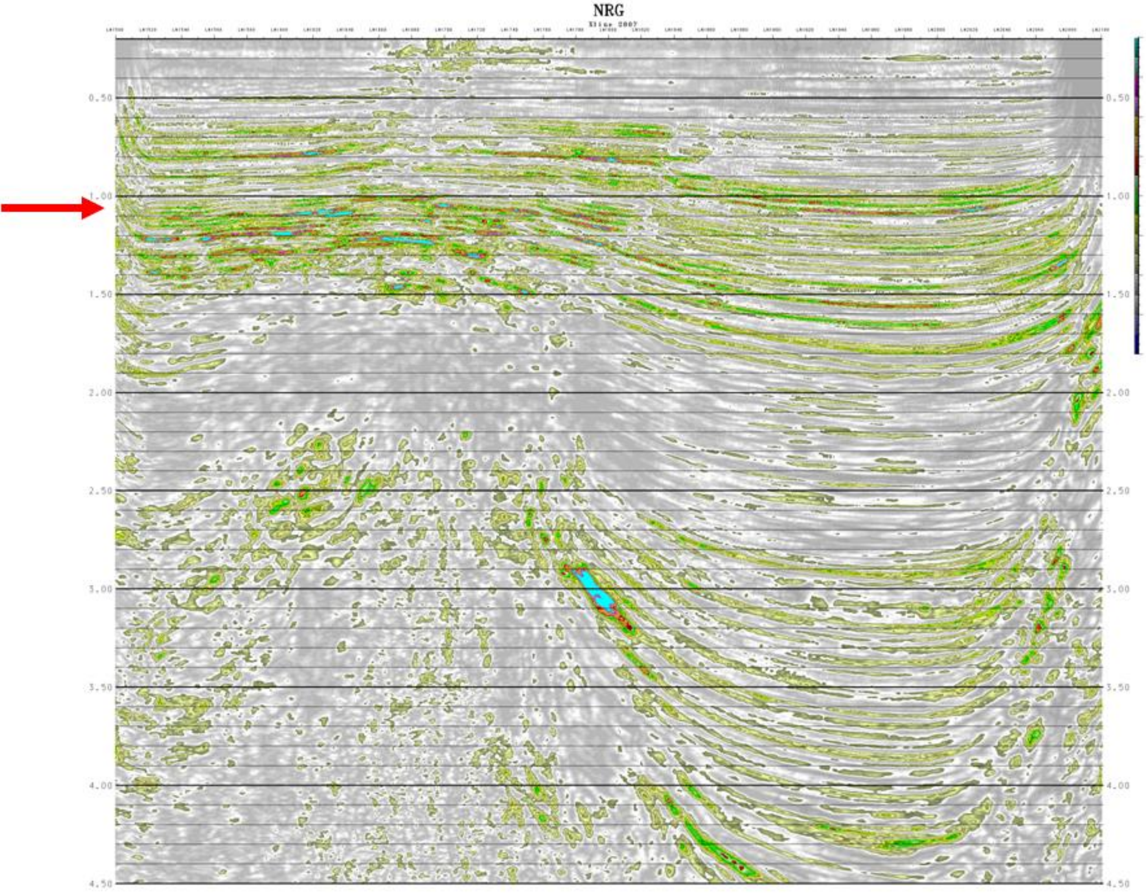
ATOLLS are large, circular or elliptical reefs that enclose a central lagoon. The reef limestones form good reservoirs, but the fine grained lagoonal limestone does not. There are numerous modern day examples of this type of reef development around the world, particularly in the SW Pacific Ocean.

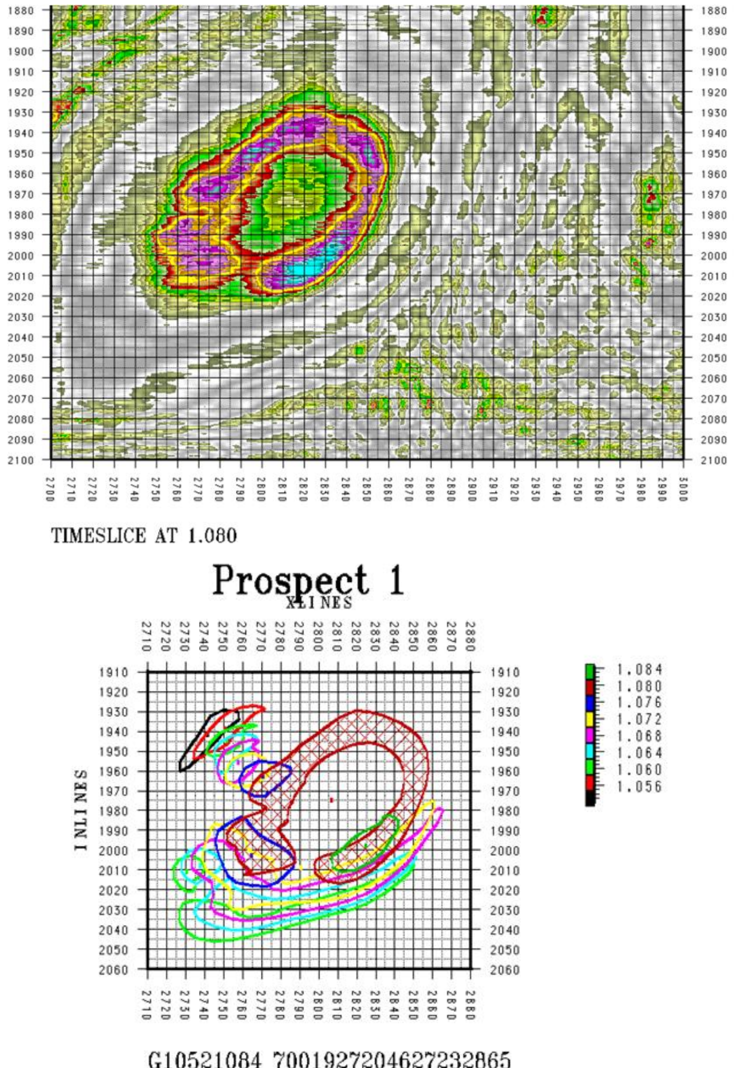


The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

1. Enhance reflection anomalies associated with the reef using color display options.
2. Add a constant to a horizon, moving it down to where it cuts other reflectors that can be associated with reefal buildup, velocity pull-down or push-up (depending on the velocities of the surrounding rocks), diffractions, etc.
3. Time-Slice sections, which are particularly useful in studying reef build-up, like those associated with an ATOLL. For 3-D surveys, these time-slices can be created at constant time or parallel to a horizon or proportional to expanding sections. These same options are available for 2-D surveys by extracting amplitudes appropriately.
4. Work back and forth between map and section displays to look for reef trends on a regional basis, along a play fairway, or specific reef configurations at a lead or prospect basis.

Seismic Atoll Example



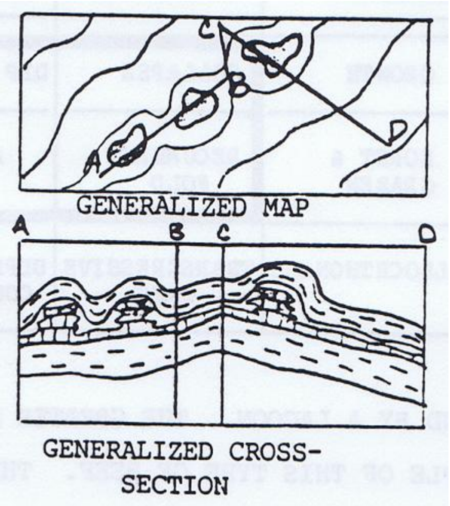


Don Vossler, **Test for Latin American Company**, Personal Communication.

Pinnacle Reefs, Patch Reefs, & Bioherms

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

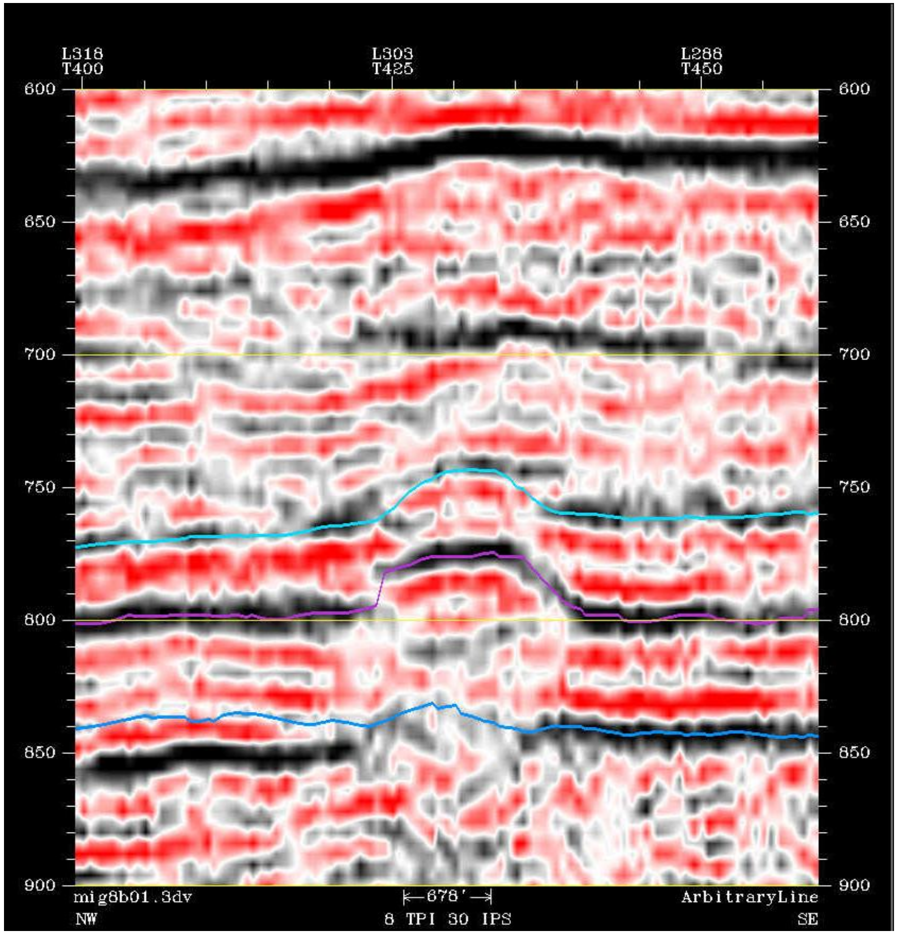
PINNACLE REEFS are small, circular reefs on the basin side of a barrier reef. PATCH REEFS typically occur in a lagoon. BIOHERMS are mounded or lens shaped deposits of biological organisms, both non-framework and framework organisms like corals. These three types of traps tend to produce small fields. Bioherms are more isolated. PINNACLE and PATCH REEFS are usually numerous along trends in several parts of the continental U.S., including Michigan.

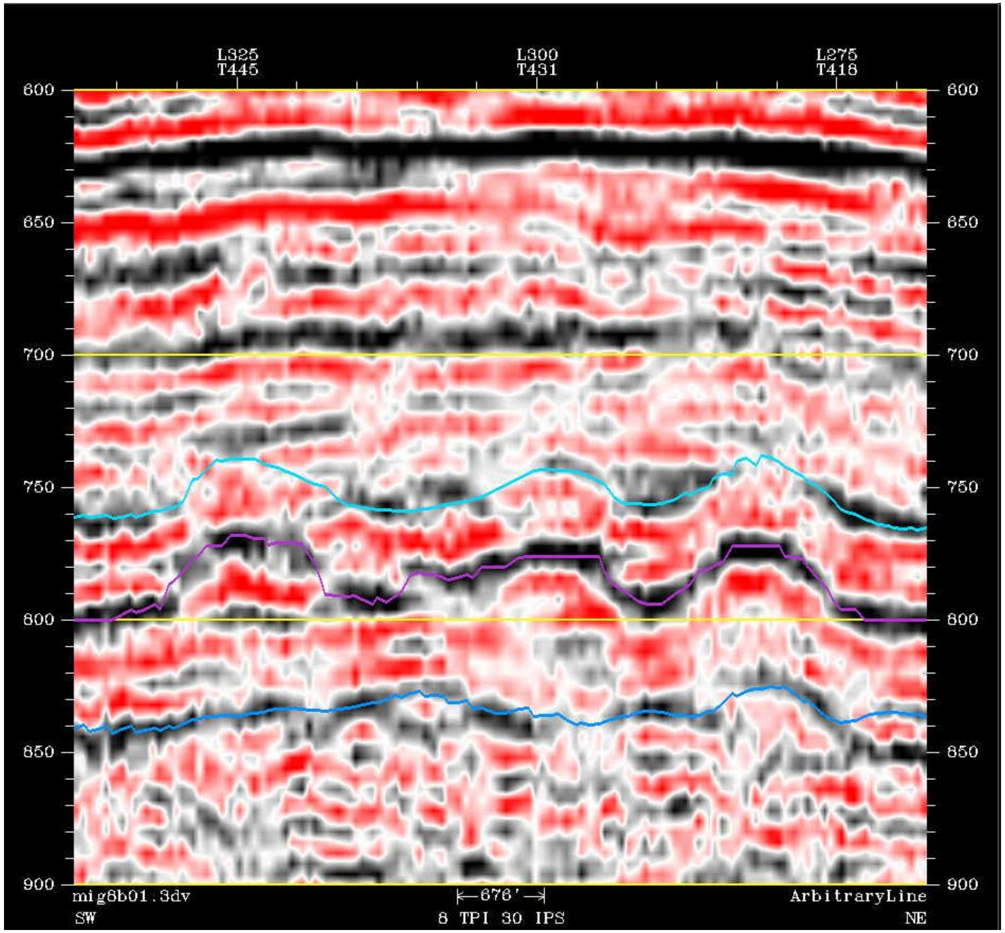


The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

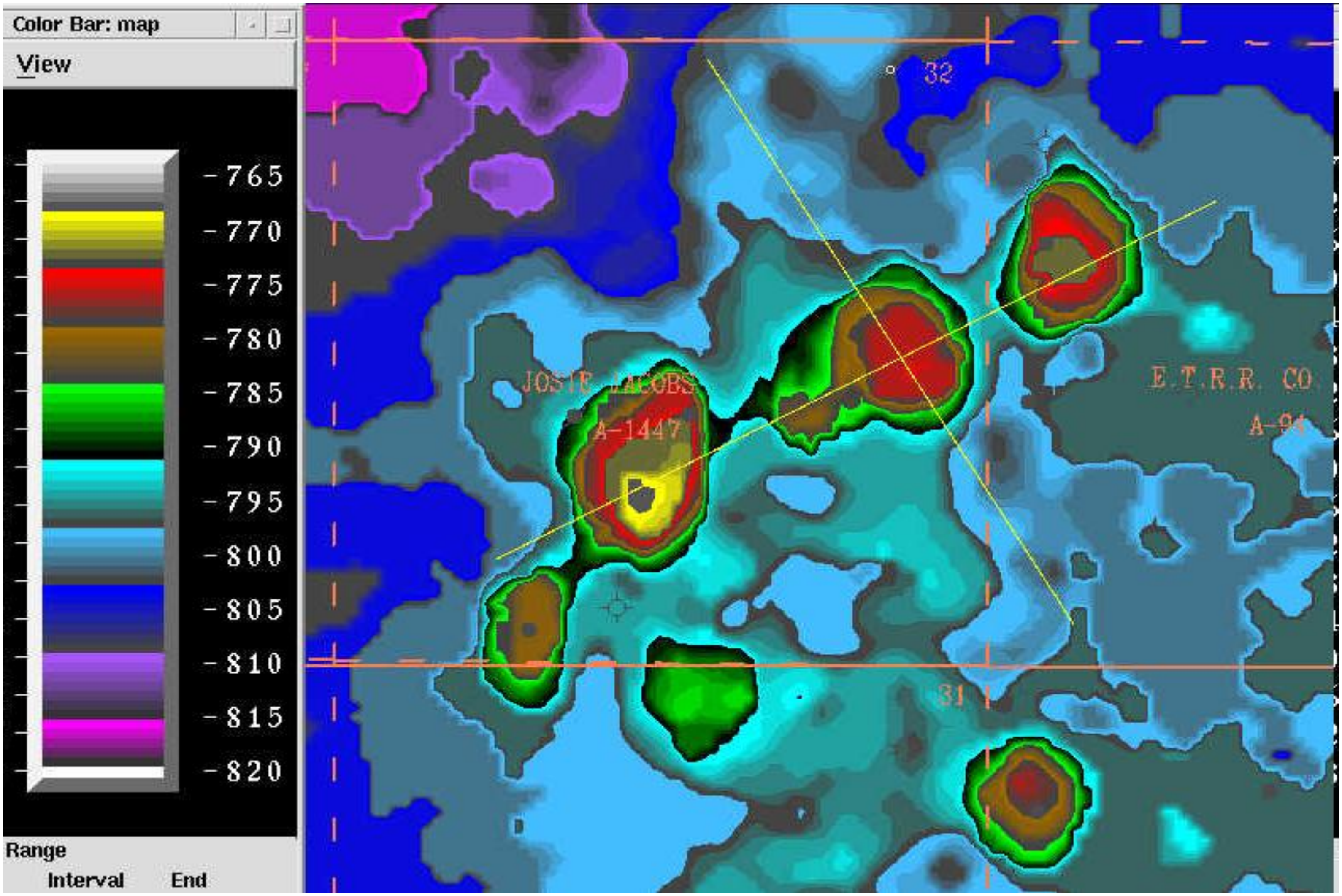
1. Plot trends on a regional basis and do detailed analysis of each local anomaly by zooming in or expanding the display scales.
2. Use these trends and local anomalies as the basis for high grading potential prospects. This might result in doing additional post-stack processing, collecting more densely spaced 2-D lines, or even a small 3-D survey, detailed modeling, etc.
3. Study the effect of variations in amplitude with offset through anomalies of interest. A single line through a reef can be loaded as a 3-D seismic survey where the 3-D axis are CMP, offset, and two-way travel time. Movies through this data show amplitude variations as a function of CMP, offset, time, or stacking velocity (extracted amplitudes parallel to reflector picks).
4. Work back and forth between map and section displays to do detailed analysis and look for regional trends.

Mississippian Pinnacle Reefs
Shackelford County, TX





Mississippian Pinnacle Reefs
Shackelford County, TX



Mississippian Pinnacle Reefs
Shackelford County, TX

	A	B	C	D	E	F
1	**S**3 FLASH Summary** (Geotechnical Risk between 0.00 (100% failure) and 1.00 (100% success)					
2	**Project Name:**	Casey Ranch		**Client Name:**	Coastland Resources	
3	**Prospect Name:**	Comanche		**Prospect Location:**	Block 32: East East Central	
4	**DESCRIPTION**	**RISK**	**REFERENCE**	**DESCRIPTION**	**RISK**	**REFERENCE**
5	**Faults**	**1.00**		**Amplitudes**	**0.72**	
6	Fault Migration Pathway (irrelevant=1, identified=1, questionable=0)	1.00		Existing Production ((sum 25:26 at $25 oil and $5 gas) *(sum of decline for first 5 years)/(area factor=$1,000,000))	**684795.45**	
7	Fault Trap (irrelevant=1, 1 fault=1, 2 faults=0.6, 3 faults=0.4, 4 faults=0.2, possible cross-fault connection=0.2)	1.00		Initial Oil Flow Rates (b/d oil)	75.00	MS 75 b/d Conglomerate 130 b/d
8	**Lithology**	**0.94**		Initial Gas Flow Rates (mmcf/d gas)	0.20	MS 200 mcf/d
9	Producing Analogs (1+ the number of Producing Analogs)	6.00		Initial Decline Rate (percentage first year)	15.00	15% first year
10	Historical Ps (unavailable=50, otherwise sum of analog success percentages)	600.00		Ongoing Decline Rate (percentage subsequent years)	25.00	25% next years
11	Well Log Tie (1.0=good, 0.0=bad, 0.0=none)	0.90		Gas Prediction (1.0=verifiable, 0.0=unvarifiable)	0.80	
12	Source Rocks (1.0=identified, 0.0=not identified or unavailable)	1.00		Oil Prediction (1.0=verifiable, 0.0=unverifieable)	0.80	
13	Reservoir Rocks (1.0=identified, 0.0=not identified or unavailable)	1.00		Prediction of No Hydrocarbons (True=0.0, False=1.0)	0.80	
14	Porosity (percentage)	12.00	7-12% for MS	Migration Timing (1.0=still trapped, 0.0=cooked or migrated out of area)	1.00	
15	Permeability (millidarcies)	1.00	1 MD reef	Prospect Water Saturation (fraction of water in a given pore space, or Sw=[R0/Rt]**1/n)	0.20	
16	Continuity (1.0=continuous, 0.0=discontinuous)	1.00		Pressure (formation psi)	2000.00	Divided by 4000 psi for Amplitude Factor
17	Seal Rocks (1.0=identified, 0.0=not identified or unavailable	1.00		Viscosity Index (VI=100x(L-U](L-H), where L=viscosity at 100 F of reference oil with VI=0, H=viscity at 100 F of reference oil with VI=100, U=viscosity at 100 F of base oil, V=viscosity at 210 F of base oil, and where VI=95 changes viscosity less with temperature than VI=90)	95.00	
18	Regional Seal (1.0=known, 0.0=unknown)	1.00		Prospect Drive Mechanism (water=1.0, gas=0.8, gravity=0.4, unknown=0.0)	0.80	
19	Local Seal (1.0=known, 0.0=unknown)	1.00		Recover Efficiency Factor	0.70	Estimaged recovery efficiency of in-place hydrocarbons
20	Fracture Gradient (1.0 if known, 0.0 if unknown, or [(Formation Pressure (psi/ft)-Fracture Pressure) psi/ft)]/Depth (feet))	0.80				
21						
22	**Stratigraphy**	**0.67**		**Horizons**	**0.73**	
23	Geomorphology (1.0=reservoir rock, 0.0=no reservoir rock)	1.00		Geometry (1.0=4 way closure, 0.8=fault trapped, 0.6=strat trap, 0.0=unknown)	1.00	
24	Stratigraphic Migration Pathway (1.0=migration pathway, 0.0=no migration pathway)	1.00		Depth (feet) (Normalized with area factor of 5000 feet)	4600.00	
25	Stratigraphic Trap (1.0=strat trap, 0.0=no strat trap)	0.00		Velocity Tie (1.0=good, 0.0=bad)	0.80	
26				Closure Area(s) (acres)	1047.26	
27				Thickness(es) (milliseconds)	19.00	
28				Volumes (thickness * area) (normalized with volume factor of 100,000)	**19897.94**	
29	**Ps (Probability of Success): F*L*A*S*H=**	**0.81**				

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P.O. Box 382
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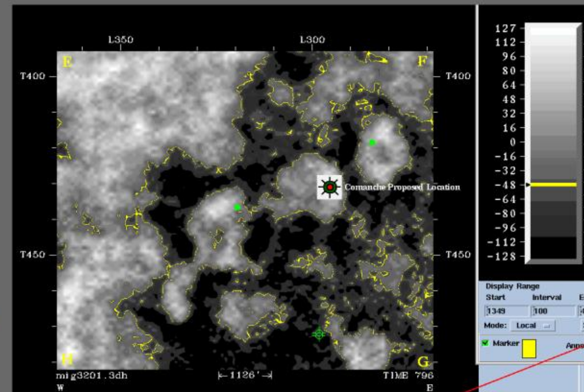
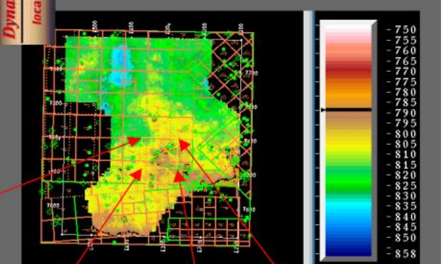
Facsimile: 281.579.2141
info@walden3d.com

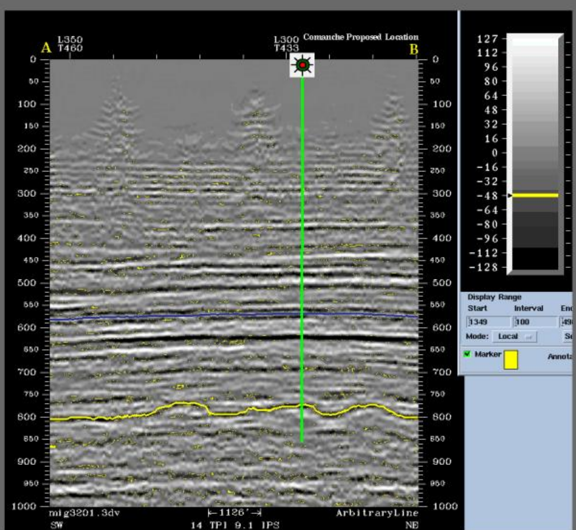
Dynamic Resources Corporation is a sister company to W3D (Walden 3-D, Inc.) and has access to W3D technologies, like the HyperEdge Software, which was used to create this prospect poster.

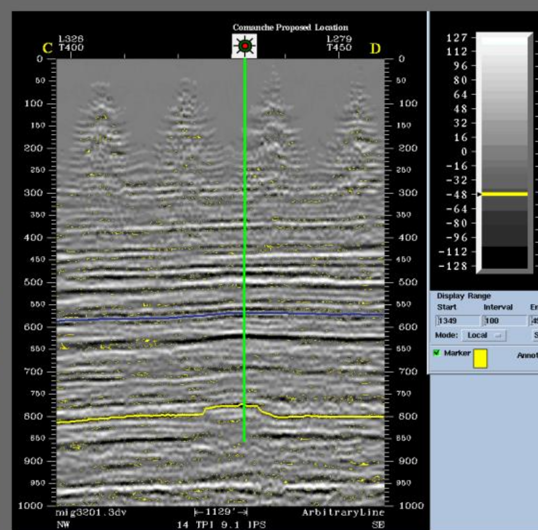
Dynamic Resources Corporation
locating replenishing reserves

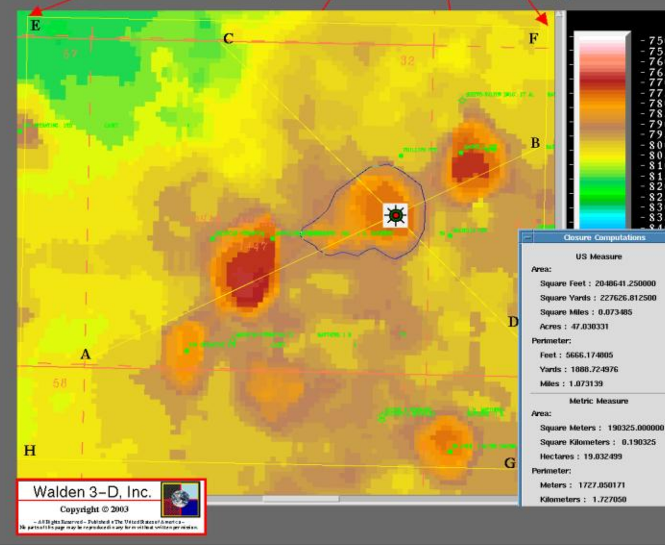
The Comanche Prospect is a 47 acre undrilled Mississippian Reef on the east edge of Section 32 in Shackelford County, just north of Albany, Texas. The reef is not as pronounced as the reef to the southwest and the reef to the northeast, as is shown on seismic section A–B. It apprears this is why it was missed by previous explorers. Four–way closure is shown by crossing seismic sections C–D, and by the travel–time map below. The reef appears to be part of an ancient island chain of reefs, and shows up very well on the seismic time slice E–F–G–H.



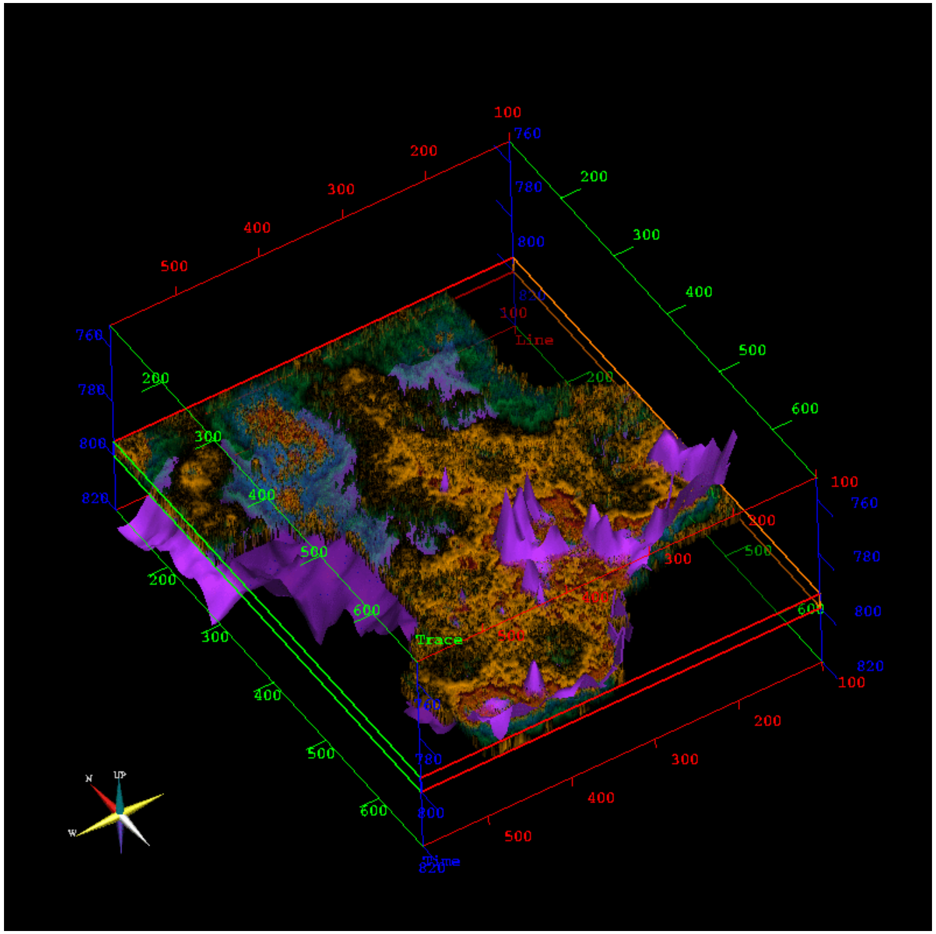


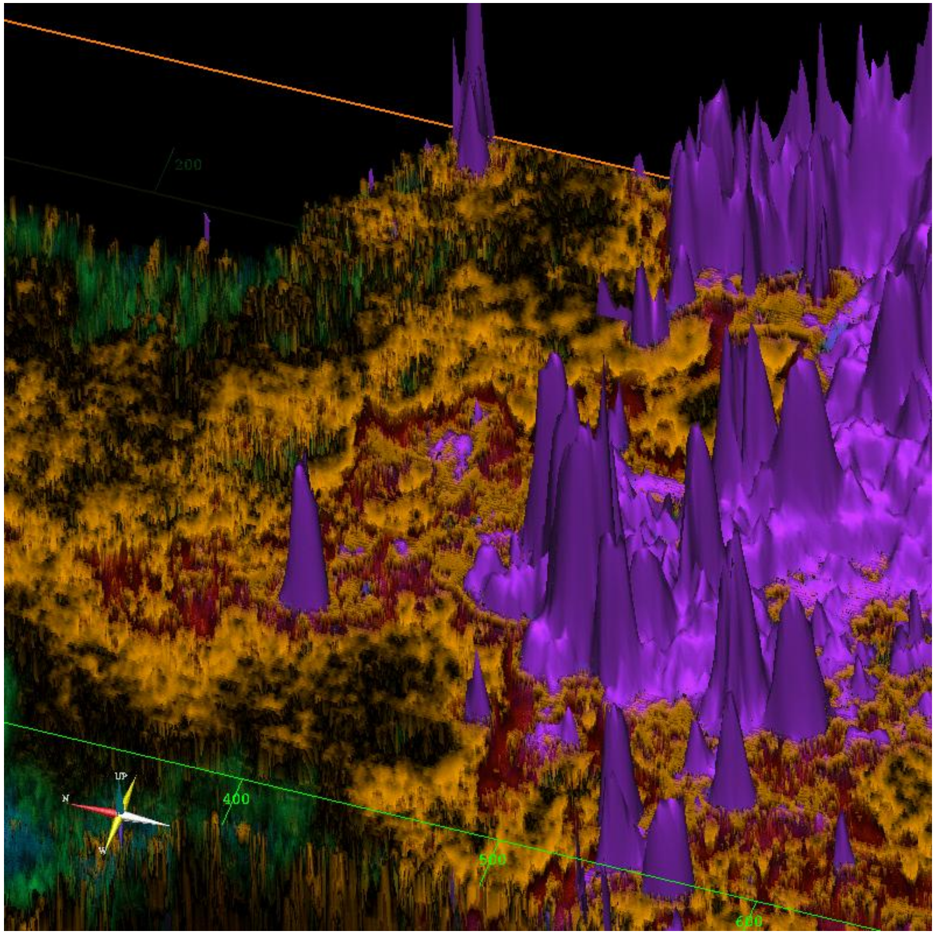






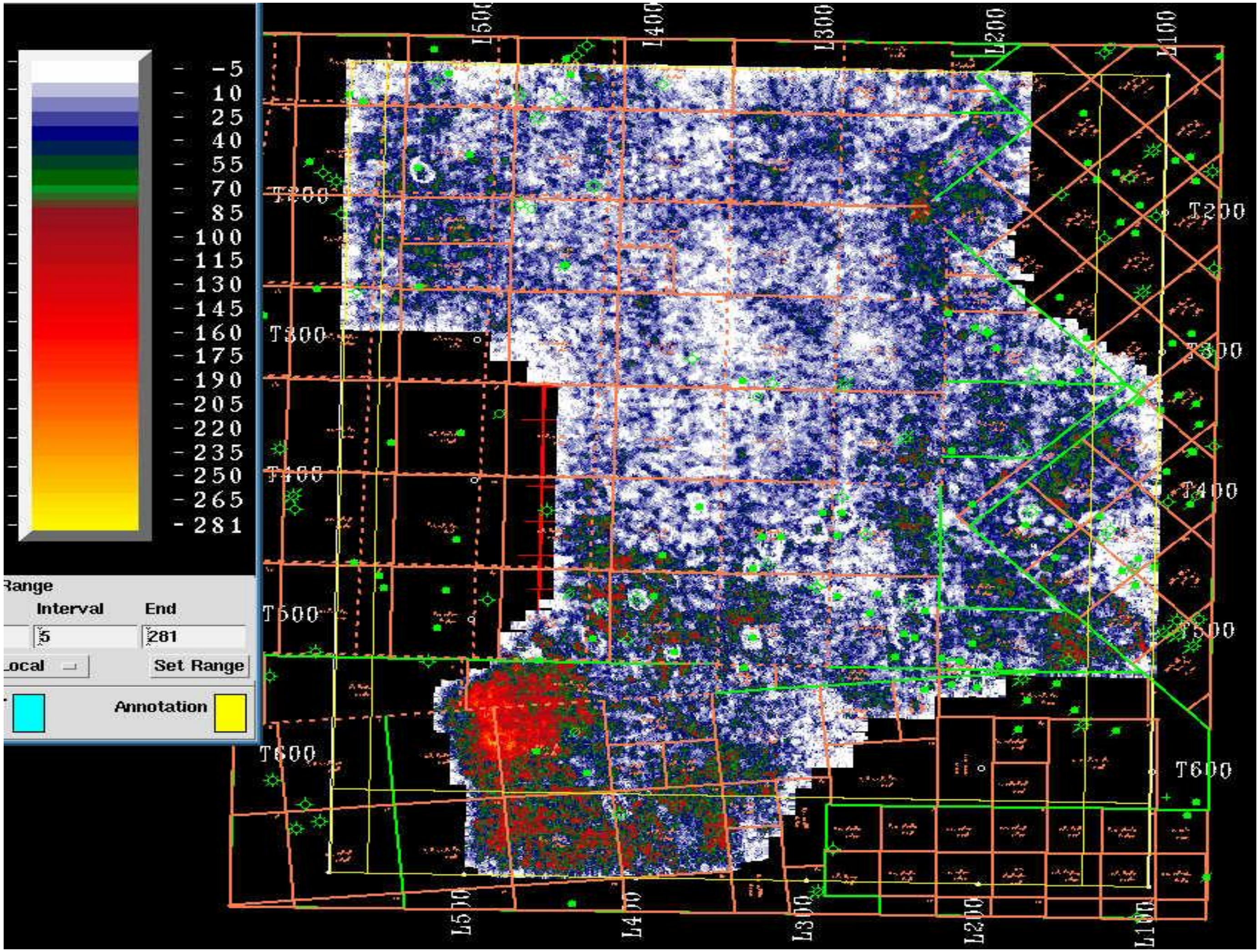
Pinnacle Reefs
Shackelford County, TX





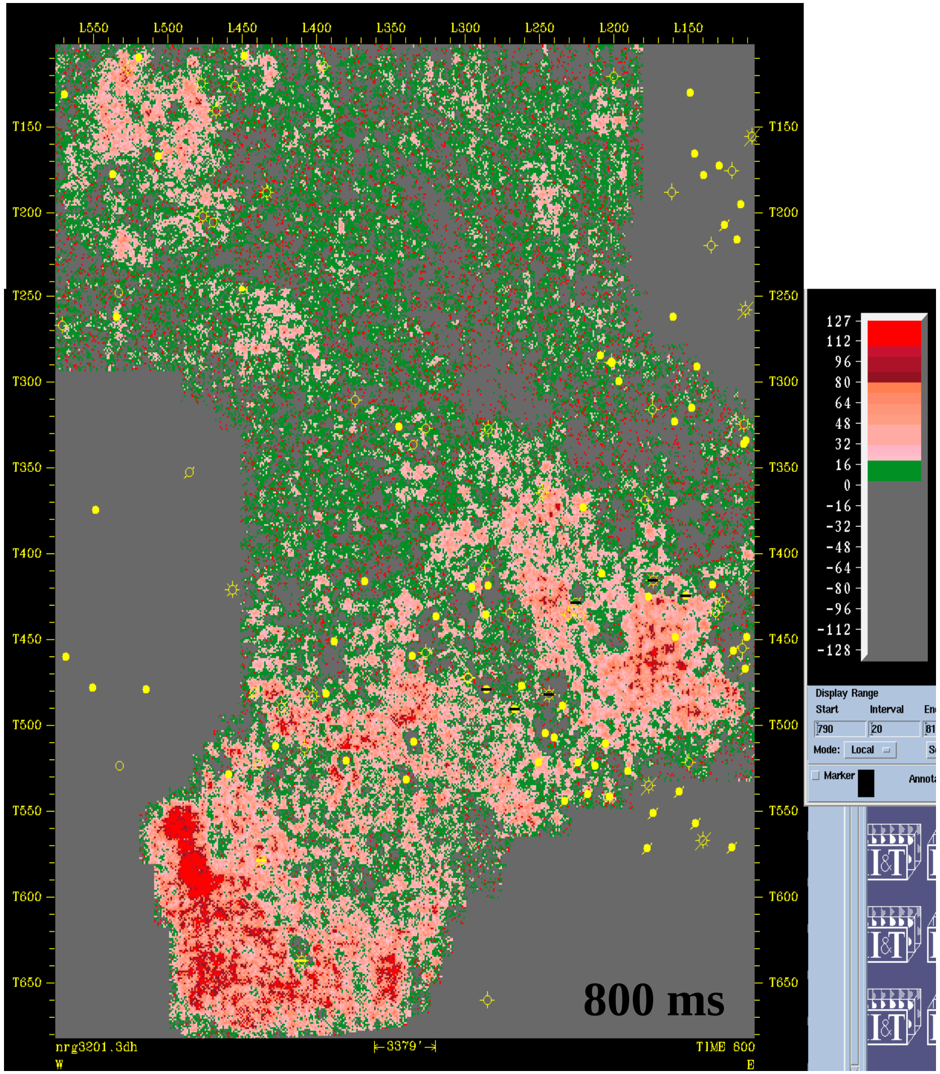
Pinnacle Reefs: Production Halos

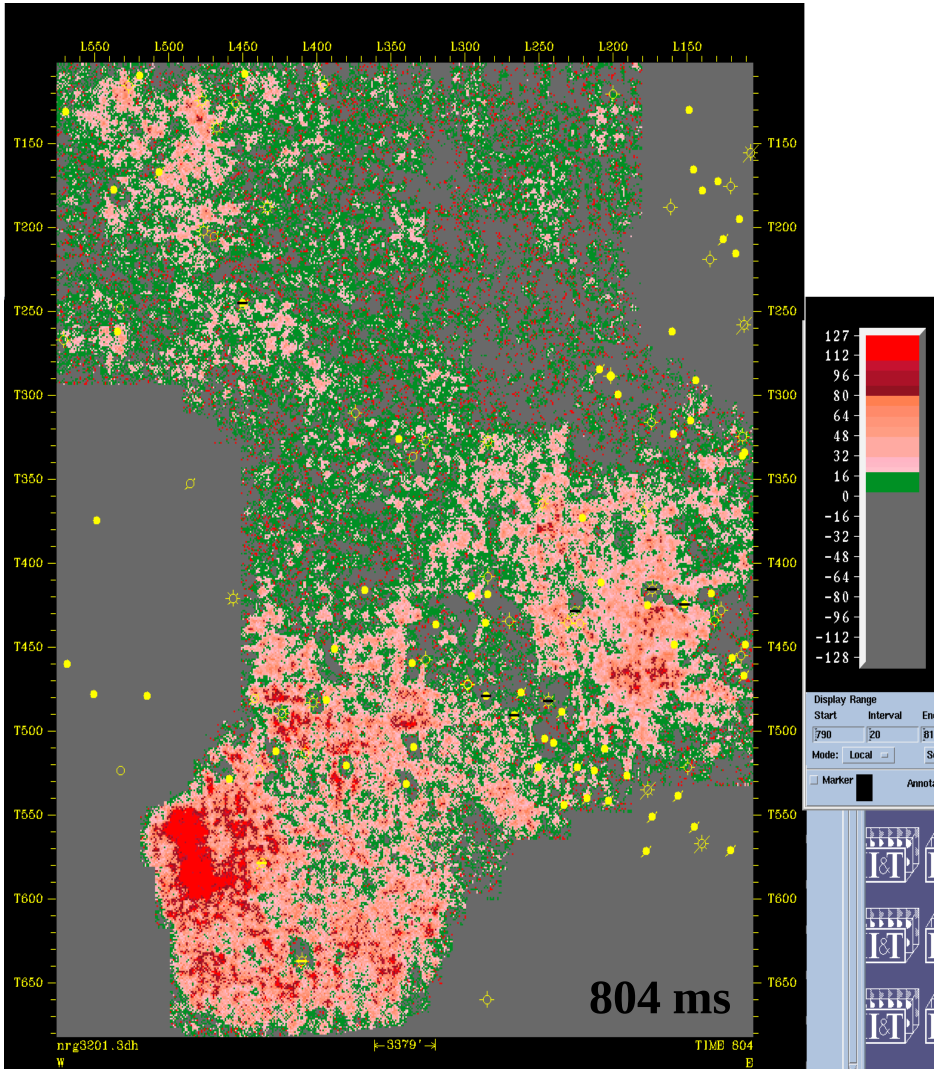
Shackelford County, TX



Pinnacle Reefs: Production Halos

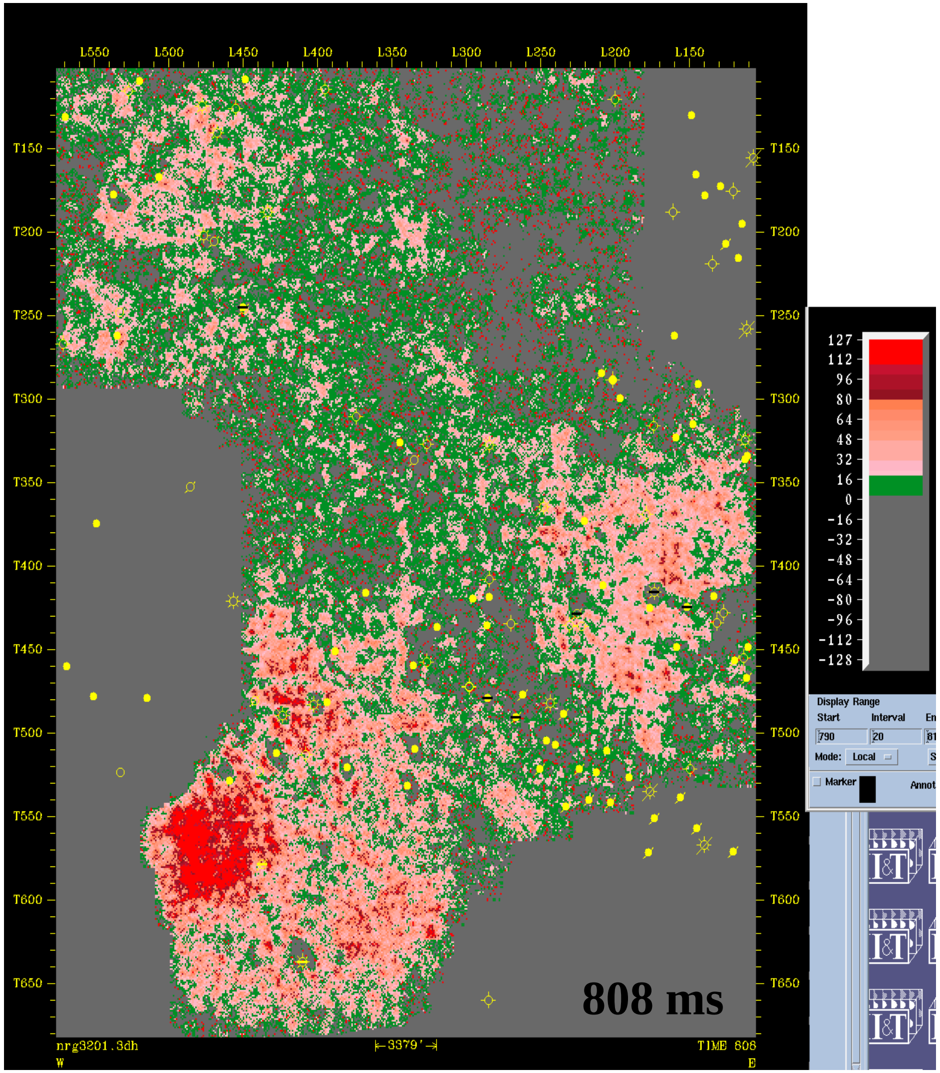
Shackelford County, TX

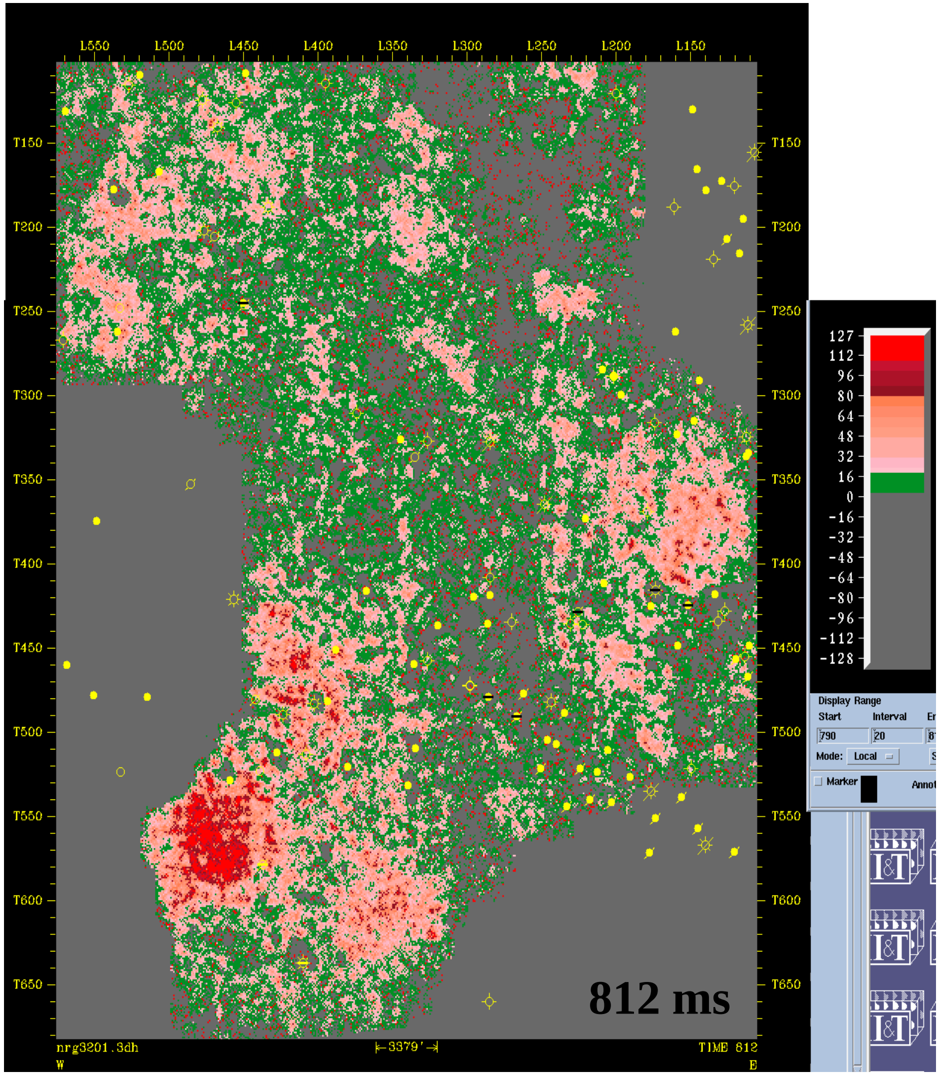




Pinnacle Reefs: Production Halos

Shackelford County, TX

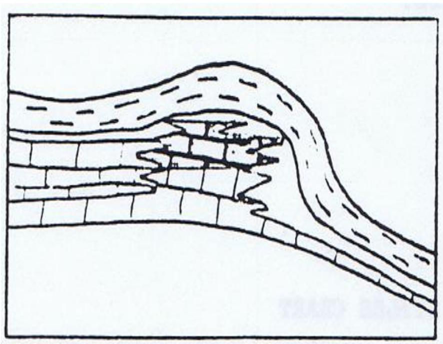




Barrier Reefs

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

<u>BARRIER REEFS</u> are large reefs separated from land by a lagoon. The Great Barrier Reef of of NE Australia is a modern day example of this type of reef. The flat, layered limestones are typically good reservoir, but the lagoonal micrite limestones are not. Of course, there can be later porosity reversals due to later recrystallizations, solution vugs, and dolomitization. Reefs form the traps for many of the oil fields in Alberta Canada, including the famous Leduc Reef with fist sized pores.

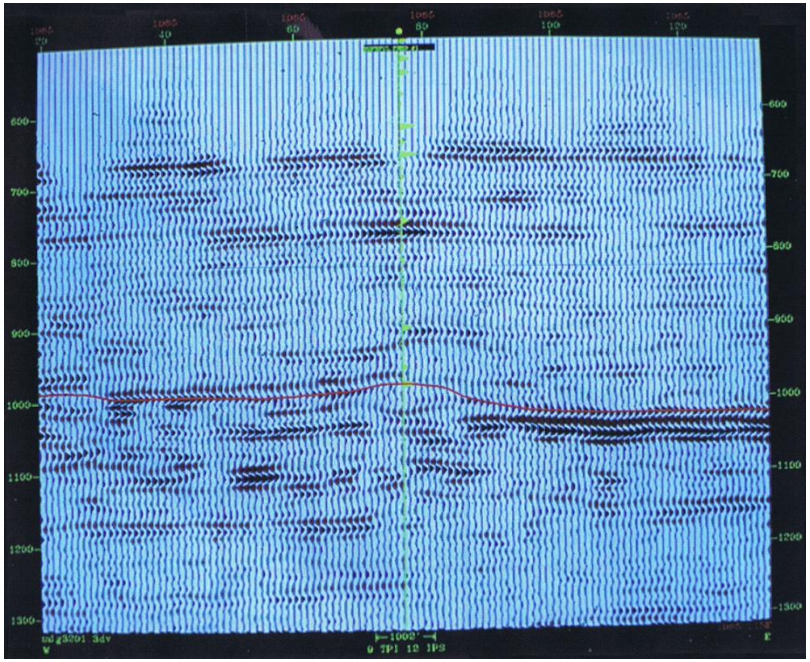


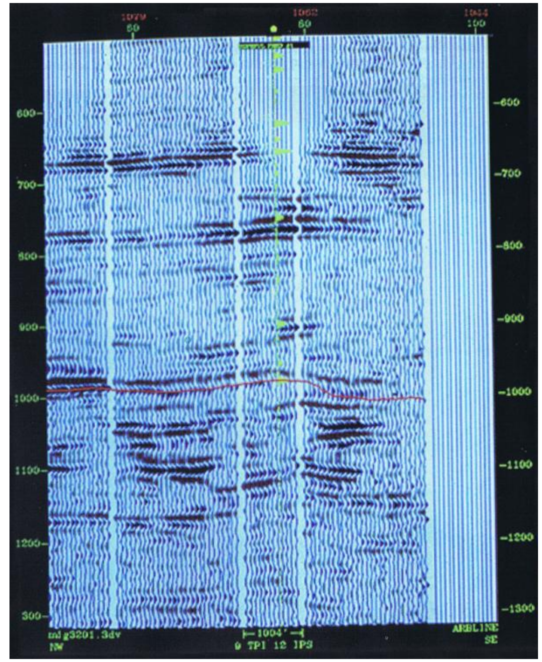
GENERALIZED CROSS-SECTION

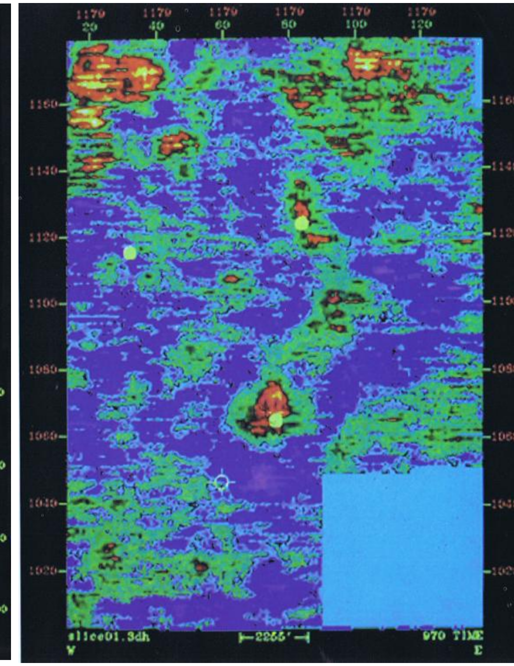
The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

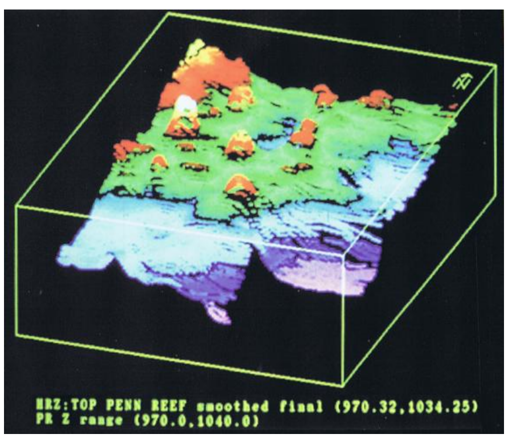
1. Interpret (pick and map) as many horizons as necessary to identify anomalous material buildup, and the lateral extent of that buildup.
2. Do detailed studies of the reflector characteristics, including: filtering, attribute studies, wavelet processing, etc. to determine the extent of the framework based limestones and the beginning of the tight micrite limestones. Detailed studies of wave form changes can be related to hydrocarbon fill, facies changes from bedded limestones to coral reef carbonates to lime sands to argillaceous limestones to course-grained dolomites. Of course, seismic can not specify all lithologies yet.
3. Extract amplitudes in order to study spatial variations of the reflection strength. As with pinnacle reefs and bioherms, time-slice or paleo-time-slice sections can show the areal extent of anomalies of interest.

Pennsylvanian Reef Interpretation
Scurry County, TX





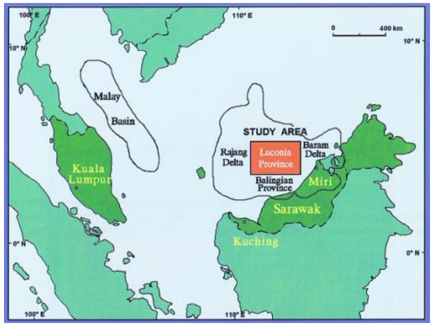


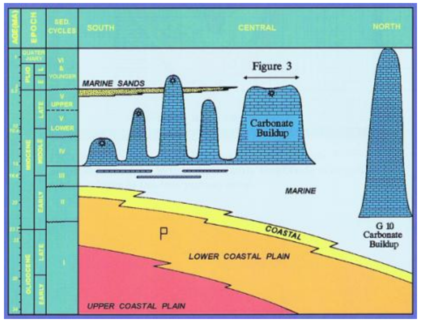


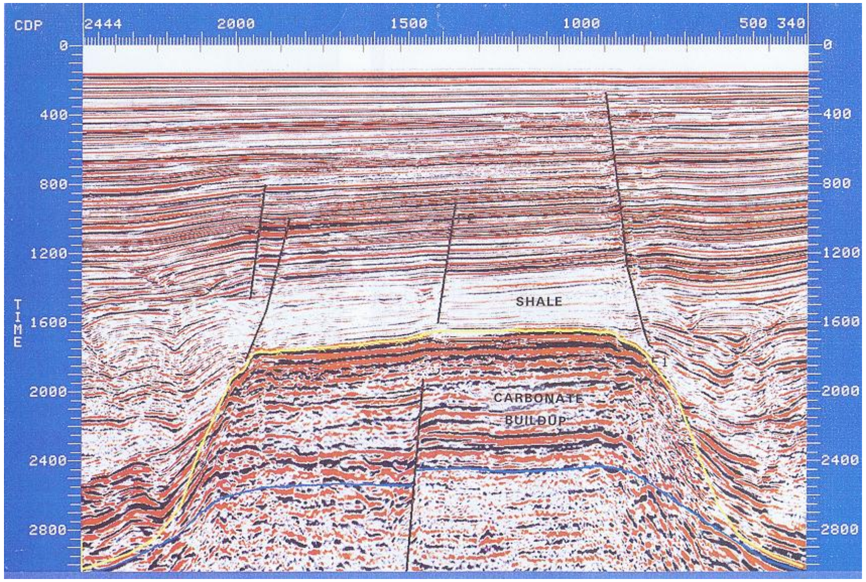
Jumper and Pardue in **Application of 3-D Seismic Data to Exploration and Production**, pages 157-159, data released by HAT Oil and Gas and Paladin Petroleum from Scurry County, TX, and were acquired and processed by Dawson Geophysical Company.

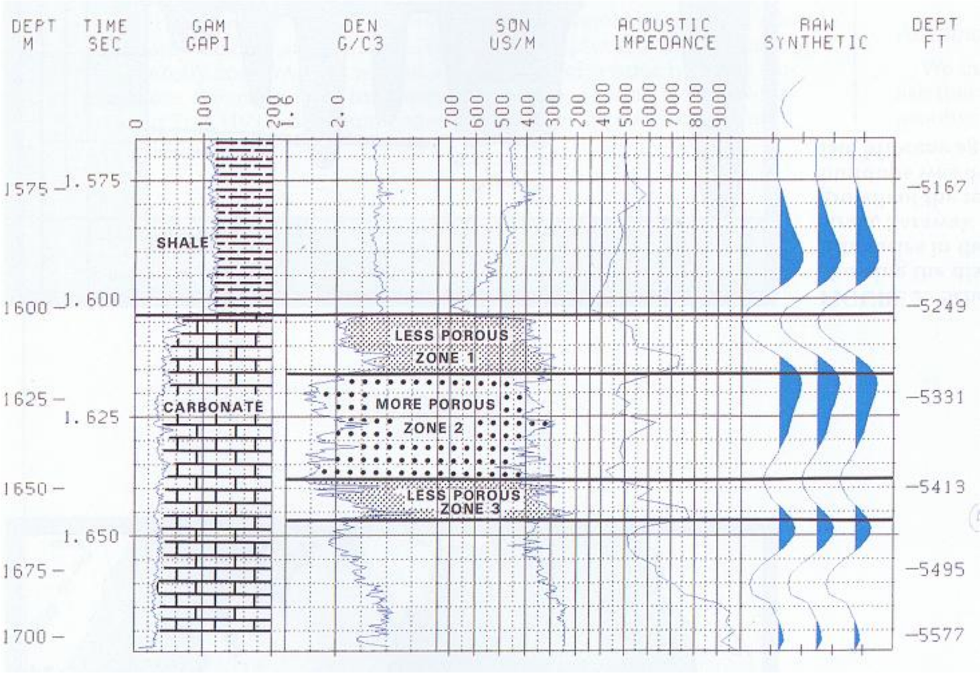
Quantitative Analysis of Seismic Reflections

Offshore Malaysia





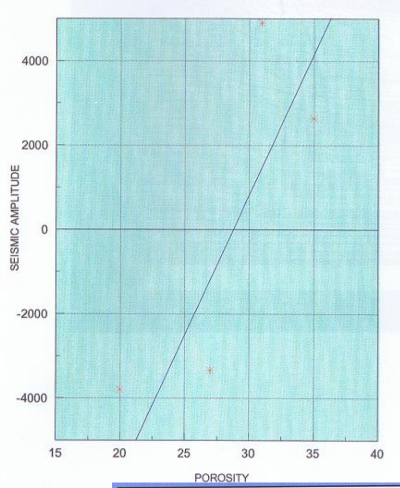




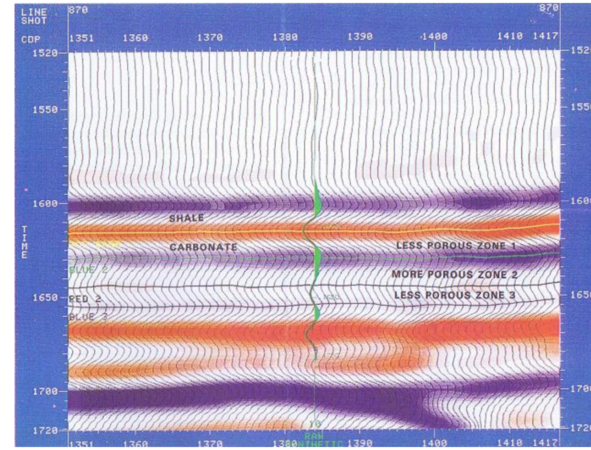
Ng Tong San and Marzuki Mohamad in **Application of 3-D Seismic Data to Exploration and Production**, pages 221-223, data from Petronas in Offshore Malaysia.

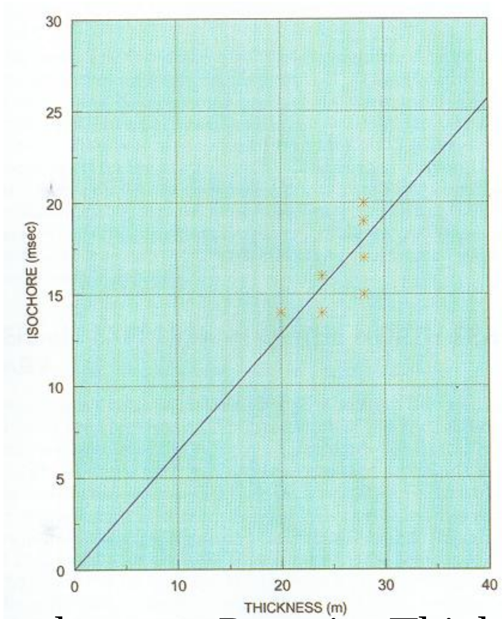
Quantitative Analysis of Seismic Reflections

Offshore Malaysia

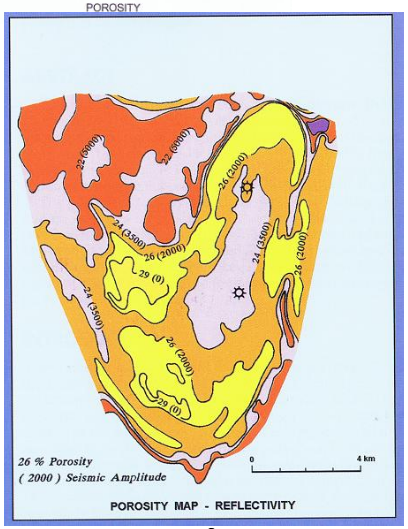


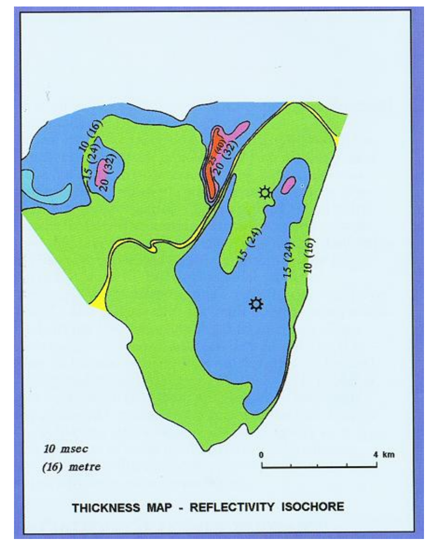
Amplitude vs. Porosity





Isochore vs. Porosity Thickness





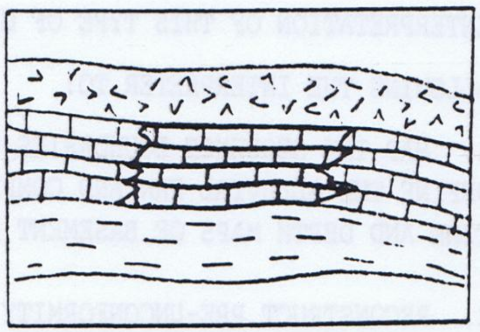
Porosity Map from Seismic Amplitude Map. Thickness Map from Isochore Map.

Ng Tong San and Marzuki Mohamad in **Application of 3-D Seismic Data to Exploration and Production**, pages 221-223, data from Petronas in Offshore Malaysia.

Primary and Secondary Dolomite

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

PRIMARY and SECONDARY DOLOMITE reservoirs are formed by the alteration of limestone in those areas beyond the tides immediately after deposition. These traps are often overlaid by a salt layer. Many of these traps can be located along basin flanks due to changing water levels.



GENERALIZED CROSS-SECTIONS

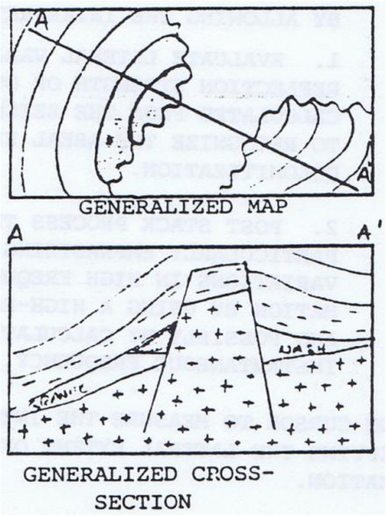
The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

1. Evaluate lateral variations in reflection strength or other attributes calculated from the seismic to attempt to recognize the areal extent of dolomitization.
2. Post stack process the data, particularly emphasizing lateral variations in high frequency information by using a high-pass filter, and possibly by calculating the instantaneous frequency.
3. Use horizon flattening and the location of the curser to measure the interval time differences along a layer, as a tool in identifying the lateral extent of overlaying salt layers which might have affected dolomitization.
4. Work back and forth between map and section displays to build trend maps and accurately evaluate the areal extent of anomalies of interest.

Granite Wash

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

A GRAITE WASH forms from weathering of a granite basement, such as in an alluvial fan formed at the mouth of a canyon cut through a granitic uplift. These types of granitic washes can be studied today in the basin and range province of the Rocky Mountains, where they cover the flanks of buried granite mountains and hills. Hydrocarbons come from source rocks deposited deeper in the basin. In the general example below, the basin to the southeast does not have source rocks at depth.

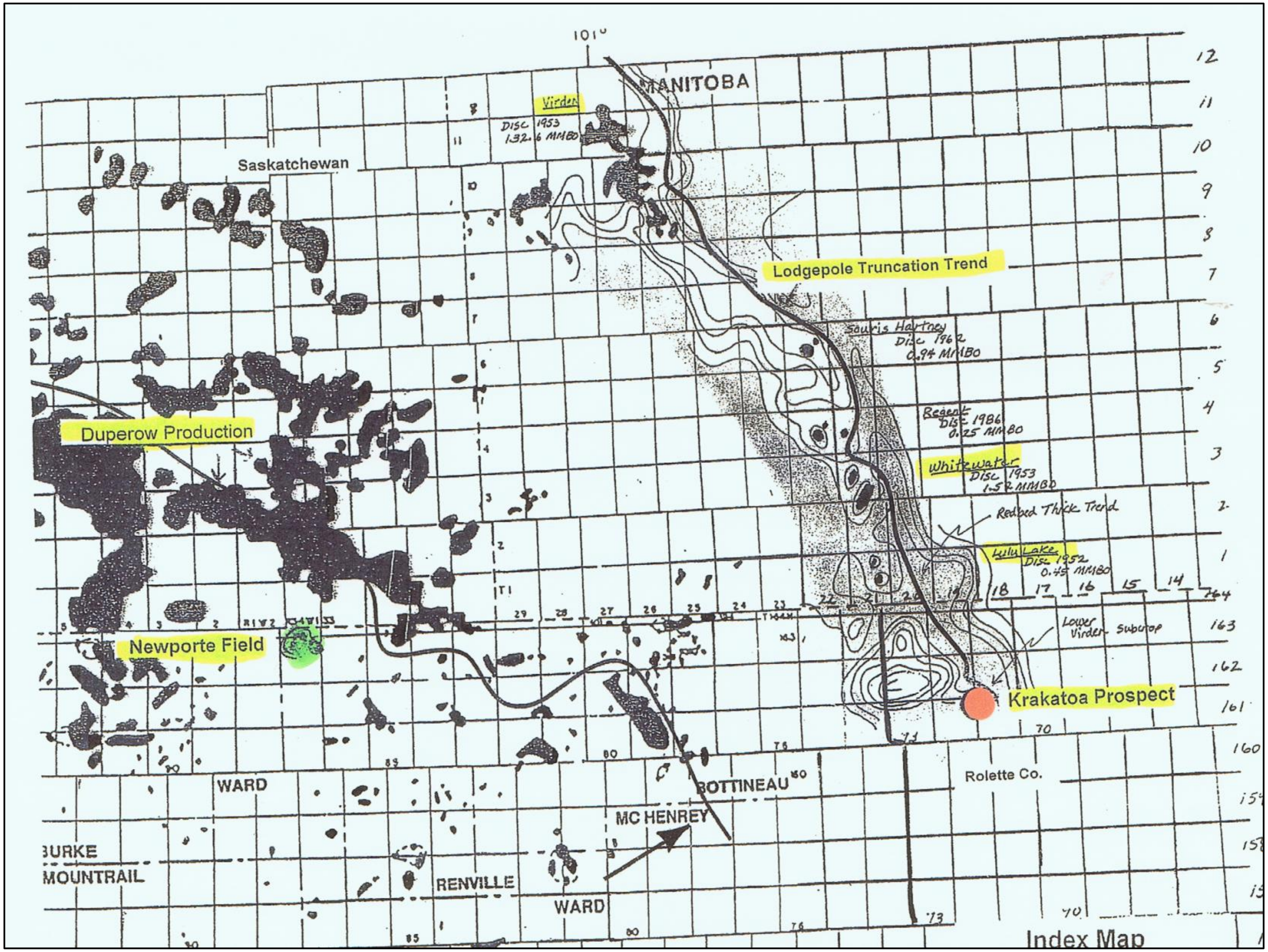


The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

1. Map the sequence boundaries defining the alluvial fan and compare them to time and depth maps of basement reflector(s).
2. Reconstruct pre-unconformity geology by flattening basement horizons or using the polygonal fault correlation window. This paleogeologic picture can be used as a basis for determining the origins of a supposed granitic wash.
3. Evaluate the potential for downdip source rocks by using the arbitrary line option in 3-D surveys and zig-zagging to critical source basins with a 2-D survey.
4. Work back and forth between the horizon map and the sections to build an accurate geologic picture of the study area.

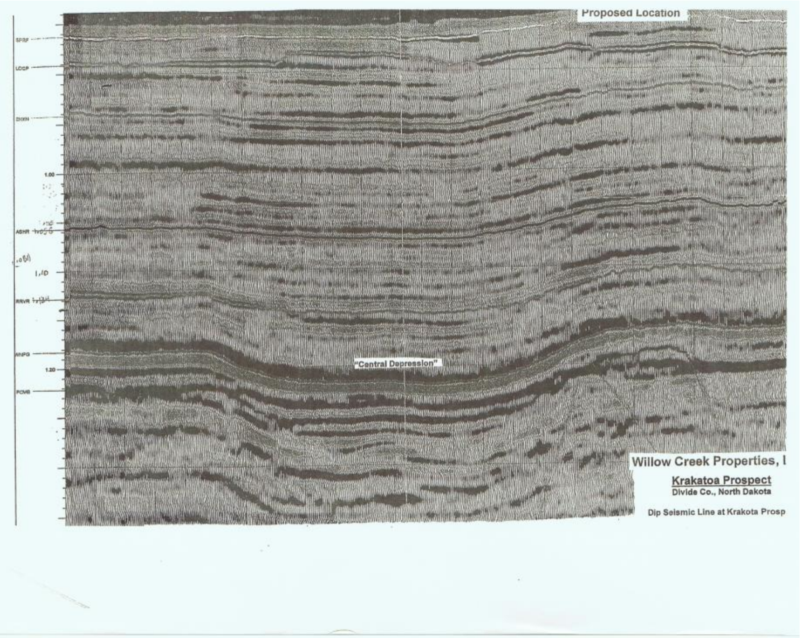
Krakatoa, Meteor Impact Crater?

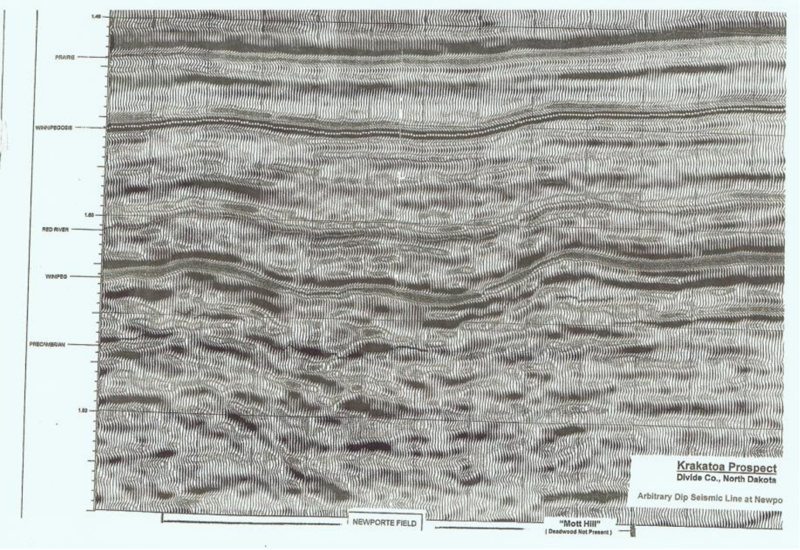
North Dakota

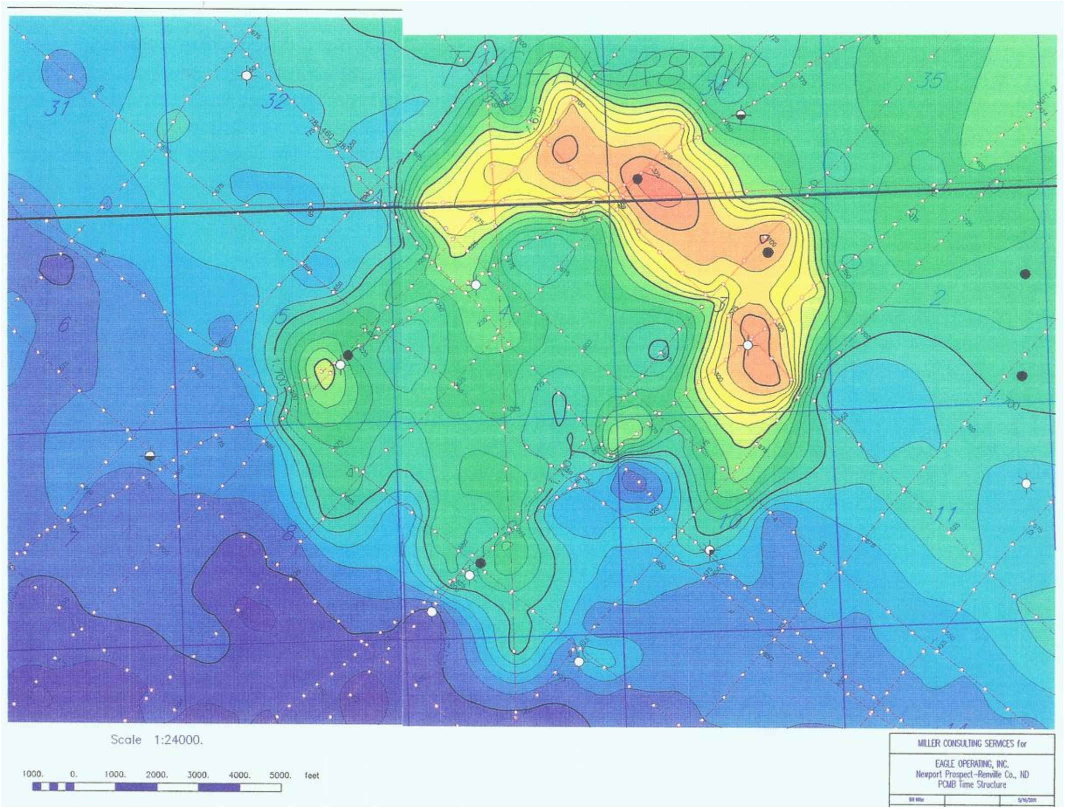


Krakatoa, Meteor Impact Crater?

North Dakota

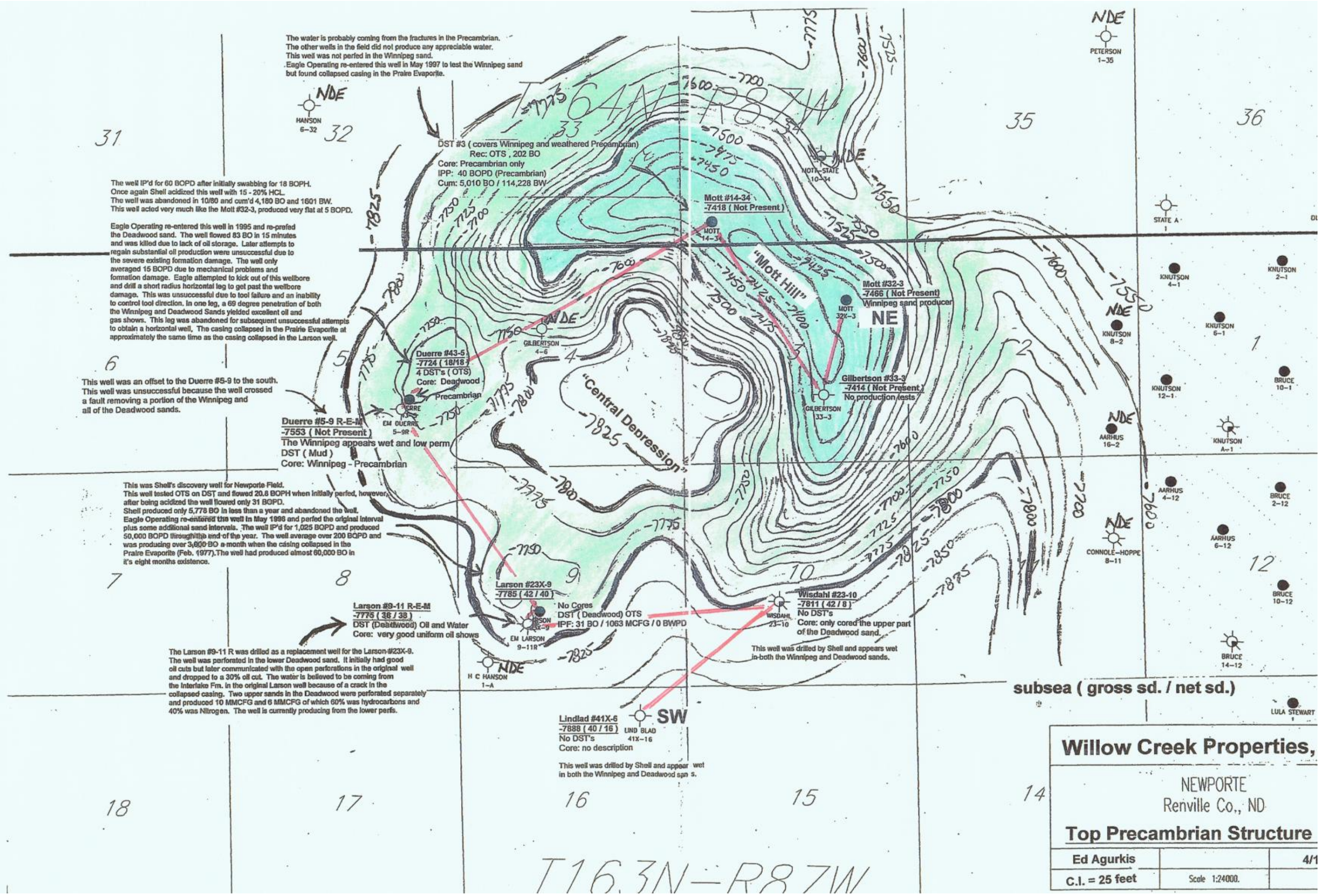






Krakatoa, Meteor Impact Crater?

North Dakota



Buttress or Onlap Sands

Tectonics / Basement	Horizontal Compression	Differential Vertical	Horizontal Extension	Regional or Basin Subsidence	Regional Upward
Detached	Thrust	Domes	Growth	Collapse	Dip & Fault
Involved	Reverse	Drape	Horst & Graben	Recumbent Fold	Arch
Weak	Strike-Slip	Decollement	Allochthonous	Transgressive Sand	Differential Compaction

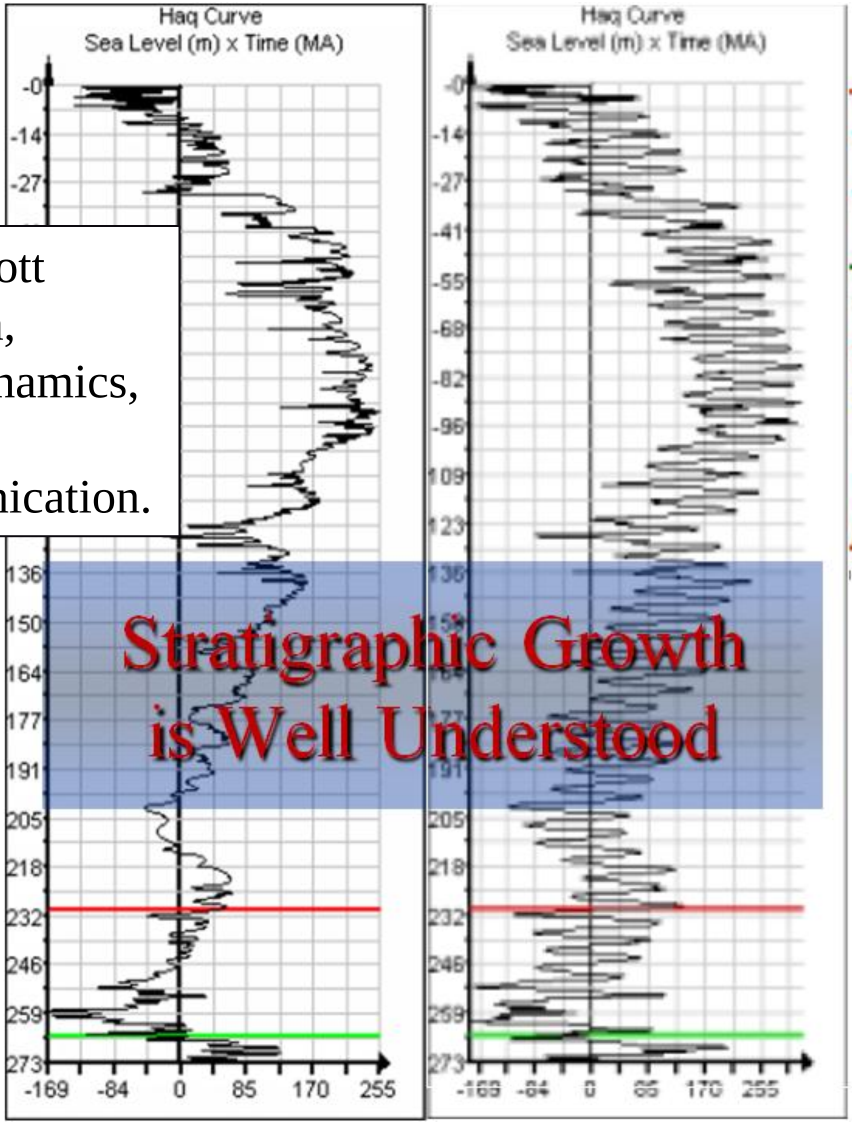
BUTTRESS or ONLAP SANDS are beach sands deposited on an unconformity surface as the sea level rises. There can be numerous of these sands along a single unconformity. This type of hydrocarbon trap can be as geographically widespread as angular unconformities.

The Interactive environment can aid the interpretation of this type of geology by allowing the interpreter to:

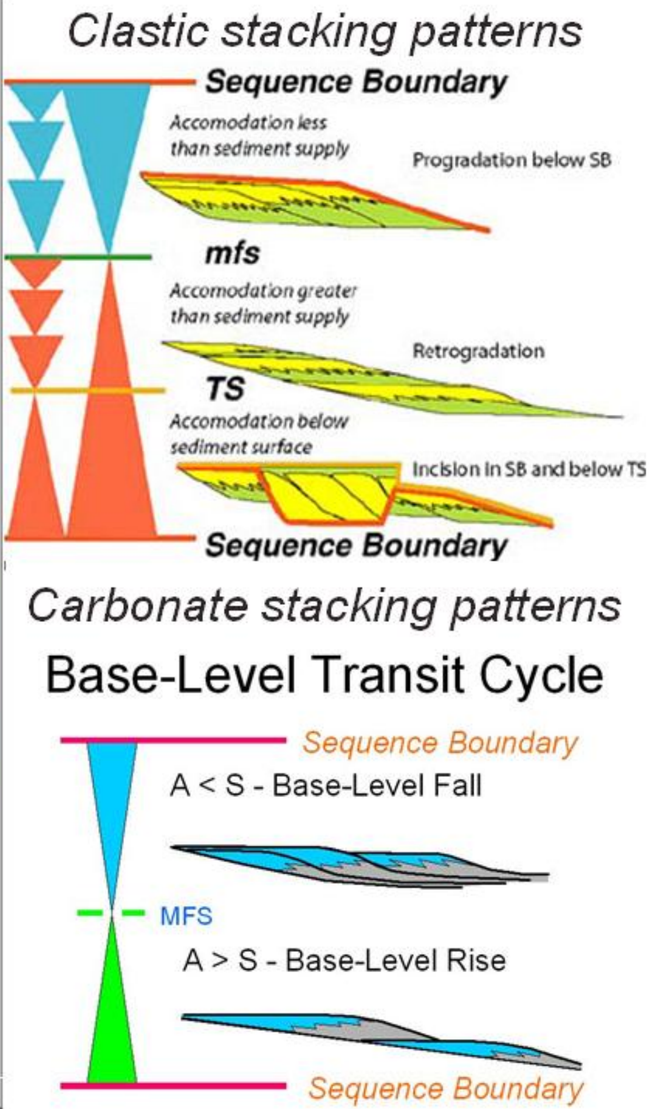
1. Identify and mark different seismic sequence boundaries by creating unique horizons for each boundary.
2. Do detailed study of the reflection characteristics of onlapping sequences of sand shales. Wiggle trace display options allow detail evaluation of the seismic waveform, and, of course, these wiggle traces can be overlain on information intensive variable density sections.
3. Do amplitude extraction at the unconformity horizon, showing variations in seismic reflection energy associated with different types of onlapping sands and shales.

3. Study standard direct hydrocarbon indicator characteristics. These include bright spots (direct hydrocarbon indicators), phase reversals at bright spot boundaries, possibly frequency absorption, amplitude variations with offset, flat spots associated with gas/water contacts, velocity push-downs, etc.

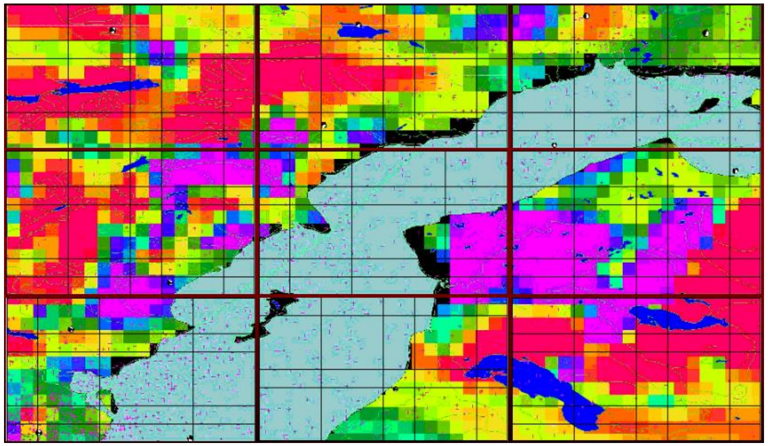
Stratigraphic Models



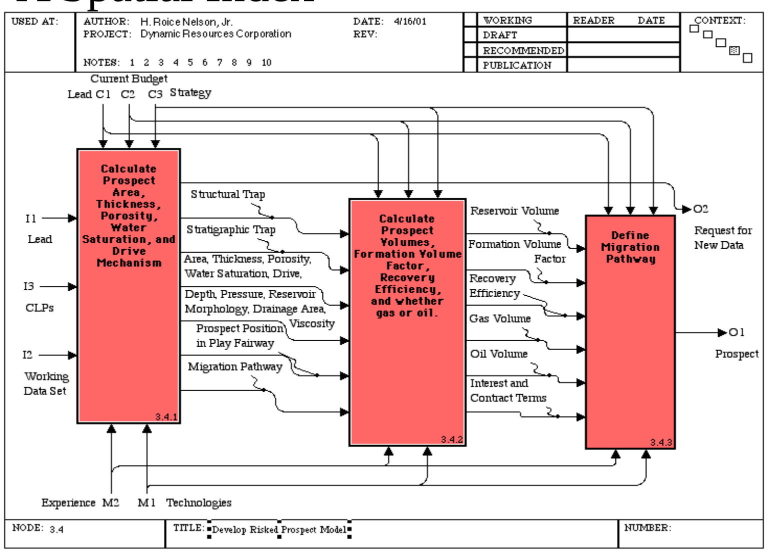
From Scott Bowman, PetroDynamics, Personal Communication.



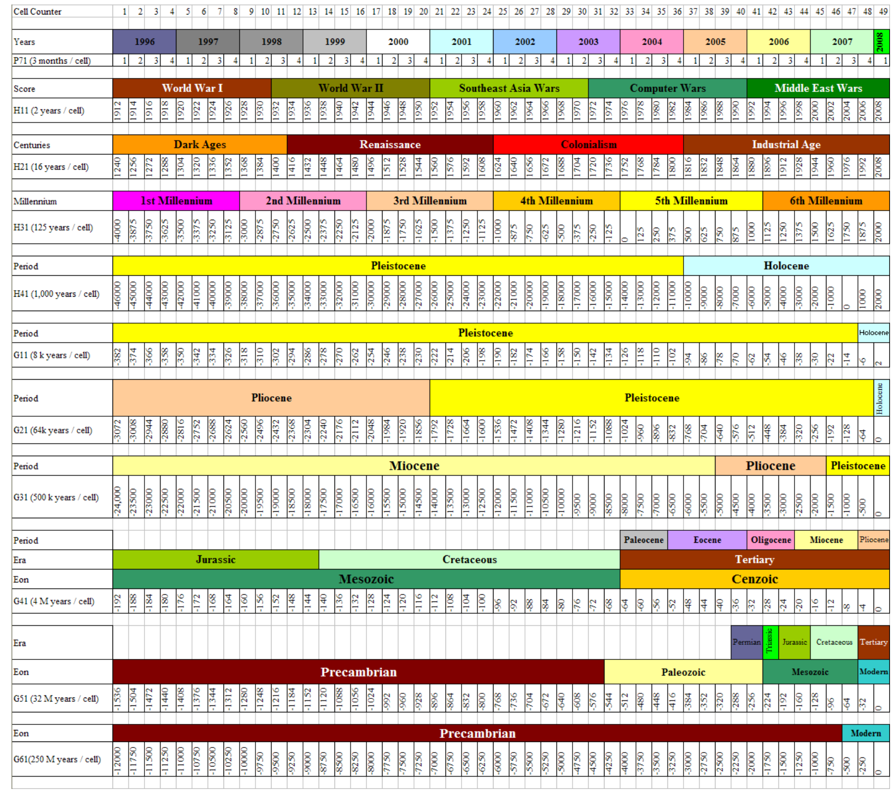
Indexing: the Key to Integrating Other Data



A Spatial Index



A Process Index



A Temporal Index

A Data Type Index

Indexing: A More Detailed Workflow

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Reference 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7		1 2 3 4
A1	Manage Assets	
A2	Acquire Assets	
A3	Enhance Assets	
A31	Explore and Produce	
A311	Explore	
A3111	Build Working Data Set	
A3112	Develop Geologic Model for an Economic Prospect with Acceptable Risk	
A31121	Build Geologic Model	
A311211	Determine Customer Requirements	
A311212	Determine Workplan to Improve Conceptual Geologic Model	
A311213	Quality Control Data for Interpretation	
A311214	Implement Workplan for Improvement Conceptual Geologic Model	
A3112141	Determine Structural and Stratigraphic Elements	
A31121411	Interpret Seismic Data	
A311214111	Determine Customer Requirements	
A311214112	Determine Workplan for Interpretation	
A3112141121	Generate Interpretation Options	
A31121411211	Select Seismic Interpretation Approach	
A311214112111	Select Technique for Determining Structure	
A3112141121111	Select Technique for Determining Terminations	
A3112141121112	Select Technique for Determining Faults	
A3112141121113	Select Technique for Determining Horizons	
A311214112112	Determine Technique for Determining Litho-Stratigraphy	
A3112141121121	Select Technique for Determining Stratigraphy	
A3112141121122	Select Technique for Determining Lithology	
A311214112113	Determine Technique for Determining Fluids	
A31121411212	Select Data To Be Used	
A311214112121	Select Geological Data	
A311214112122	Select 2-D Seismic Data	
A311214112123	Select 3-D Seismic Data	
A311214112124	Select Other Geophysical Data	
A31121411213	Select Resource Options	
A311214112131	Select Interpretors	
A311214112132	Select Manual Interpretation Tools	
A311214112133	Select Interactive Interpretation Tools	
A311214112134	Select Support Staff	
A31121411214	Select Deliverable Option	
A311214112141	Select Media for Transferring Interpretation Results	
A311214112142	Select Review Options	
A311214112143	Select Project Documentation Options	
A311214112144	Select Final Report Format	
A3112141122	Evaluate Interpretation Options	
A3112141123	Determine Constraints	
A31121411231	Determine Time Constraints	
A31121411232	Determine Budget Constraints	
A31121411233	Determine Resource Constraints	
A31121411234	Determine Skill Constraints	
A3112141124	Select Optimal Interpretation Option	

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Reference 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7		1 2 3 4
A311214113	Prepare Data for Seismic Interpretation	
A3112141131	Gather Background Information	
A31121411311	Prepare Data for Manual Interpretation	
A31121411312	Prepare Data for Loading onto Interactive System	
A31121411313	Load Data on Interactive System	
A31121411314	Identify Need for Post Stack Processing	
A3112141132	Build Geological Project Data Base	
A31121411321	Prepare Data for Manual Interpretation	
A31121411322	Prepare Data for Loading onto Interactive System	
A31121411323	Load Data on Interactive System	
A31121411324	Identify Need for Data Refinement	
A3112141133	Build Seismic Project Data Base	
A31121411331	Prepare Data for Manual Interpretation	
A31121411332	Prepare Data for Loading onto Interactive System	
A31121411333	Load Data on Interactive System	
A31121411334	Identify Need for Post Stack Processing	
A3112141134	Build Other Geophysical Data Base	
A31121411341	Prepare Data for Manual Interpretation	
A31121411342	Prepare Data for Loading onto Interactive System	
A31121411343	Load Data on Interactive System	
A31121411344	Identify Need for Further Geophysical Data Refinement	
A3112141135	Select Project Datum	

Indexing: A More Detailed Workflow

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Reference 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7		1	2	3	4
A311214114	Perform Seismic Interpretation				
A3112141141	Delineate Horizons and Faults in Time Domain				
A31121411411	Tie well log synthetics to seismic				
A311214114111	Build Depth to Time Transform				
A3112141141111	Extract Wavelet				
A3112141141112	Build raw Synthetic Seismogram				
A31121411411121	Prepare Logs				
A31121411411122	Display Synthetic				
A31121411411123	Overlay Synthetic on Seismic				
A31121411411124	Adjust Synthetic				
A311214114112	Time Convert Well Logs and Data				
A31121411412	Determine Spatial Locations of Horizons and Terminations				
A311214114121	Post Tops on Seismic Displays				
A3112141141211	Display Seismic Section between Well Control				
A3112141141212	Post Tops				
A3112141141213	Identify Mis-ties between wells				
A3112141141214	Determine Cost Justification for Correction of Mis-ties				
A31121411412141	Determine Acceptable Uncertainty				
A31121411412142	Verify ties within Specs				
A31121411412143	Identify Source of Mis-tie				
A311214114121431	Check Display Accuracy				
A311214114121432	Identify Inconsistent Well Picks				
A311214114121433	Identify Inconsistent Velocities				
A311214114121434	Identify Static Busts				
A31121411412144	Identify Cost to Resolve Mis-ties				
A311214114122	Pick Horizons on the Seismic				
A3112141141221	Determine Volume of Interest				
A3112141141222	Pick Horizon Framework				
A3112141141223	Make Horizon picks on Framework				
A3112141141224	Interpolate and Extrapolate Horizons				
A311214114123	Locate Terminations				
A31121411413	Pick and Correlate Faults				
A311214114131	Pick Fault Segments				
A3112141141311	Pick Faults in Cross Section				
A3112141141312	Pick Faults in Map View				
A3112141141313	Pick Faults from Time Slices				
A311214114132	Correlate unassigned fault segments				
A3112141141321	Correlate Faults in Cross Section				
A3112141141322	Correlate Faults in Map View				
A3112141141323	Correlate Faults in Time Slices				
A3112141141324	Reconcile Faults				
A3112141142	Convert to Depth				

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Reference 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7		1	2	3	4
A3112141143	Determine Lithologies and Facies				
A31121411431	Prepare known Lithology and Facies information				
A31121411432	Determine Seismic Facies				
A311214114321	Identify Appropriate Interval				
A311214114322	Characterize Facies from Seismic Attributes				
A311214114323	Perform Seismic Facies Analysis				
A31121411433	Determine Correlation between Lithologies and Facies and Seismic				
A311214114331	Determine Seismic Facies by Ray Tracing				
A311214114332	Determine Seismic Facies by Finite Difference Seismic Modeling				
A311214114333	Determine Seismic Facies by Full Wave Equation Seismic Modeling				
A311214114334	Determine Seismic Facies by Performimg Physical Modeling				
A31121411434	Determine Locations of Seismic Facies				
A3112141144	Determine Fluids				
A31121411441	Prepare Known Fluids Information				
A31121411442	Determine Fluid Indicators				
A31121411443	Determine Seismic Response to Fluid				
A311214114431	Characterize Fluids from Seismic Attributes				
A311214114432	Determine Fluid Response by Ray Trace Seismic Modeling				
A311214114433	Determine Fluid Response by Finite Difference Seismic Modeling				
A311214114434	Determine Fluid Response by Full Wave Equation Seismic Modeling				
A311214114435	Determine Fluid Response by Performing Physical Modeling				
A31121411444	Determine Locations of Fluid Indicators				
A311214115	Perform Benchmark On Seismic Interpretation				
A311214116	Perform Lookback On Seismic Interpretation				
A31121412	Interpret Geochemical Property Data				
A31121413	Interpret Geologic Data				
A311214131	Interpret Well Info				
A311214132	Analyze Well Logs				
A311214133	Interpret Core Data				
A311214134	Interpret Paleontological Data				
A311214135	Interpret Surface Data				
A311214136	Interpret Remotely Sensed Data				
A31121414	Interpret Well Logs				
A311214141	Prepare and Pre-Process Well Logs				
A311214142	Define Environmental Conditions				
A311214143	Interpret Well Logs to Determine Petrophysical Parameters				
A311214144	Determine Rock Properties				

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Reference	1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7	1	2	3	4
A31121415	Interpret Sequence Stratigraphy				
A311214151	Determine Stratigraphic Ages				
A3112141511	Perform Biostratigraphic Analysis				
A31121415111	Acquire Fauna and Flora References				
A31121415112	Describe Fauna and Flora Species				
A31121415113	Acquire Biozone Reference				
A31121415114	Assign Samples to Established Biozonation				
A3112141512	Assign Absolute Ages				
A31121415121	Acquire Standard Chronostratigraphic Reference				
A31121415122	Assign Samples to Standard Chronostratigraphic Zonation				
A31121415123	Acquire Magneto- Chronostratigraphic Reference				
A31121415124	Relate Chrono standard to Magneto- Chronostratigrapic Zonation				
A31121415125	Assign Ages from Magneto- Chronostrat				
A311214152	Perform Bioenvironmental Analysis				
A3112141521	Describe Environmentally Significant Fauna and Flora Species				
A3112141522	Assign Samples to Established Paleoenviroments				
A3112141523	Point Count Flora and Fauna				
A3112141524	Acquire Reference to Assign Species to Paleoenvironments				
A3112141525	Acquire Fauna and Flora References				
A311214153	Distinguish Lithofacies				
A3112141531	Determine Vertical Changes in the Paleoenvironment				
A3112141532	Determine Vertical Grain Size Changes				
A3112141533	Determine Vertical Mineralogic Changes				
A311214154	Interpret Sequence Boundaries, Systems Tracts, Maximum Flooding				
A3112141541	Identify Candidates for Sequence Strat Components from Geologic				
A31121415411	Determine Environment				
A31121415412	Identify Intermontane Non-Marine Seq. Strat Components				
A31121415413	Identify Non-Marine Seq. Strat Components				
A31121415414	Identify Non-Marine to Neritic Seq. Strat Components				
A31121415415	Identify Bathyal and Abyssal Strat Components				
A3112141542	Identify Candidates for Sequence Strat Components from Seismic				
A31121415421	Determine Reflection Patterns				
A31121415422	Determine Sequence Boundaries				
A31121415423	Determine Maximum Flooding Surfaces				
A31121415424	Determine Systems Tracts				
A3112141543	Integrate Geologic and Seismic Interpretations				
A31121415431	Convert to Time Domain				
A31121415432	Project Geologic Derived Components on Seismic Data				
A31121415433	Reconcile Seismic and Geologic Seq. Components at Well Location				
A31121415434	Determine Spatial Distributions of Sequence Components				
A3112141544	Identify Inconsistencies				
A311214155	Distinguish Lateral Distribution of Lithology				
A3112141551	Calibrate Seismic Facies with Lithofacies Control				
A3112141552	Determine Areas of Similar Seismic Facies				
A3112141553	Distribute Lithofacies to Areas Controlled by Control Points				
A3112141554	Distribute Lithofacies to Areas Outside Control				
A31121415541	Identify Areas of Consistent Seismic Facies				
A31121415542	Select Lithofacies for Each Seismic Facies				
A31121415543	Assign Lithofacies to Areas of Consistent Seismic Facies				

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Reference	1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7	1	2	3	4
A31121416	Interpret Other Geophysical Data				
A311214161	Interpret Gravity Data				
A311214162	Interpret Magnetic Data				
A311214163	Interpret Electrical Data				
A311214164	Interpret Lightning Data				
A311214165	Interpret Satellite Data				
A311214166	Interpret Other Remote Geophysicsal Data				
A3112142	Integrate Interpretations and Update Earth Model				
A31121421	Integrate Structural Elements into Earth Model				
A31121422	Integrate Facies into Earth Model				
A311214221	Identify Distribution of Depositional Environments				
A311214222	Select Correlation Consistent with Depositional Environment				
A311214223	Assign Lithology and Facies				
A31121423	Integrate Lithologies into Earth Model				
A311214231	Identify Distribution of Depositional Environments				
A311214232	Select Correlation Consistent with Depositional Environment				
A311214233	Assign Lithology				
A31121424	Integrate Fluids into Earth Model				
A311214241	Identify Distribution of Trapping Environments				
A311214242	Select Correlation Consistent with Trapping Environment				
A311214243	Assign Locations of Fluids				
A3112143	Identify Inconsistencies in Interpretations				
A311215	Perform Benchmark on Model Building				
A311216	Perform Lookback on Model Building				

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Reference 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7		1	2	3	4
A311122	Determine Source, Seal, Trap, Timing and Reservoir				
A3111221	Develop Regional Perspective				
A31112211	Manage Data				
A31112212	Interpret Regional Data				
A311122121	Determine Regional Geometry				
A3111221211	Determine Chronostratigraphy				
A31112212111	Pick Boundaries from Seismic				
A31112212112	Pick Boundaries from Wells Logs				
A31112212113	Pick Boundaries from Lithology				
A31112212114	Cross Validate Boundaries				
A3111221212	Summarize Tectonic History				
A31112212121	Backstrip				
A31112212122	Determine Local Structural Elements (Faults, Ridges, etc)				
A31112212123	Determine Regional Tectonic Boundaries (Mega-Sequence Boundarie				
A31112212124	Summarize Tectonic History				
A3111221213	Reconstruct Basin in Time				
A31112212131	Determine Resolution Required				
A31112212132	Select Simulation Tool				
A31112212133	Perform Simulation				
A3111221214	Determine Depositional Setting and Paleobathymetry				
A311122122	Develop Regional Source Model				
A3111221221	Determine Direct Evidence of a Working Source System				
A31112212211	Check Historical Records for Seeps and Well Shows				
A31112212212	Check for Direct Seepage				
A31112212213	Analyse Fluid Samples from Seeps or Wells				
A3111221222	Determine the Stratigraphic and Areal Extent of the Source Rock				
A31112212221	Identify Potential Source Rocks				
A31112212222	Characterize Source Rock Facies				
A31112212223	Determine Areal Extent and Bulk Volume of Source Rocks				
A3111221223	Determine the Maturity of the Source Rocks				
A31112212231	Measure Maturity from Fluid or Source Rock Samples				
A31112212232	Model Maturity of Proposed Source Rock				
A3111221224	Determine the Hydrocarbon Charge				
A31112212241	Analyze Direct Evidence & Model to Determine Charge				
A31112212242	Analyze Source Rock & Model to Determine Charge				
A31112212243	Infer a Source Model to Determine Charge				
A3111221225	Determine the Model & Confidence in the Geologic Source Model				
A31112212251	Generate a Possible Regional Geologic Source Model				
A31112212252	Evaluate Alternative Source Models & Compare				
A31112212253	Determine a Range of Errors and Risk the Geologic Source Model				
A311122123	Develop Regional Seal Model				
A3111221232	Determine Presence of Facies that Would Seal Hydrocarbon Migrat				
A3111221233	Determine Area Extent of Effective Sealing Facies				
A3111221234	Combine Stratigraphic Position; Facies and Areal Extent of Seal				
A311122124	Develop Regional Reservoir Model				
A3111221241	Determine Presence of Facies that could reservoir Hydrocarbons				
A3111221242	Determine Areal Extent of Reservoir Facies				
A3111221243	Combine Stratigraphic Position, Facies and Areal extent of Poss				
A311122125	Combine Source, Seal & Reservoir Models				
A3111221251	Determine Range of Hydrocarbon Fill Possible in the Region				
A3111221252	Build a Regional Geology Model with Associate Risk and Uncertai				
A311122126	Check Internal Consistency				

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Reference 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7		1	2	3	4
A3112213	Evaluate Regional Economics				
A3112214	Assess Strategic Fit				
A3112215	Evaluate Viability using Performance Indicators				
A311222	Develop Play Fairway				
A3112221	Manage Data				
A3112222	Interpret Play Fairway				
A3112223	Evaluate Play Economics				
A3112224	Determine Viability Using Performance Indicators				
A311223	Generate Prospect				
A3112231	Manage Data				
A3112232	Interpret Prospect				
A31122321	Integrate Seismic and Well Information/Data				
A31122322	Identify Trapping Mechanisms				
A311223221	Determine Present Day Structure and Stratigraphic Closure				
A3112232211	Map Structural Contours on Reservoir Top				
A3112232212	Map Fault Planes within and bounding Prospect through the seal				
A3112232213	Map Diapir within and bounding Prospect through the seal and Re				
A3112232214	Map Lithofacies Changes bounding Reservoir				
A3112232215	Map Porosity Changes bounding Reservoir				
A3112232216	Combine Components to Determine 360° Closure				
A31122322161	Construct Time Structure Map with Faults, Diapirs and Pinchouts				
A31122322162	Construct Geologic Crossections in the Dip and Strike Direction				
A31122322163	Determine Prospect Closure				
A311223222	Determine Presence of Top Seal and Reservoir				
A311223223	Determine Migration Path and Timing from Source to Reservoir				
A3112232231	Define Trapping Mechanism				
A3112232232	Evaluate Migration of Hydrocarbons from Source to Trap				
A3112232233	Determine Effectivemenss of Trap for Type of Hydrocarbon				
A3112232234	Model History of Trap and Migration (Timing)				
A311223224	Convert Trapping Mechanism into Prospect				
A31122323	Calculate Prospect Volumes				
A31122324	Calculate Risked Prospect Model				
A3112233	Evaluate Prospect Economic Indicators				
A31122331	Estimate Production Forecasts				
A31122332	Estimate Capital Costs				
A31122333	Estimate Operating Costs				
A31122334	Calculate Economic Measures				
A31122335	Construct Decision Tree				
A31122336	Establish Development Plan				
A3112234	Determine Viability Using Performance Indicators				

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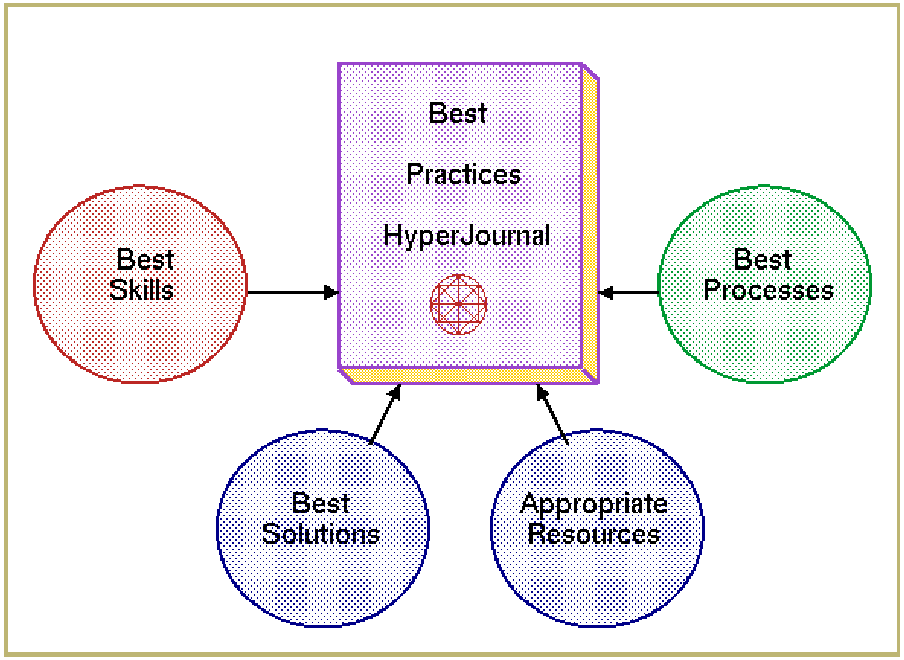
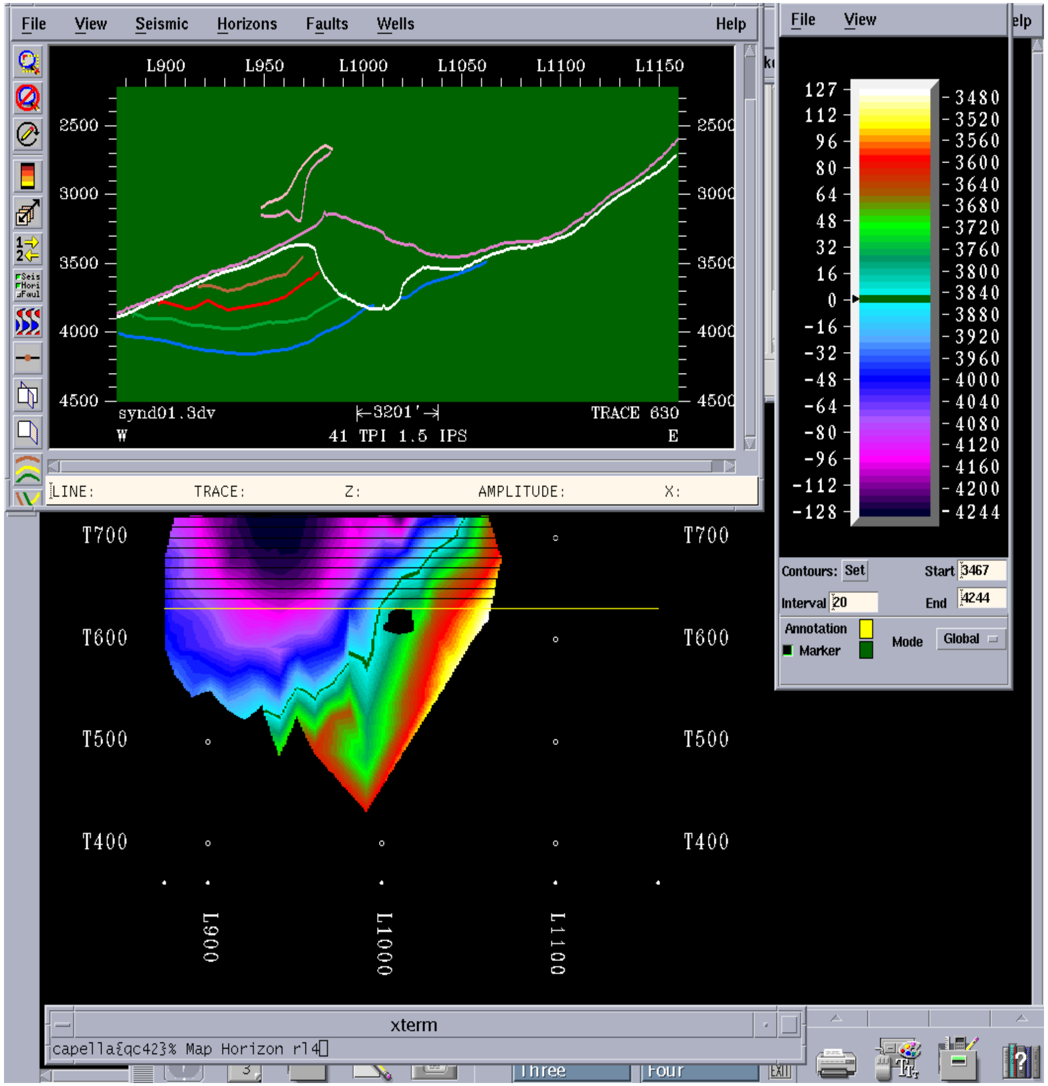
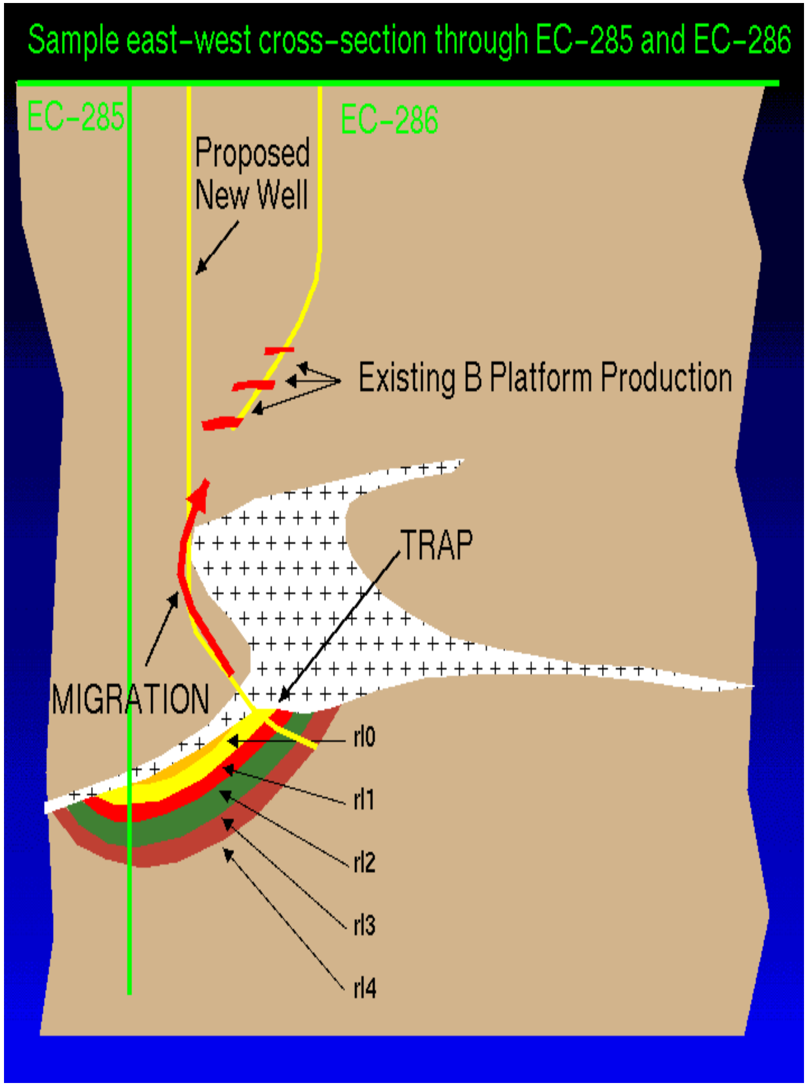
Reference	1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7
A3113	Acquire Acreage
A3114	Acquire Data
A31141	Determine Data Type Necessary for Request
A31142	Determine how to Acquire
A31143	Procure the Data
A311431	Generate Authorization for Expenditure for Acquisition of Propr
A311432	Purchase Data if Available Off the Shelf
A311433	Drill a Well Acquire a Seismic Survey Acqurie Misc. G&G Data
A3114331	Drill a Well
A3114332	Acquire a Seismic Survey
A31143321	Plan and Model a Seismic Survey
A31143322	Acquire the Raw Seismic Data
A31143323	Process the Seismic Data
A31143324	Determine Customer Requirements
A3114333	Acquire Mics. G&G Data
A3114334	Transfer Data to Information Management
A3115	Benchmark
A312	Develop
A3121	Build Working Data Set
A3122	Acquire Dynamic Data
A3123	Develop Reservoir
A3124	Benchmark Reservoir Development
A313	Exploit
A3131	Identify Exploitable Opportunities
A3132	Evaluate Exploitation Opportunities
A3133	Determine Viability Against Performance Indicators
A314	Produce
A32	Refine
A33	Market and Sell

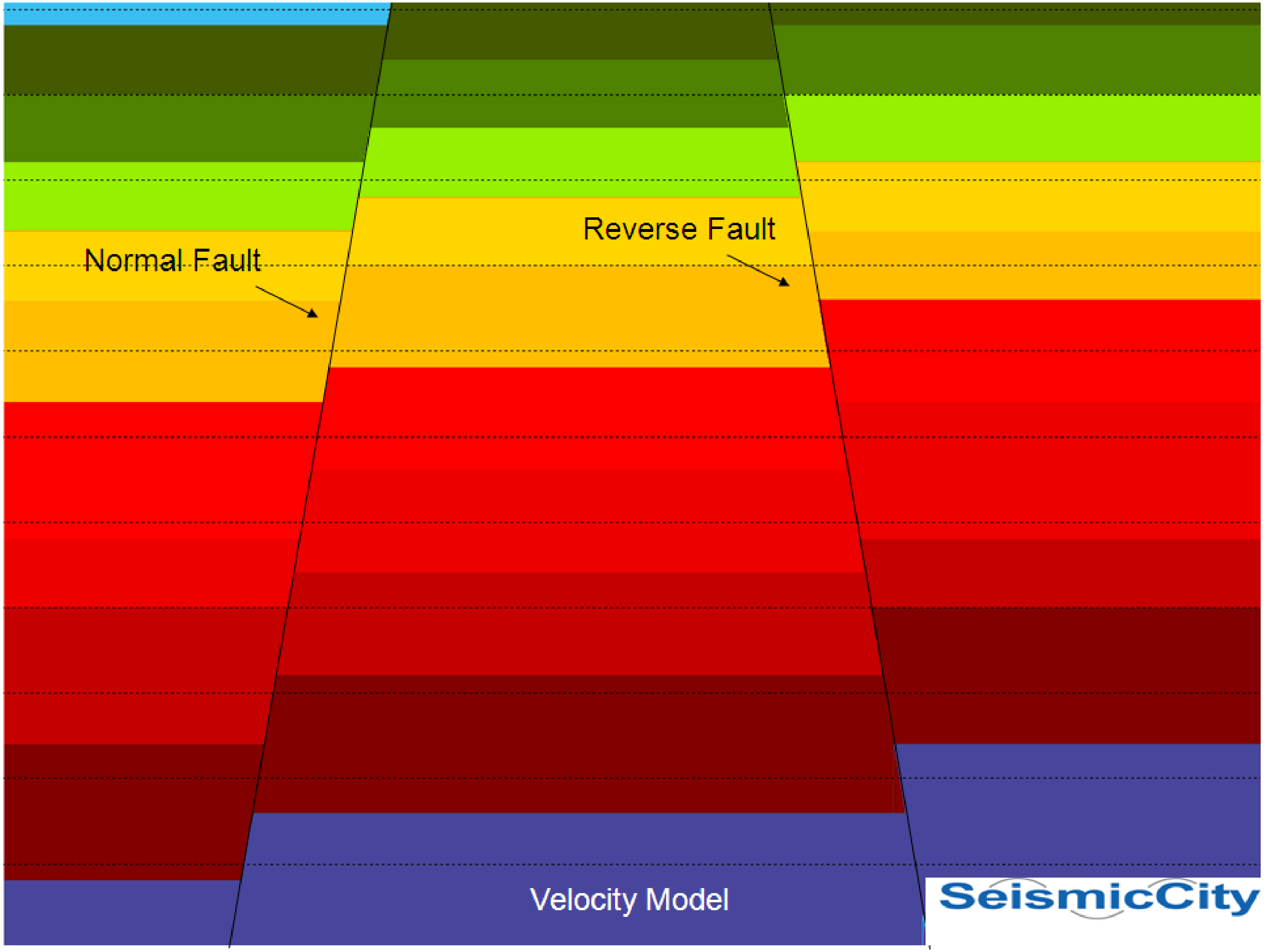


Salt Interpretation

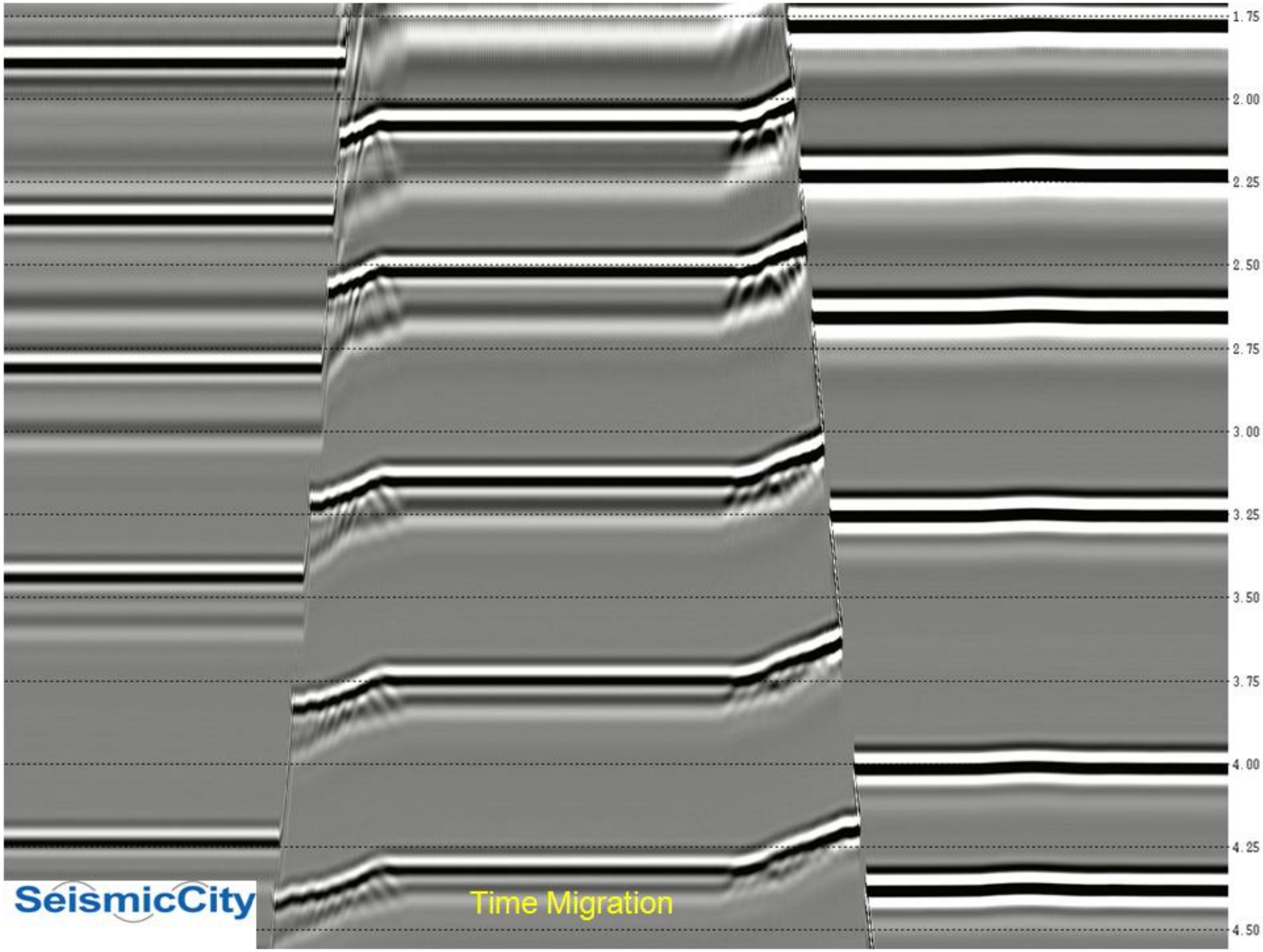




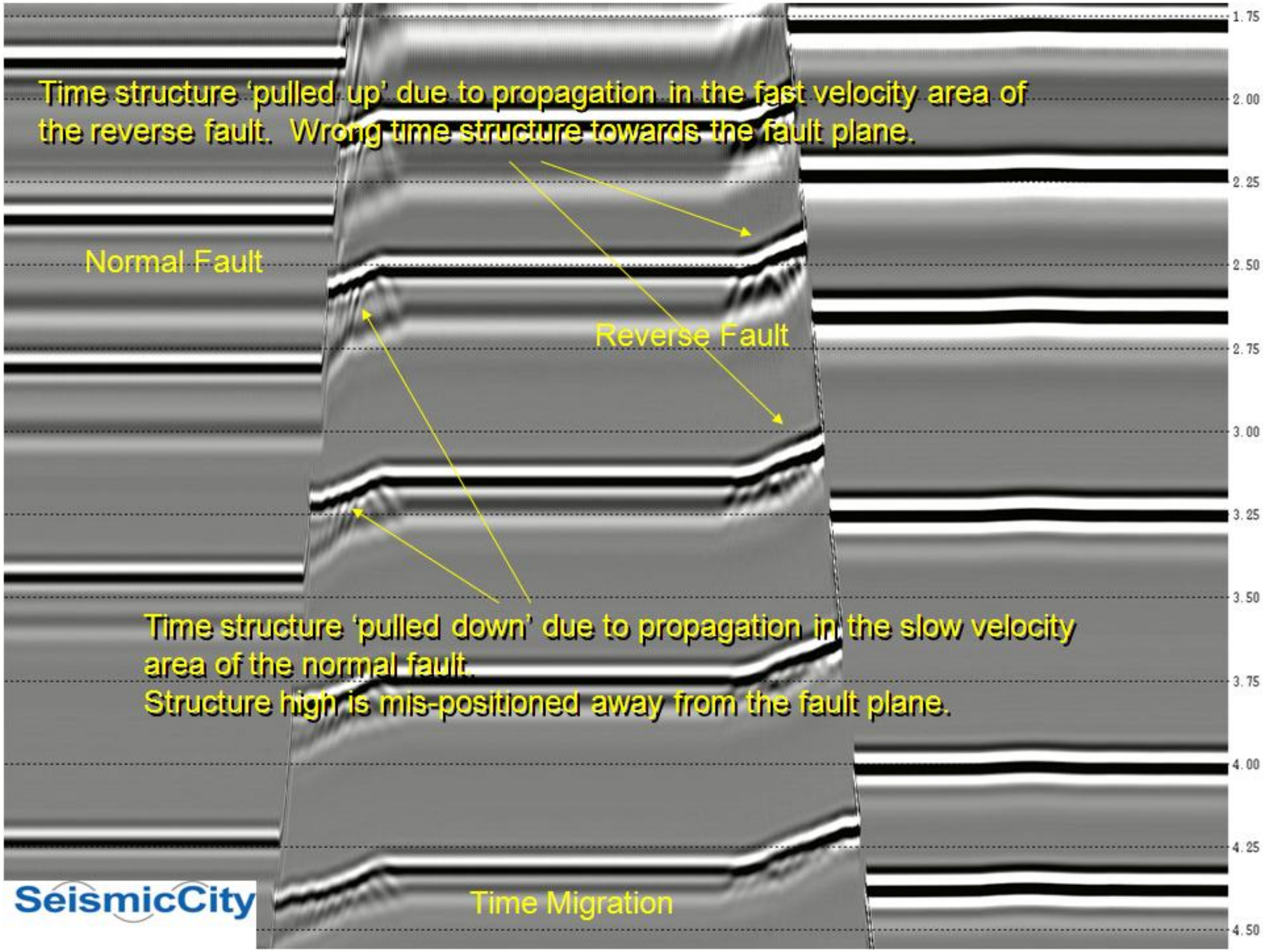
Fault Shadow Modeling



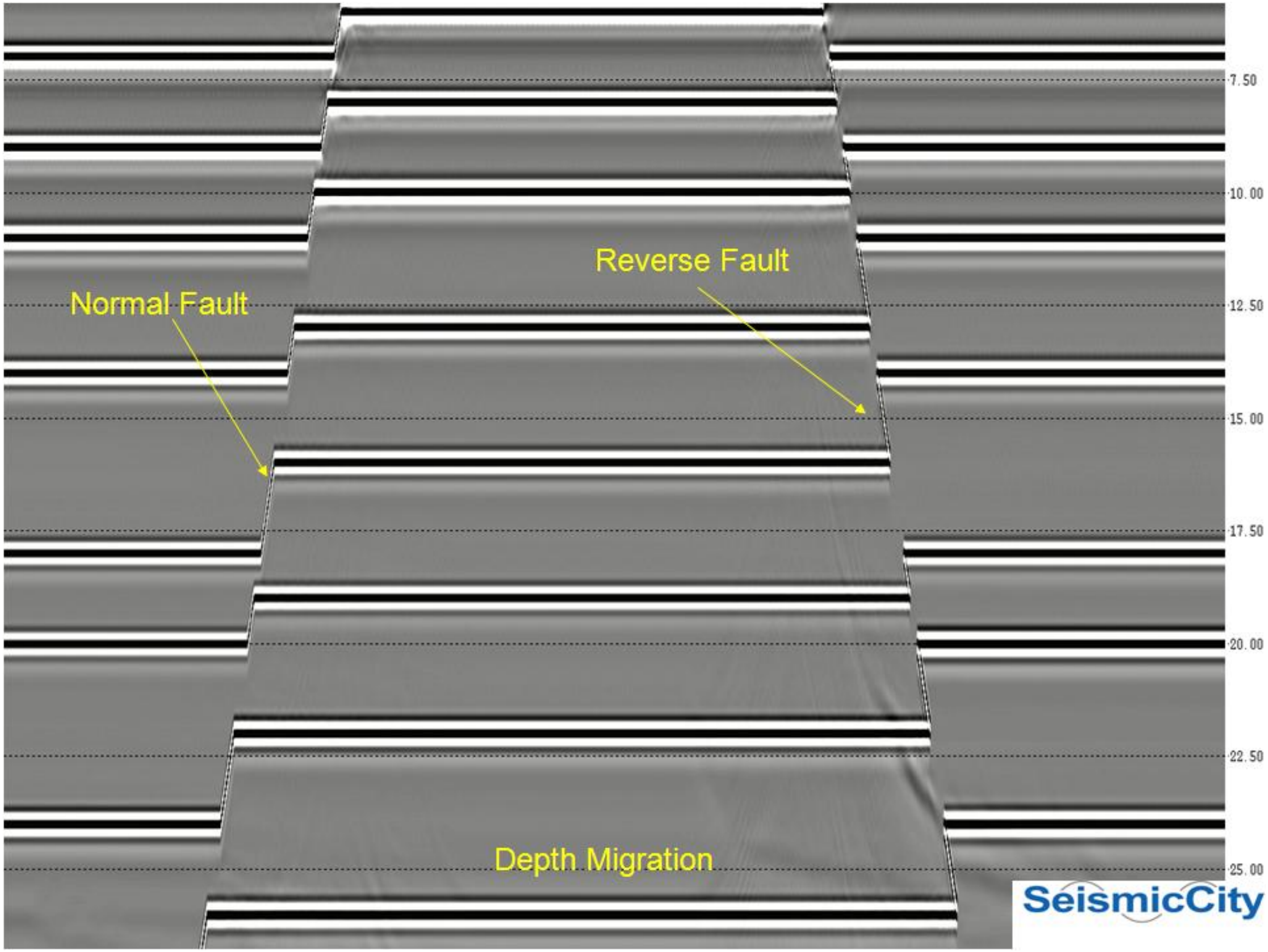
Fault Shadow Modeling



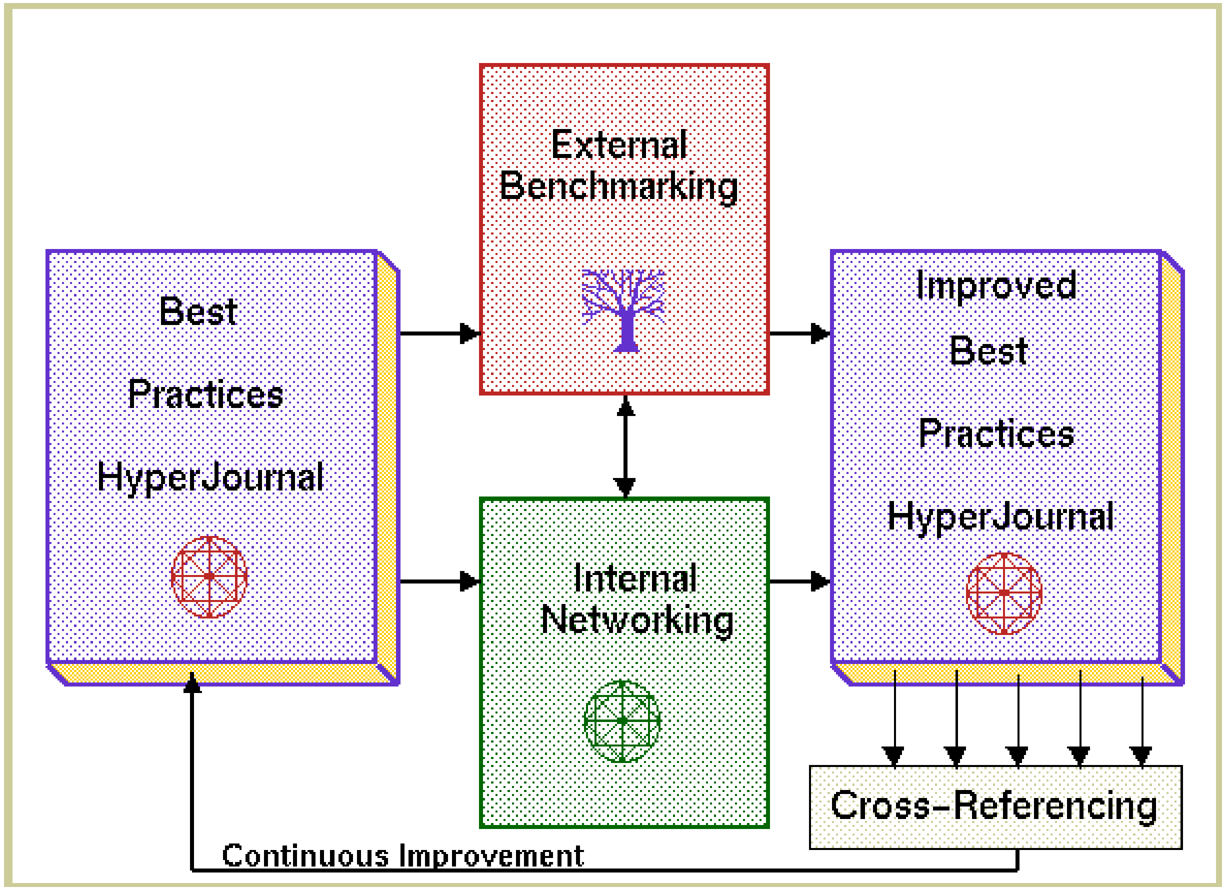
Fault Shadow Modeling

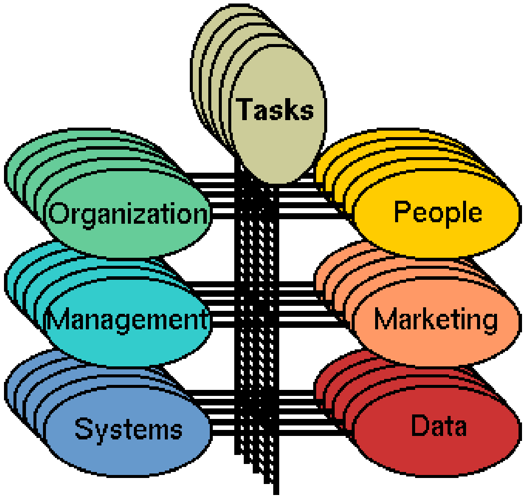


Fault Shadow Modeling



Project Documentation





Linked Indexed Experience Becomes Available to All Authorized Users.

Automation of documentation, indexing, and availability through a standard Browser allows improvement and Knowledge Capture.

Pre-Program Questionnaire

- How does interpretation workflow optimize documentation, visualization, and presentation?
  - How do seismic velocities impact seismic interpretation?
  - What is the impact of fault shadows on seismic interpretation?
  - What are other key seismic interpretation pitfalls?