Abstract

Polygonal fault systems (PFS) are present in the Niobrara Formation of the Denver Basin. This type of fault system is recognized primarily on 3D seismic.

The PFS is detached from basement faults and occurs in distinct layer-bounded systems (Niobrara and lower Pierre Shale). The faults are minor extensional faults, randomly oriented and form polygonal networks in map view. Faults dip 30 to 80 degrees; have throws of 30 to 70 ft; and lengths of generally less than 4000 ft.

The polygonal fault system deforms the Niobrara over a large part of the Denver Basin. Relatively undeformed sequences occur above and below the Niobrara faulted interval. This type of fault structure may also be present in other Rocky Mountain basins.

An additional and separate PFS zone is seen towards the base of the Larimer-Rocky Ridge Member of the Pierre Shale.

The faults are similar to ones reported in North Sea shale sequences. PFS are thought to represent volumetric contraction resulting from compaction-driven fluid expulsion. PFS are probably common features in thick shale sequences in sedimentary basins.

Layer-bounded faults in the Niobrara and Pierre have previously been interpreted as listric faults. The new interpretation does not support the listric interpretation. This new interpretation explains the random orientation of the faults which previously was not explained. Recognition of this structural style is important for future wells targeting the Niobrara petroleum system.

Other types of fault systems also occur in the Cretaceous section of the Denver basin.
References


Polygonal Fault Systems: A New Structural Style for the Niobrara Formation, Denver Basin, CO
Stephen A. Sonnenberg, David Underwood
Colorado School of Mines

ABSTRACT

Polygonal fault systems (PFS) are present in the Niobrara Formation of the Denver Basin. This type of fault system is recognized primarily on 3D seismic.

The PFS is detached from basement faults and occurs in distinct layer-bound systems (Niobrara and lower Pierre Shale). The faults are minor extensional faults, randomly oriented and form polygonal networks in map view. Faults dip 30 to 80°, have throws of 30 to 70 ft, and lengths of generally less than 4000 ft.

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Fracture Related Fields:
- Florence Caledon City (Pierre Shale)
  - 1984
  - 15.3 MMBO
  - Bowlder (Pierre Shale)
  - 1961
  - 9 MMBO
- Rangely (Mancos)
  - 1993
  - 11.7 MMBO, 12.2 BCF
  - Salt Creek
    - 1967
    - "Upper shale" Cretaceous
  - Tow Creek (Niobrara)
    - 1954
    - 5 MMBO, 0.3 BCF
  - Buck Peak (Mancos, Nio)
    - 1948
    - 4.7 MMBO, 8.2 BCF
  - Puerto Chiquito (Mancos/Nio)
    - 1960
    - 18.3 MMBO, 52 BCF
- Wattenberg (Nio, Codee)
  - 1970
  - 66 MMBO, 1.1 Tcf
  - Silo (Niobrara)
    - 1951
    - 10.4 MMBO, 8.2 BCF

Cretaceous Stratigraphic column, Denver Basin, Niobrara consists of four chalks and three marl intervals.

Niobrara facies map, Western Interior Cretaceous Basin.

Niobrara Petroleum System - Denver Basin
Shallow Biogenic Gas
Deep Thermogenic Oil and Gas

Structure map Niobrara Fm. Denver Basin, stars show location of Bunting and Sooner 3-D surveys.

Diagrammatic cross section Denver Basin. Niobrara is in the oil maturity window in the basin center.
Origin of Fractures

- Folding and Faulting
  - Tectonic, diagenic, slumping
  - Wrench faults
- Geologic History of Fractures
  - Recurrent movement on basement shear zones
- Solution of Evaporites
- High Fluid Pressure
  - Saturation of source rocks
- Polygonal Fault Systems (PFS)
- Regional Stress Field
- Regional Epeirogenic Uplift

Structures and Associated Fractures

Force Folds, Faults, and Fractures

Force (drape) folds over basement fault systems. Fracturing is expected where radius of curvature is the greatest.

Examples of Niobrara Faults in Little Beaver Field. Note faults do not extend below upper Greenhorn.

Examples of Detached Faults Niobrara Formation

Basement faults and detached faults, Denver Basin.

Seismic illustrating the listric fault model, Denver Basin, CO (Davis, 1985).

Basement faults influencing structure at Silo Field; basement faults also control salt dissolution edge and fracturing in Niobrara.

Seismic illustrating timing of salt dissolution, Silo Field. Dissolution is interpreted to be Upper Jurassic and Lower Cretaceous.

Seismic line over Black Hollow Field showing fold over basement fault system (from Stone, 1985).

Examples of Niobrara faults in Little Beaver Field. Note faults do not extend below upper Greenhorn.
Polygonsal Fault Systems

**Polygonal Fault Systems (PFS)**

- Layer-bounded fault systems
- Small extension faults
  - 10-50 m throw
  - Faults dip 30 to 70°
- Compactional flattening with depth
- Random oriented fault patterns

Areas where PFS have been identified.

**PFS**

- Form early in burial history
- Pervasively deformed fine grained sediments:
  - Claystones and biogenic mudstones: carbonate and bioturbated
  - Hemipelagites
- Shear fractures and normal faults aggregate into networks which are polygonal planforms
- Non-tectonic in origin
- Recognized in over 100 basins

Diagram illustrating two tiers of polygonal faults.

Polygonsal Fault Systems

- Volumetric contraction resulting from compaction-driven fluid expulsion
- Compaction dewatering occurs at shallow depth
- Vertical effective stress exceeds horizontal effective stress and inclined fractures result
- Stress state in plane in which polygons are developed is either isotropic or close to isotropic

**PFS: The Origin Debate**

- Non-tectonic nature of deformation and its relationship to early dewatering recognized
- Gravity collapse
- Density inversion
- Compactional loading
- Syneresis
- Diagenetically-induced shear failure

**Diagrams illustrating compaction of fine grained sediment with depth. Most porosity loss is early.**

Diagram illustrating compaction & loss of water in fine-grained sediments with depth. Note early water loss or compaction.

Diagram illustrating early loss of porosity in mud rock intervals (expulsion of pore water and compaction).

**North Bunting 3-D**

**T6N-R60W**

**16 square miles**

**1998**

Data provided by Enerplus

Seismic line, Bunting survey, showing two tiers of normal faults.

**Lower Pierre Shale amplitude map. Note polygonal shapes.**

**Lower Pierre Shale**

- Most negative curvature attribute
- Note polygonal shapes.

**Lower Pierre Shale**

- Most positive curvature attribute
- Note polygonal shapes.

**Lower Pierre Shale**

- Similarity attribute
- Note polygonal shapes.
Niobrara time structure, note polygonal shapes.

Similarity attribute top Niobrara, note polygonal shapes.

Niobrara time structure map, Sooner Survey. Note partial polygonal shapes.

Seismic line with no vertical exaggeration. Note orientation of faults is approximately 45°.

Seismic line, Sooner survey, showing normal faults at Niobrara level. Faults do not extend below Greenhorn.

Niobrara Amplitude Sooner Field

Most negative curvature top Niobrara, note polygonal shapes.

Most positive curvature top Niobrara, note polygonal shapes.

Sooner 3-D DOE Study D SS Reservoir 1992

7.7 square miles

Most negative curvature top Niobrara, note polygonal shapes.

Most positive curvature top Niobrara, note polygonal shapes.

Sooner 3-D Amplitude Sooner Field

Most negative curvature top Niobrara, note polygonal shapes.

Most positive curvature top Niobrara, note polygonal shapes.

Niobrara Amplitude Sooner Field

Seismic line, Sooner Survey. Two tiers of normal faulting are present.

Sooner 3-D Amplitude Sooner Field

Most negative curvature top Niobrara, note polygonal shapes.

Most positive curvature top Niobrara, note polygonal shapes.

Niobrara Amplitude Sooner Field

Seismic line, Sooner survey, showing normal faults at Niobrara level. Faults do not extend below Greenhorn.
Polygonal Fault Systems

**Discussion Points**

- Impact of deeper structures on polygons
- Impact of salt dissolution on polygons
- Impact of regional uplift on polygons
- Horizontal Stress field – isotropic?
- Hydrocarbon migration
- Scales of polygons
- Partial polygons

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**REFERENCES**


**Summary**

- Two layer bounded polygonal fault systems are recognized in Denver Basin
  - Below Hygiene Sandstone
  - Niobrara Formation
- PFSS common in fine-grained systems (shales and chalks)
- Most faults are NOT listric but low angle
- Basement faults still important
- Permian salt dissolution creates faults
- Compartmental features over DSS

**Most negative curvature through lower Pierre Shale time slice. Note the presence of smaller polygons within the larger polygons.**

**Polygonal weathering fractures, Fox Hills Sandstone, Boulder, CO. Two or more scales of polygons are present.**

**Lower Hygiene time structure. Note polygonal shapes.**

**Lower Hygiene amplitude map. Note polygonal shapes.**

**Scales of Polygonal Structures**

**REFERENCES**


