PS Tepee Buttes, Methane Seeps, and Polygonal Faults Systems*

Stephen Sonnenberg[1]

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[1]Colorado School of Mines, Golden, CO, United States (sasonnenbg@aol.com)

Abstract

Tepee Buttes are conical mounds found in the Upper Cretaceous Pierre Shale. The origin of the mounds is generally accepted based on biotic zonation and geochemical data to be due do nutrient-rich submarine springs and methane-seeps on the ancient Pierre Shale seafloor. The mounds have dipping flank beds (3-34 degrees) and a limestone core. They resemble carbonate-cemented lithoherms around modern hydrocarbon seeps. The buttes range in height from 5 to 75 feet. The circumference of the buttes lies between 200 and 900 feet. The mounds are held up by an irregular pipe-like vertical to sub vertical limestone core. Facies outwards from a central vuggy limestone core include: limestone with lucinid bivalves; limestone with diverse mollusks; limestone with inoceramids; shale with stromatolites (Kauffman et al., 1996). The Tepee Buttes are common in Cretaceous shale outcrops from south of Colorado Springs to Pueblo. Hundreds of buttes or mounds are present in this area. The buttes are thought to form along fracture systems that vented methane-charged fluids. The source of the methane is from the Sharon Springs member of the Pierre Shale and the Niobrara Formation (biogenic gas from microbial degradation of organic-rich beds). The evidence for the fracture systems is the very linear arrangement of the buttes. Reinterpretation of the linear features suggest they may form polygons and originate from polygonal fault systems. Recent work in the Denver Basin suggests that these polygonal fault systems are quite abundant and form early in burial history. These fault systems are abundant in zones above the Niobrara Formation. The Tepee Buttes zones are easily recognized in well logs in the subsurface by relatively clean gamma ray signature and high resistivities. The carbonate build-ups range in height from a few feet to approximately 75 feet. The buttes often have hydrocarbon shows but their small size suggests very limited accumulations. Maps and cross sections in the Wattenberg field area illustrate the common occurrence of the Tepee Buttes. Tepee Buttes or mounds associated with methane seeps and fracture systems are present in other shale plays (e.g., Vaca Muerta, Argentina).

Tepee Buttes, Methane Seeps, and Polygonal Fault Systems

Stephen A. Sonnenberg, Colorado School of Mines

ABSTRACT

Tepee Buttes are conical mounds found in the Upper Cretaceous Pierre Shale. The origin of the mounds is generally accepted based on biotic zonation and geochemical data to be due do nutrient-rich submarine springs and methane-seeps on the ancient Pierre Shale seafloor. The mounds have dipping flank beds (3-34 degrees) and a limestone core. They resemble carbonate-cemented lithoherms around modern hydrocarbon seeps. The buttes range in height from 5 to 75 feet. The circumference of the buttes lies between 200 and 900 feet. The mounds are held up by an irregular pipe-like vertical to sub vertical limestone core. Facies outwards from a central vuggy limestone core include: limestone with lucinid bivalves; limestone with diverse mollusks; limestone with inoceramids; shale with stromatolites (Kauffman et al., 1996). The Tepee Buttes are common in Cretaceous shale outcrops from south of Colorado Springs to Pueblo. Hundreds of buttes or mounds are present in this area.

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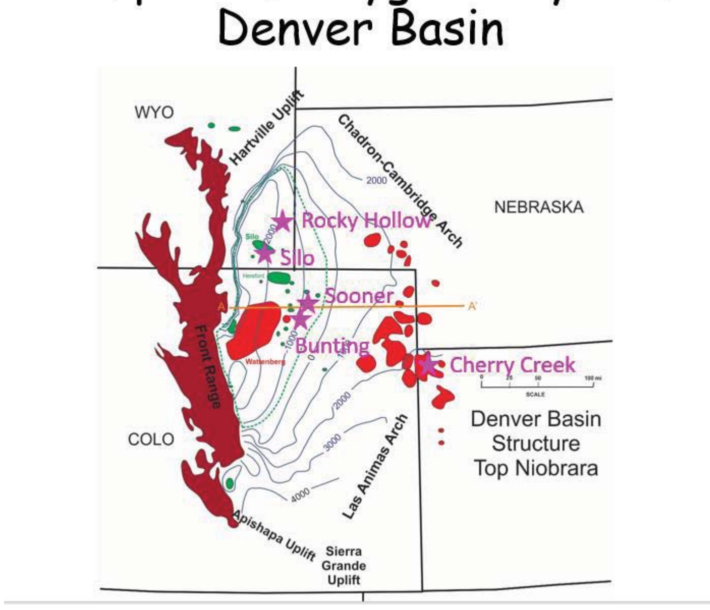
The Tepee Buttes zones are easily recognized in well logs in the subsurface by relatively clean gamma ray signature and high resistivities. The carbonate build-ups range in height from a few feet to approximately 75 feet. The buttes often have hydrocarbon shows but their small size suggests very limited accumulations. Maps and cross sections in the Wattenberg field area illustrate the common occurrence of the Tepee Buttes.

Tepee Buttes or mounds associated with methane seeps and fracture systems are present in other shale plays (e.g., Vaca Muerta, Argentina).

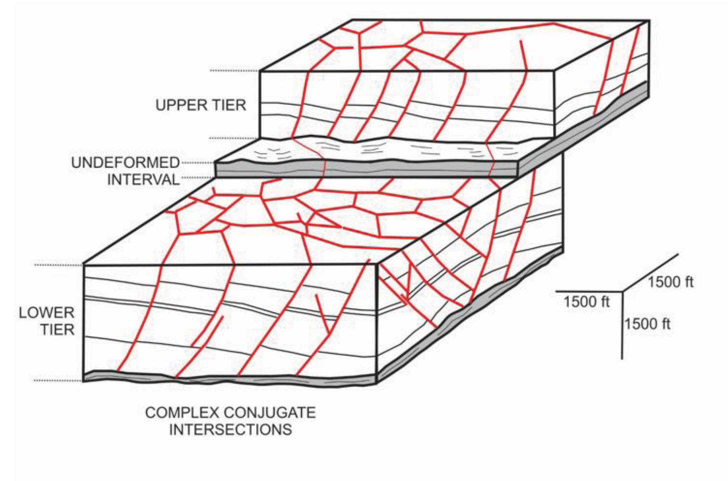
Examples of Polygonal Systems Denver Basin



Index map of Denver Basin showing fields containing 3-D data sets. Polygonal types of faulting have been documented in the various locations. Bunting survey illustrated in this poster.

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



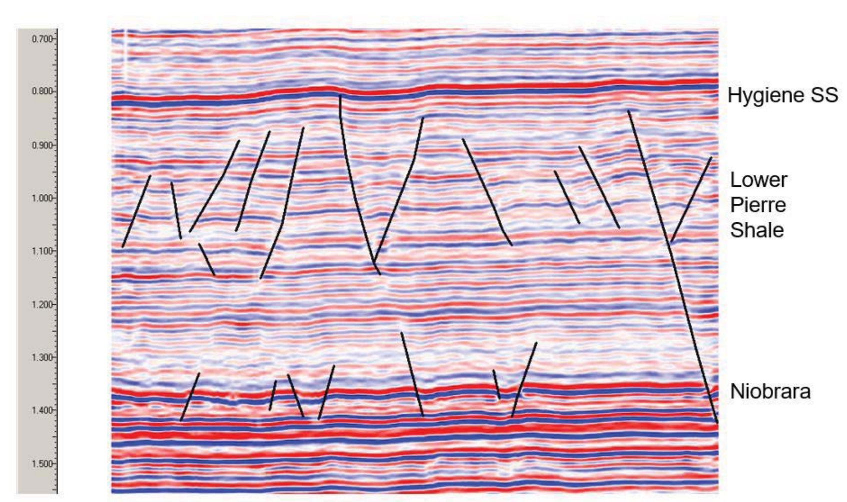
Sonnenberg and Underwood, 2013; modified from Cartwright, 1996

Polygonal 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
- Horizontal stress state in plane in which polygons are developed is either isotropic or close to isotropic

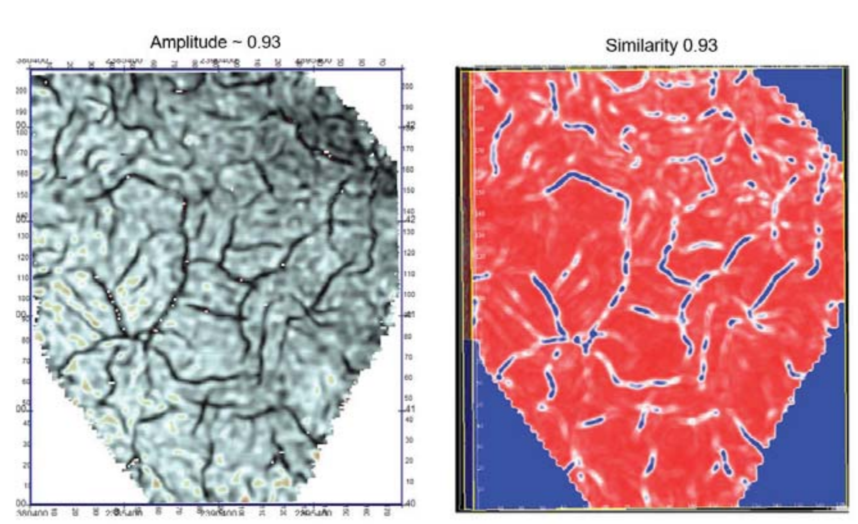
North Bunting 3-D

- T6N-R60W
- 16 square miles
- Acquired 1998
- Data provided by Enerplus

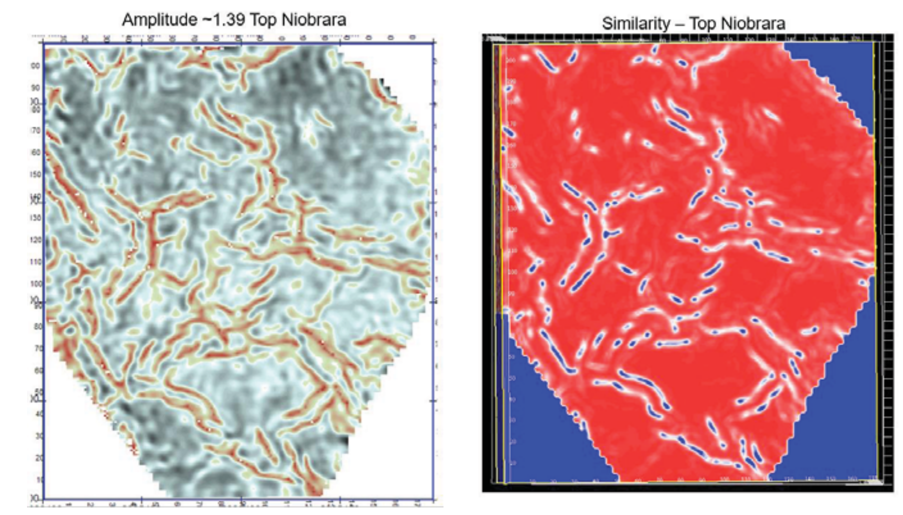


Data courtesy of Enerplus

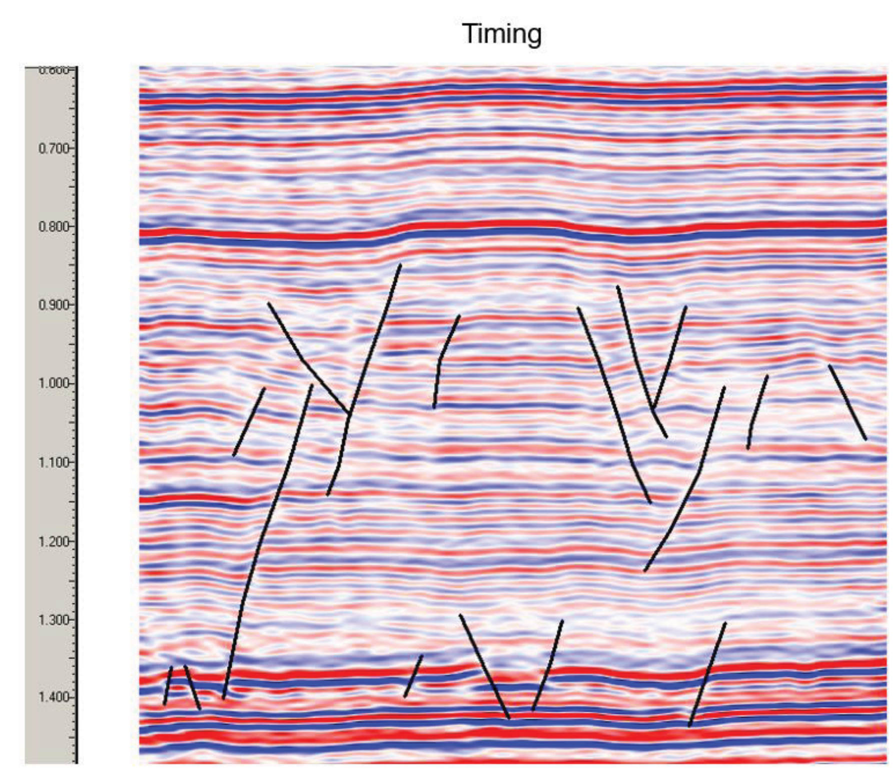
Seismic line illustrating two tiers of normal faults in Bunting 3-D



Seismic amplitude and similarity attribute shown for 0.93 time slice (upper fault tier in Pierre Shale). Faults are linear features on seismic data. Note how faults form polygonal features.



Seismic amplitude and similarity attribute shown for top Niobrara (lower tier of faults shown on seismic line). Faults are linear features on seismic data. Note how faults form polygonal features.



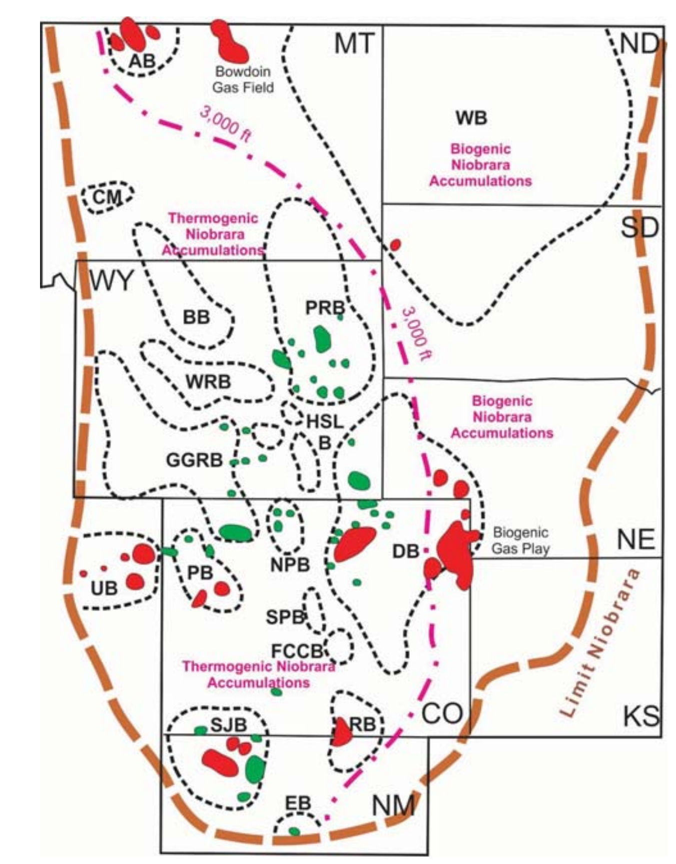
Timing of faulting is interpreted to be **"early"** because of "growth strata" observed on seismic. Subsurface well data support the occurrence of the growth strata.
Thus, Early Formed Faults.

Summary

- Two layer bounded polygonal fault systems are recognized in Denver Basin
  - 1) Below Hygiene Sandstones
  - 2) Niobrara Formation
- PFS common in fine grained systems (shales and chalks)
- Most faults low angle, slightly listric (?)

PFS forms early.

Biogenic Gas Niobrara Petroleum System



Niobrara producing fields, Rocky Mountain region. East of dashed line fields produce biogenic gas; west of dashed line, fields are thermogenic.

"Early" Biogenic Methane Gas

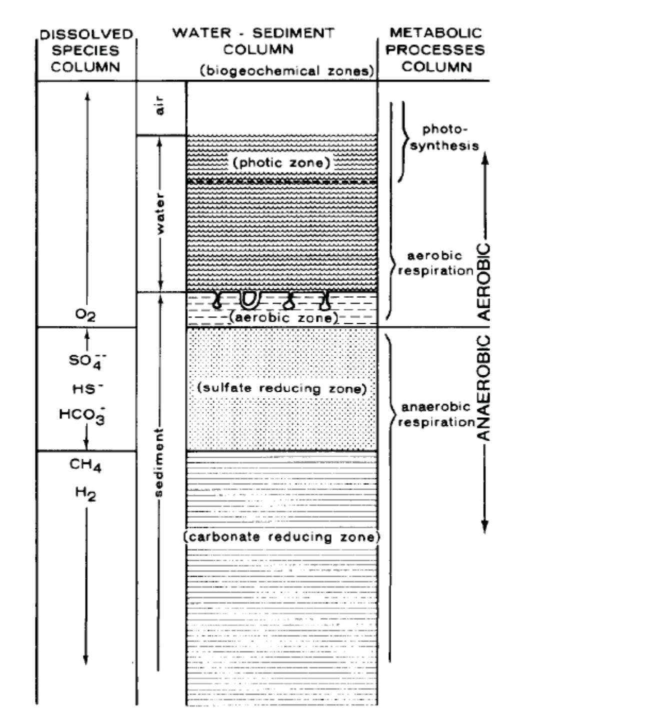
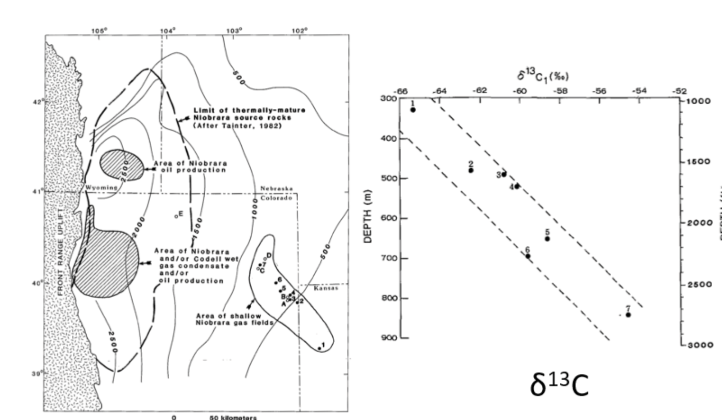
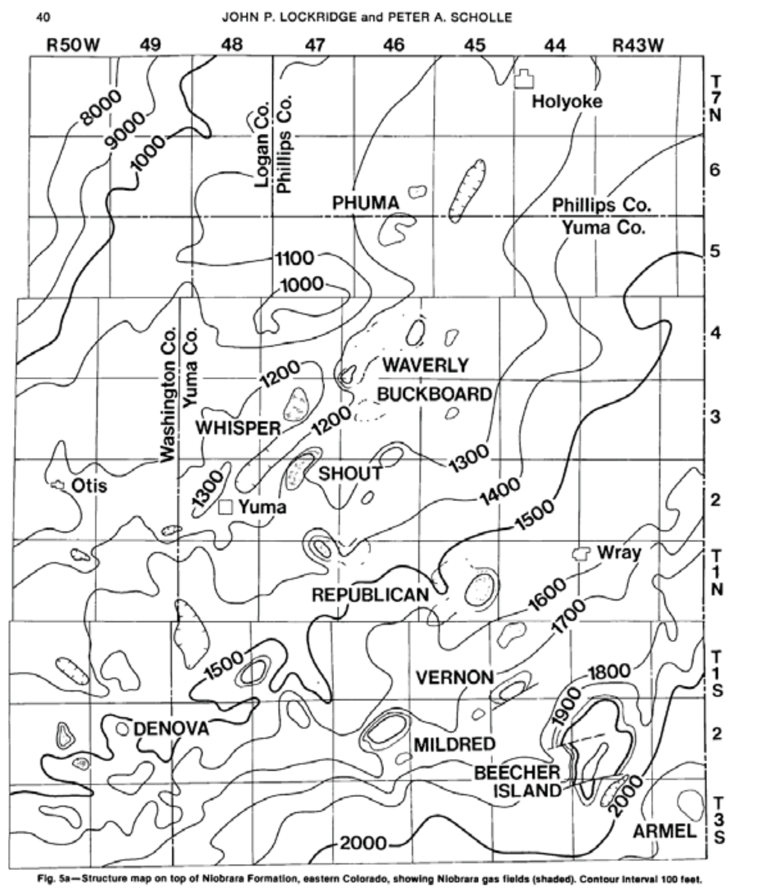


Diagram of organic-rich, marine environment showing succession of microbial ecosystems that lead to methane generation (from Rice and Claypool, 1981)



Index map showing present-day depth of burial to top of Niobrara Formation. Shallow Niobrara gas fields produce biogenic gas. $\delta^{13}C_1$ of natural gas with depth also shown.

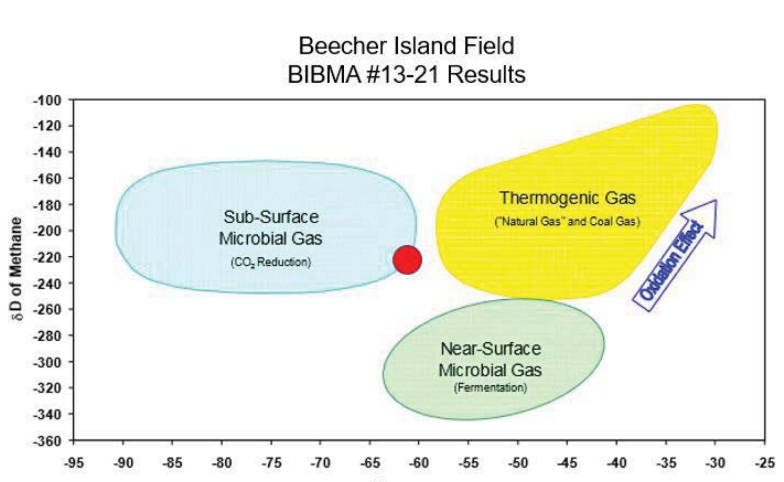
Tepee Buttes, Methane Seeps, and Polygonal Fault Systems 2



Structure top Niobrara eastern Colorado. Fields shown produce biogenic gas (from Lockridge and Scholle, 1978)

State	Field	Producing Unit	Depth (m)	$^{13}C_1$ (‰)	C_1/C_{1-5}
Colorado	Armel	Niobrara Fm.	482	−62.5	0.981
	Beecher Island	Niobrara Fm.	491-518	−60.8 to −60.1	0.982 to .981
	Republican	Niobrara Fm.	691	−59.7	0.981
	Vernon	Niobrara Fm.	647	−58.8	0.98
	Whisper	Niobrara Fm.	842	−54.7	0.976

Isotopic composition of Niobrara biogenic gas and C1/C1-5 ratios (from Rice and Claypool, 1981)



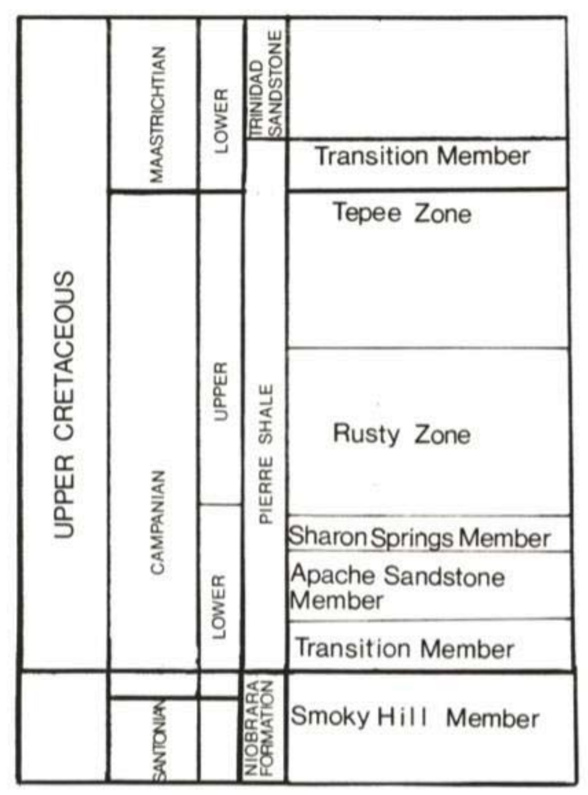
Isotopic composition of gas from Beecher Island field (data from Mountain Petroleum)

Summary

- Carbon and oxygen isotopes suggest biogenic gas
- Structural accumulations of 98% methane gas in eastern Colorado fields
- C1/C1+C5 ratios = 0.98
- $\delta^{13}C$ -54 to -62 $^o/_{oo}$
- δD of methane: -200 to -220

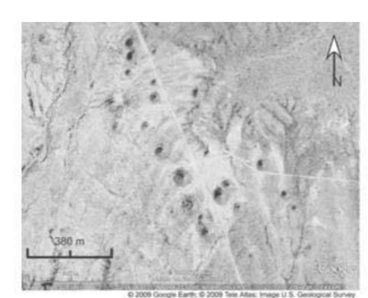
∴ Biogenic Gas common with organic-rich shales

Tepee Buttes



Stratigraphic column showing the Tepee Zone in the Denver Basin (from Howe, 1987)

Kauffman et al., 1996

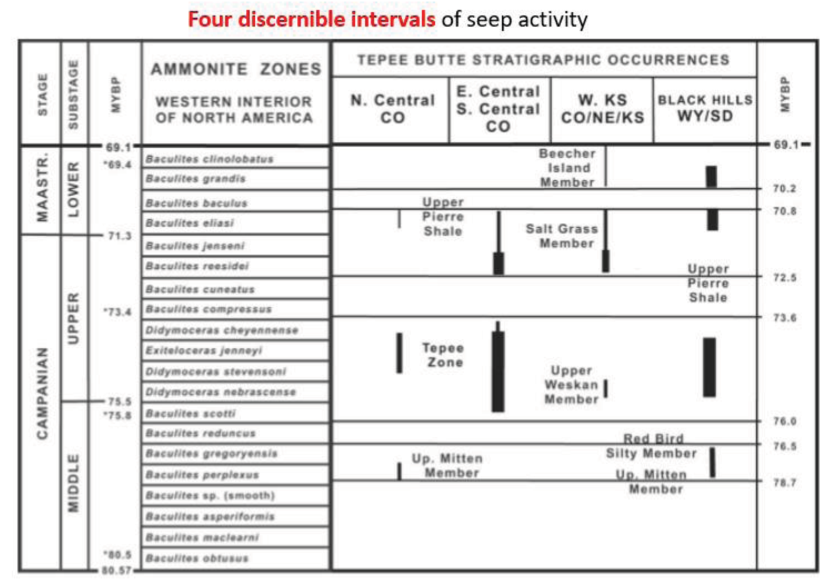


Meetz, 2009

Shapiro and Fricke, 2002

Shapiro and Fricke, 2002

Aerial views of Tepee Buttes from various publications/

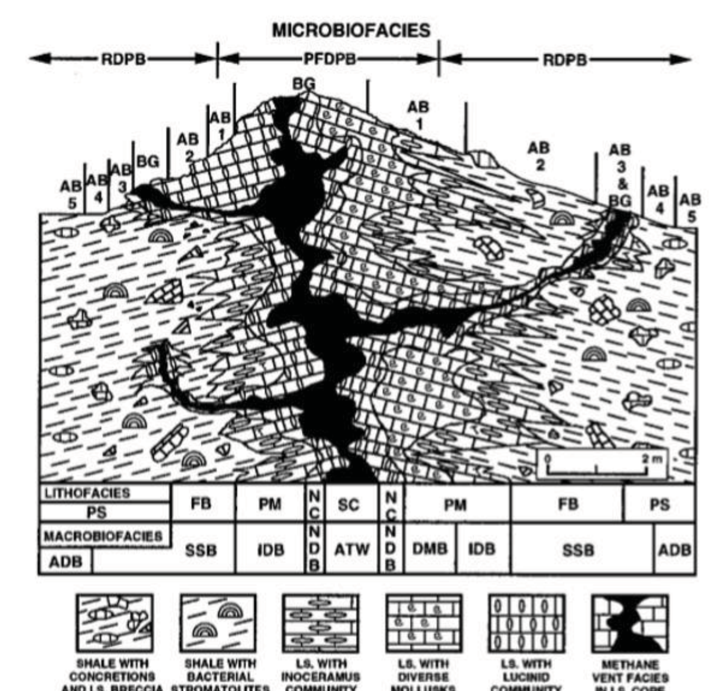


Age of Tepee Butte seep occurrences in the Late Cretaceous Western Interior Basin of North America in relation to their stratigraphic distribution (Meetz, 2009)

Tepee Buttes, fossil seep mounds

- occurred intermittently over a 10-m.yr. period within a narrowly restricted paleogeographic region
- northern Black Hills southward into southern Colorado
- **Four discernible intervals** of seep activity are identified over a time span of 10 m. yr., from late Middle Campanian (78.7 Ma) through the Early Maastrichtian (69.1 Ma)

(Meetz, 2009)



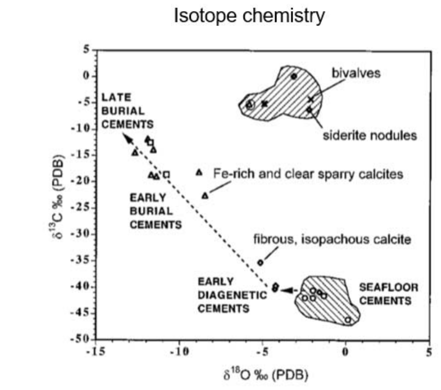
Microbiofacies across Tepee Butte (from Kauffman et al., 1996)

Tepee Buttes

- Conical limestone mounds in the Pierre Shale
- Named Tepee Buttes by Gilbert and Gulliver (1895)
- Possible origins debated: shale hills capped by concretions; aggregations of lucinoid bivalves; carbonate mud mounds formed within marine sea grass; sites of emergent submarine springs and seeps
- Dane et al. (1937) argued for a submarine spring hypothesis
- Kauffman (1961) established biotic zonation supporting the submarine spring hypothesis
- Arthur et al. (1982) presented extensive evidence in support of the submarine spring hypothesis including geochemical data suggesting methane-enriched waters during cementation in early diagenesis
- Kauffman et al. (1996) provide additional support methane-rich submarine springs

- Size range of 5 to 7 meters, sizes of 10 to 13 meters also common; largest observed 25 meters
  - Carter Lake area: 2 meters high
- Circumference of small and medium sized buttes lies between 75 and 300 meters
- Mounds held up by irregular pipe-like vertical limestone cores
- Most cores consist of unfossiliferous vuggy limestone surrounded by dense Nymphalucina coquinas
- Campanian shales contain submarine spring and seep deposits
- Elevated carbonate mounds on Cretaceous sea floor with dipping flank beds (3-34°) and pipelike, fossiliferous limestone core
- Resemble carbonate-cemented lithoherms around modern hydrocarbon and methane seeps
- Characteristic Lithofacies: 1. vuggy pelletoid micrite core to 30 m in height; 2. lucinoid bivalve coquina in pelletoid micrite; 3. carbonate slump breccia; 4. concretion bearing shale; 5. organic-rich shale
- Venting of methane-charged fluids along fracture zones
- Carbonate deposition around submarine springs

Isotope chemistry



Early cements:

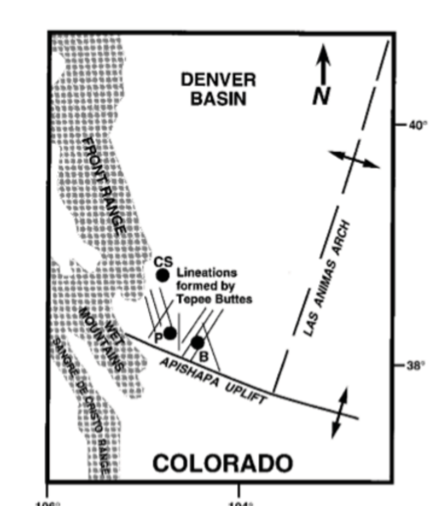
- $\delta^{18}O$ values of early fibrous cements and matrix and pellets range from -1°/oo to -3°/oo consistent with normal marine origin but carbon isotope values of these cements extremely depleted (-40°/oo to -45°/oo) values obtainable by deriving the total dissolved carbon pool from methane oxidation (-45°/oo observed in modern methane springs)

Kauffman et al., 1996

Evidence for Methane Springs

- Very early diagenetic cementation
  - Pellets are uncompacted
  - Multiple generations of botryoidal cement
- Algae- and/or bacteria-mediated carbonate crusts (similar crusts form on modern methane seeps)
- Isotope chemistry
  - $\delta^{18}O$ values of early fibrous cements and matrix and pellets range from -1°/oo to -3°/oo consistent with normal marine
  - Carbon isotope values of these cements are extremely depleted (-40°/oo to -45°/oo) values only obtainable by deriving the total dissolved-carbon pool from methane oxidation
  - OM in pelletoid matrix yield $\delta^{13}C$ values of -29°/oo to -32°/oo consistent with a source derived from methane oxidation
- **Submarine springs vented methane-rich and nutrient-rich pore fluids derived from Pierre (Sharon Springs mbr) and Niobrara formations**
- Siderite concretions around buttes confirm sufficient OM existed in coeval sea-floor to promote early diagenetic methanogenesis
  - High siderite content (>70%) and heavy $\delta^{18}O$ (-2°/oo to -3°/oo) suggest high porosity, shallow burial, and total exhaustion of pore-water sulfate during bacterial sulfate reduction
  - Heavy $\delta^{13}C$ values of the siderite and trend from relatively depleted to enriched values from the center to the edge of concretions consistent with siderite precipitation during in situ methanogenesis
- Thus, varied sources for vented methane at the sites of Tepee Buttes

Kauffman et al., 1996

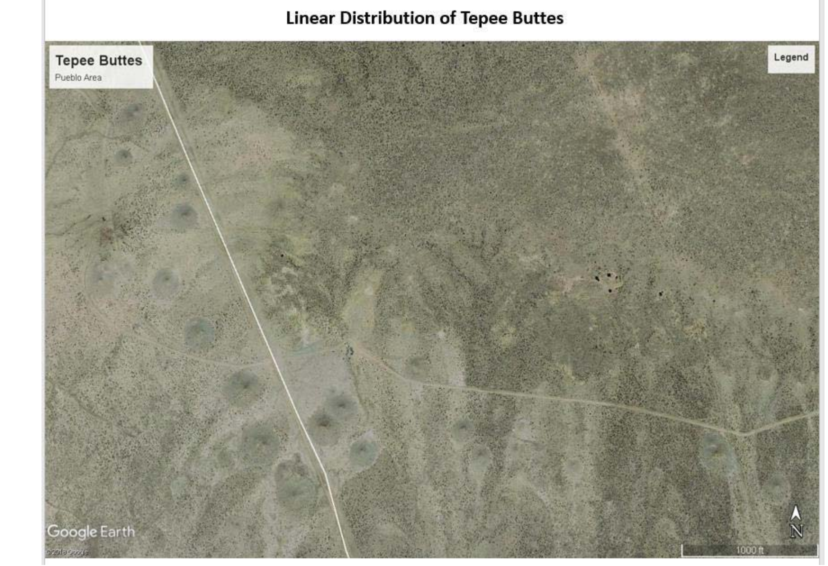


Linear north-northwest and northeast trends of Tepee Butte fields (from mapping by Howe and Kauffman, 1985)

Natural cross sections show that the Tepee vent cores are associated with steep, east-dipping, normal faults (Howe and Kauffman, 1985),

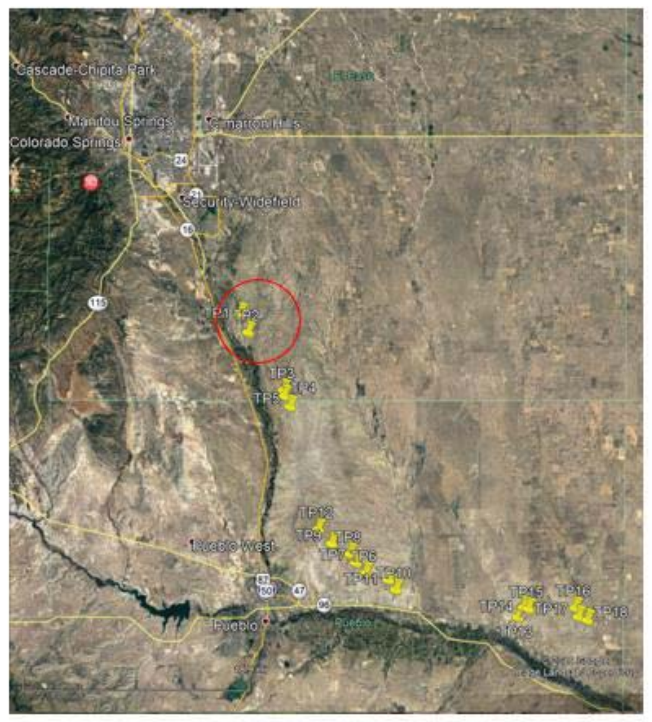
Kauffman et al., 1996

Linear Distribution of Tepee Buttes



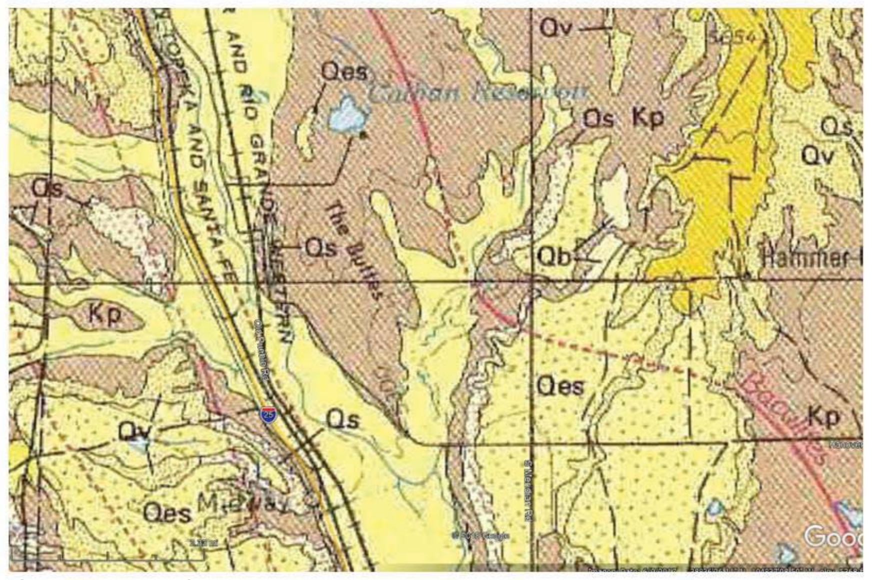
Linear distribution of Tepee Buttes, Pueblo area. The linear distribution suggests a fault control.

Tepee Buttes and interpreted Polygonal Fault Systems
3

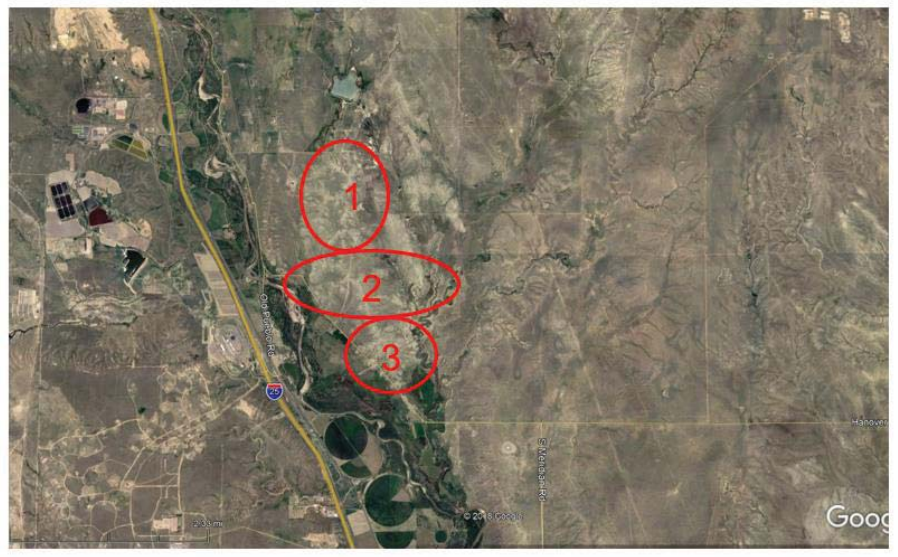


Google Earth image from Colorado Springs to Pueblo showing distribution of Tepee Butte areas (yellow pins) in Pierre Shale.

Geologic map of the above area showing distribution of Tepee Buttes in Pierre Shale.

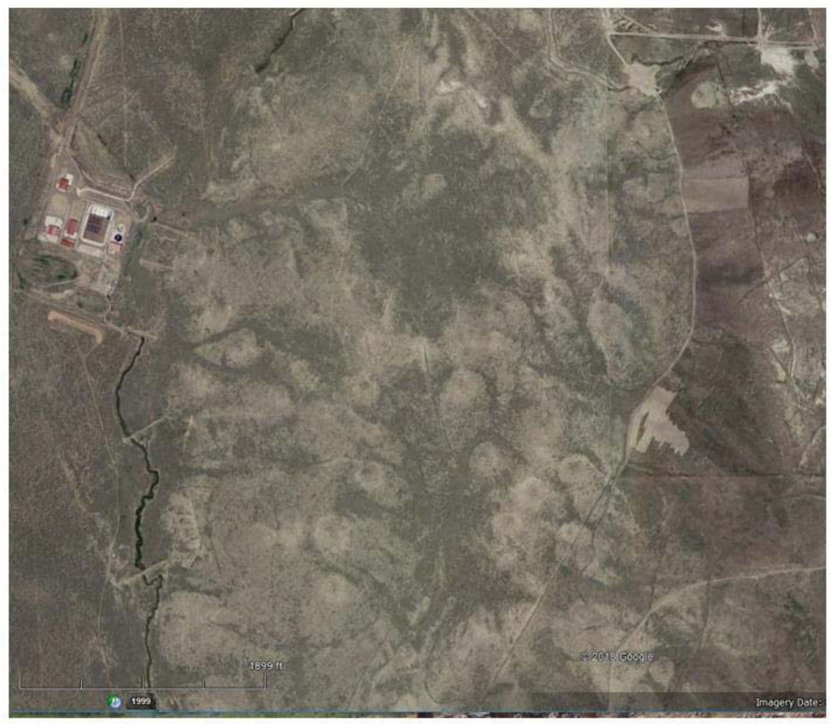


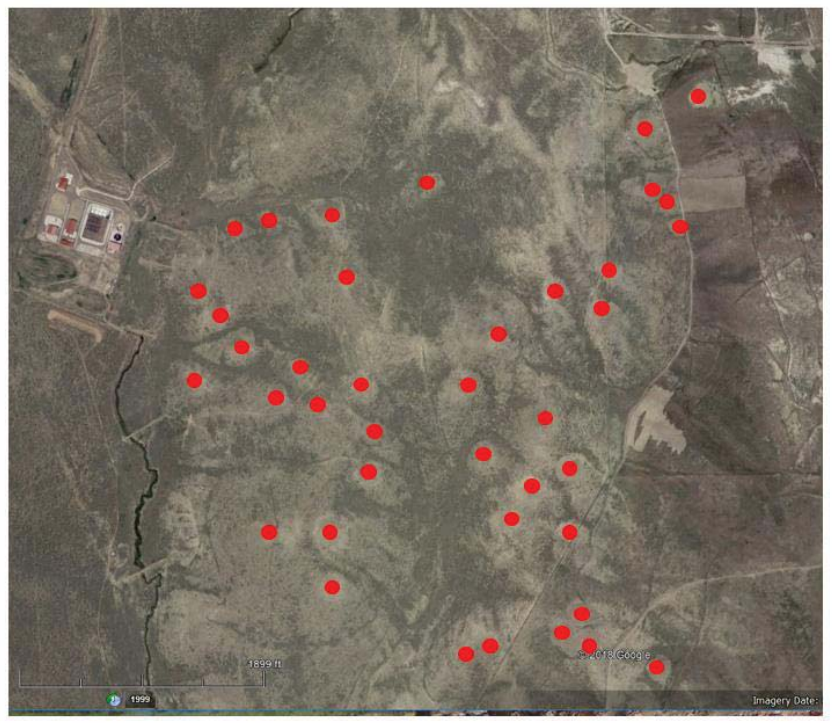
Circle area from above.

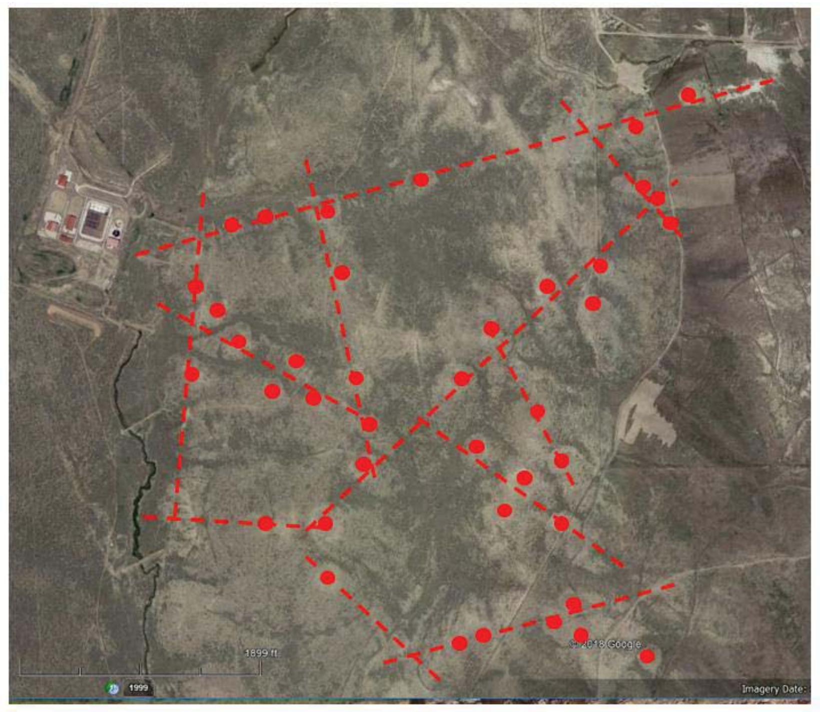


Areas 1-3 shown on Poster.

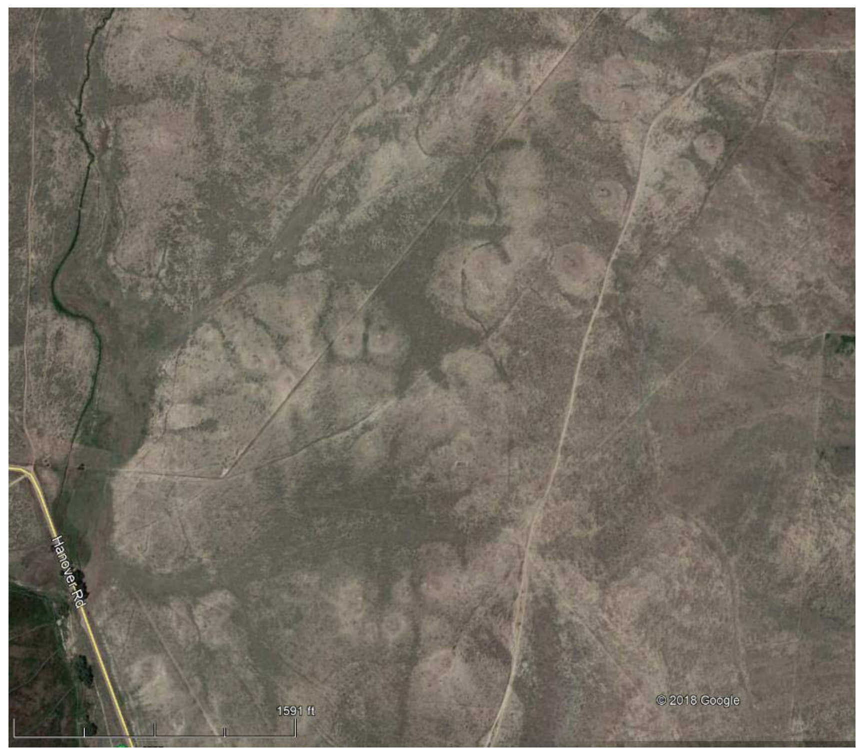
Area 1

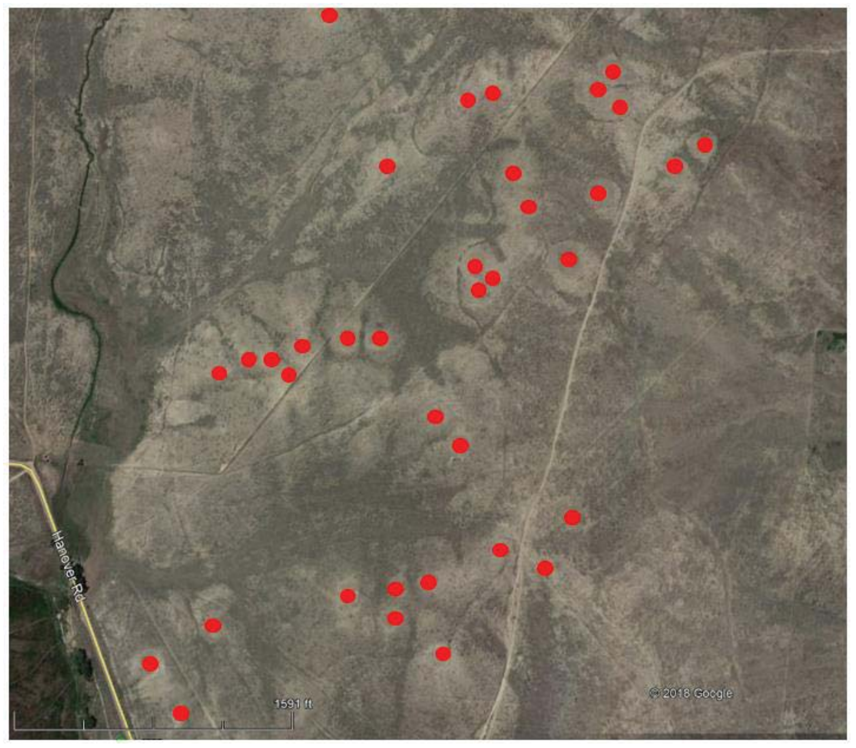


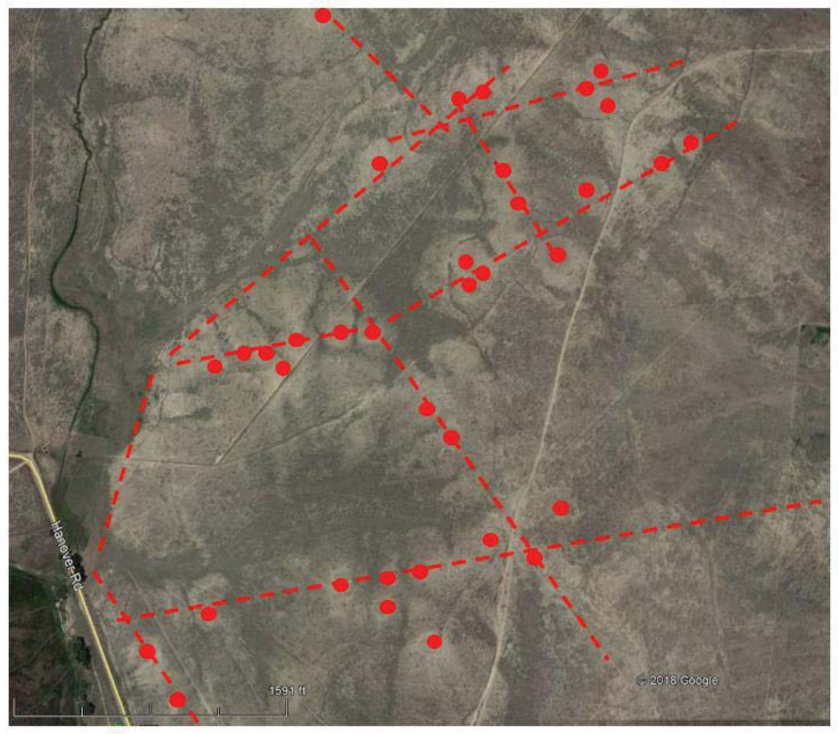




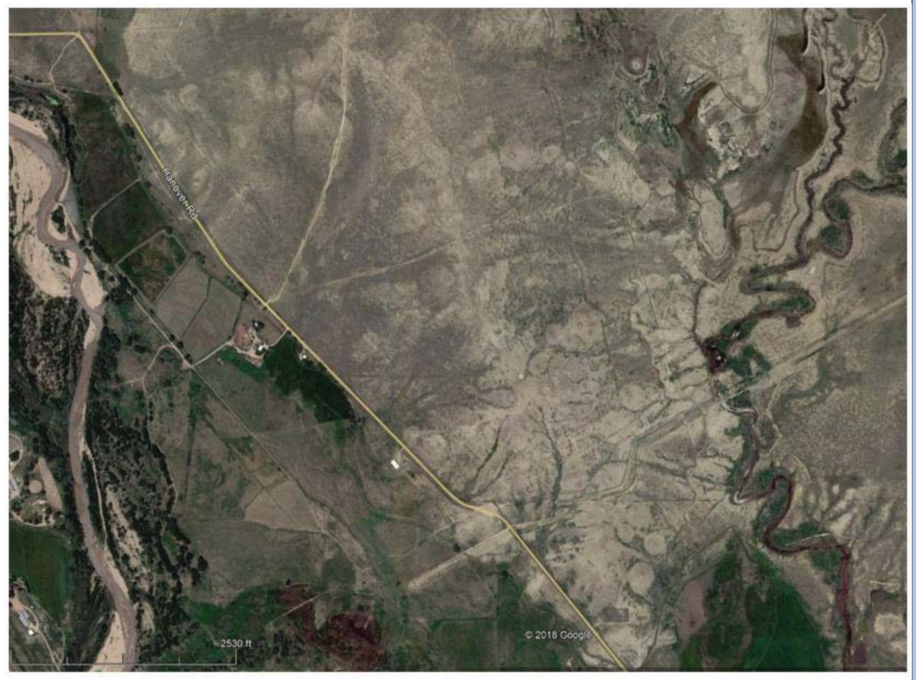
Area 2

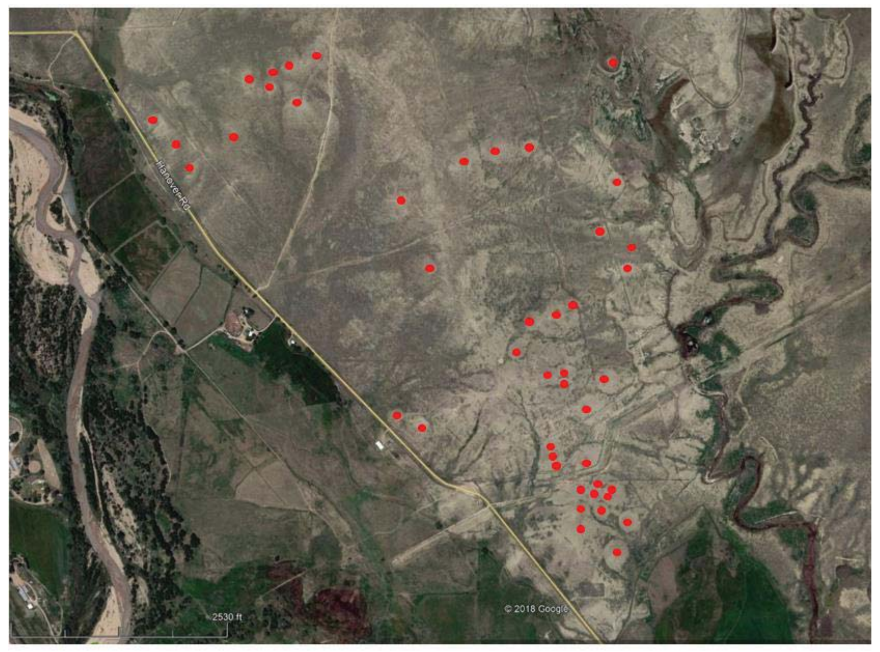


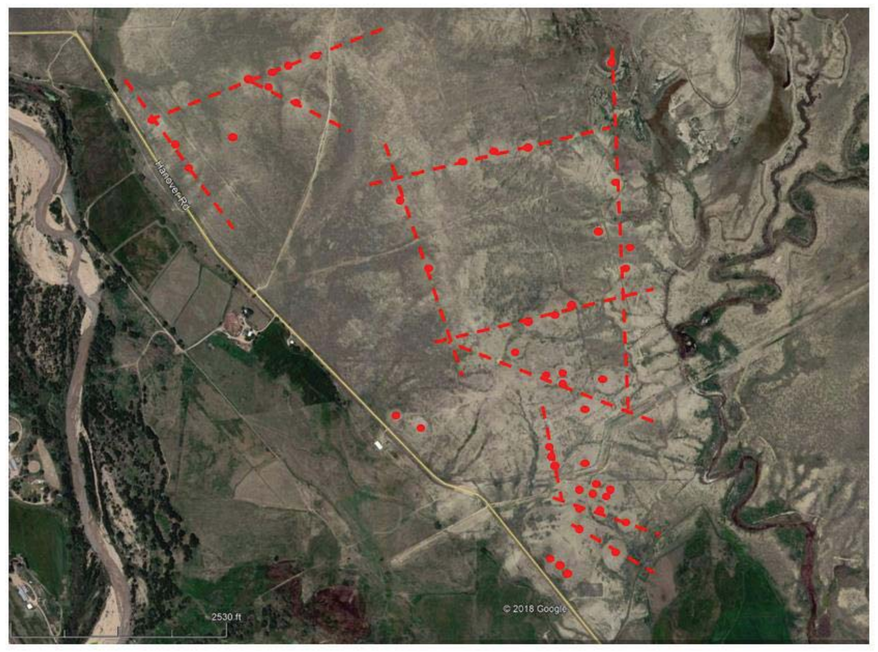




Area 3







Areas 1-3 from “the Buttes” showing distribution of Buttes and possible fault trends controlling their distribution. Area is south of Colorado Springs east of HW I-25. Note interpreted polygons.

Tepee Buttes, Methane Seeps, and Polygonal Fault Systems
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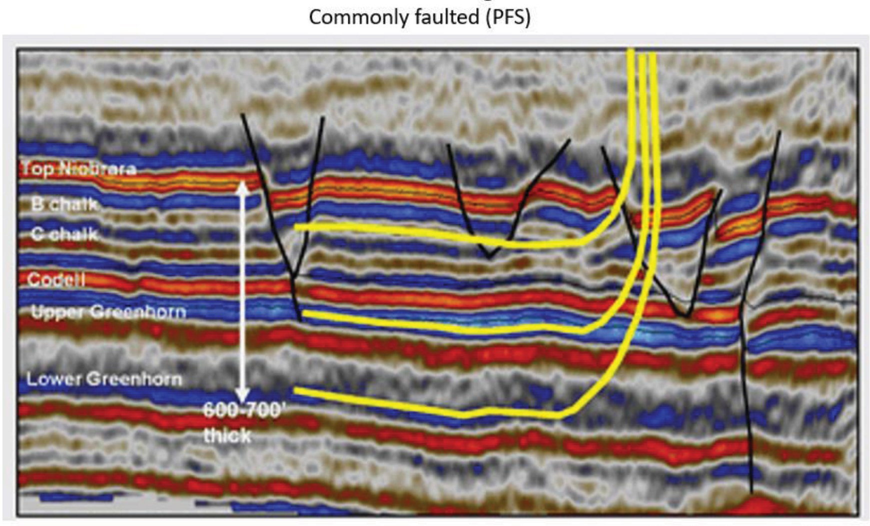
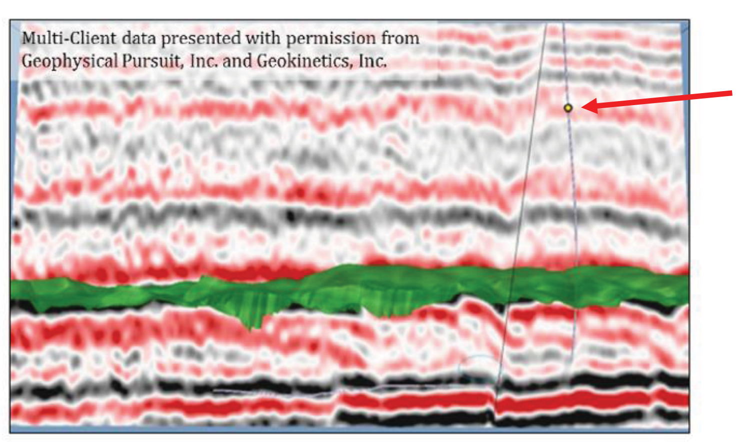
Subsurface data

Niobrara Wattenberg Field
Commonly faulted (PFS)



Noble Energy, 2011

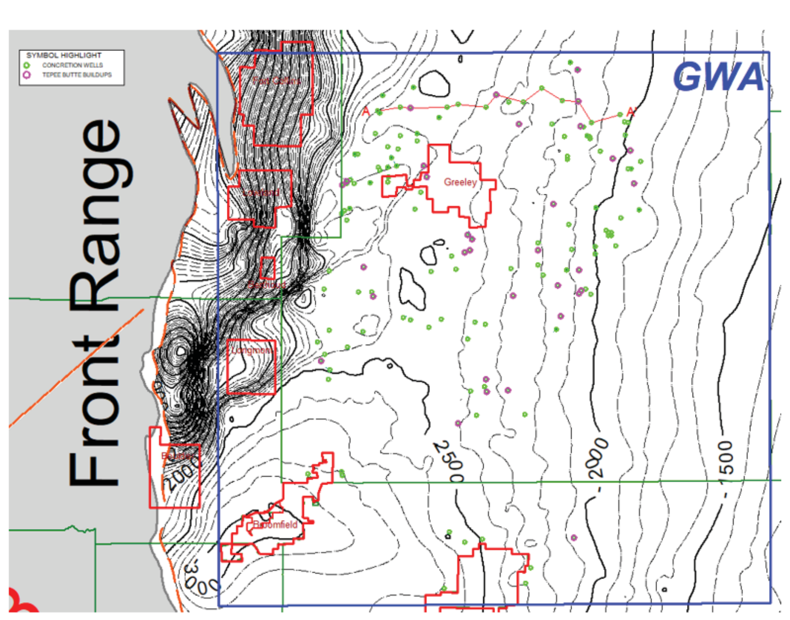
Seismic line from Noble Energy showing extensive faulting in Niobrara, Wattenberg field.



Top Niobrara, green area. Tepee Butte associated with normal fault Yellow circle

Clark, 2018

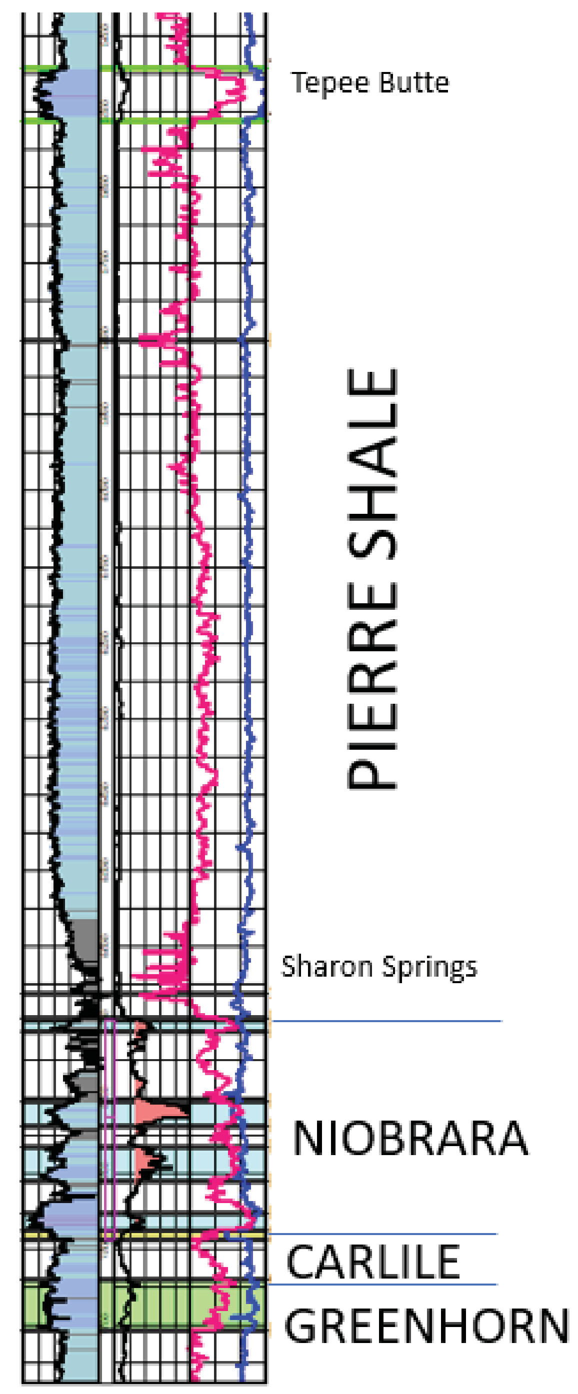
Documented Tepee Butte associated with Fault system (Clark, 2018)



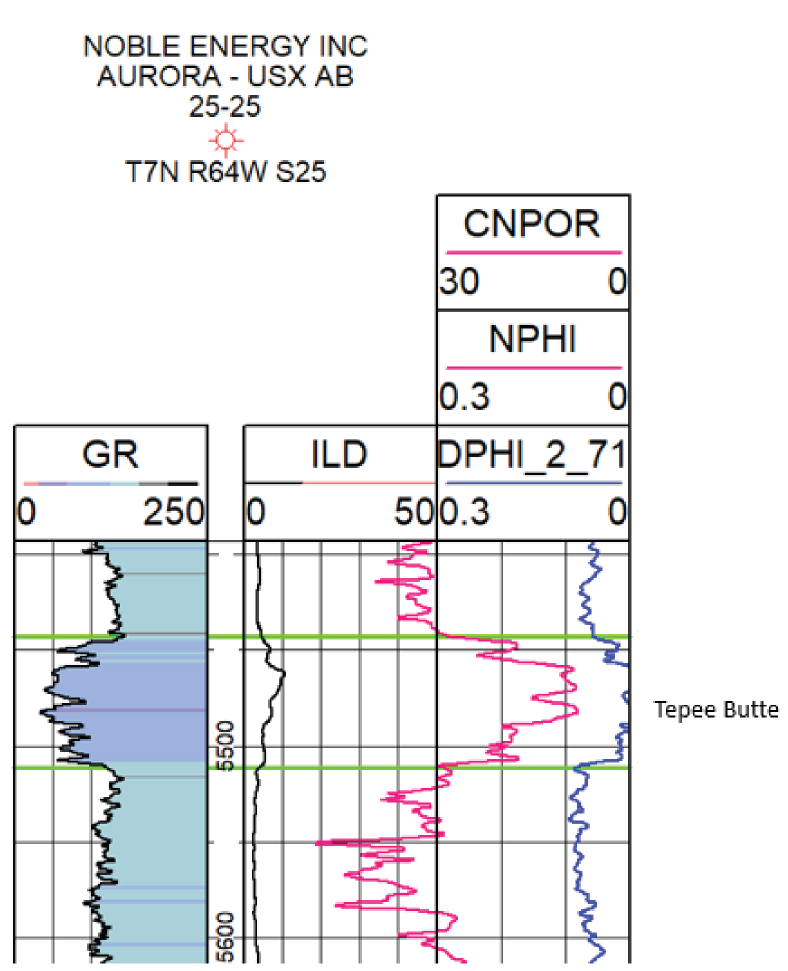
Structure Codell SS

Distribution of Tepee Buttes and/or concretions from well logs, Wattenberg field area. Carbonate buildups > 5 ft interpreted to be Tepee Buttes; < 5 ft interpreted to be concretions.

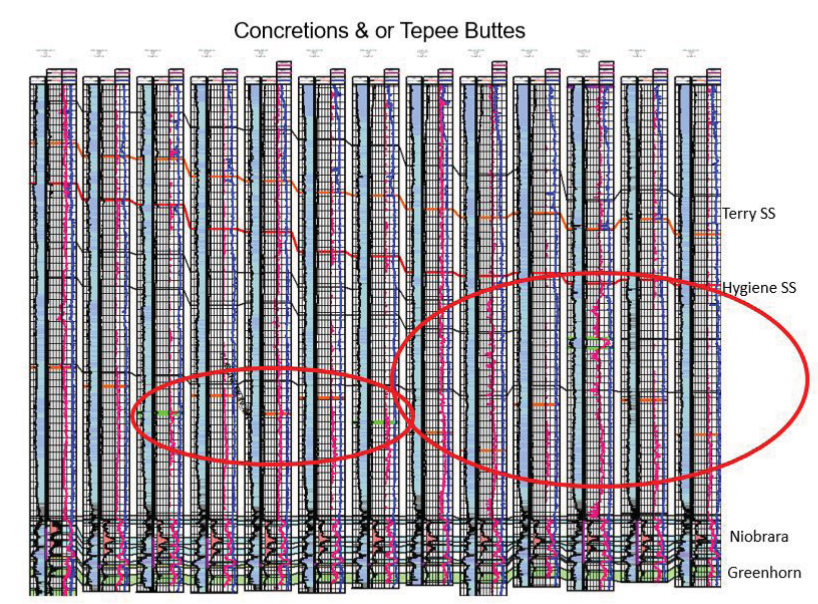
Example of Tepee Butte on well log, Wattenberg Field Area



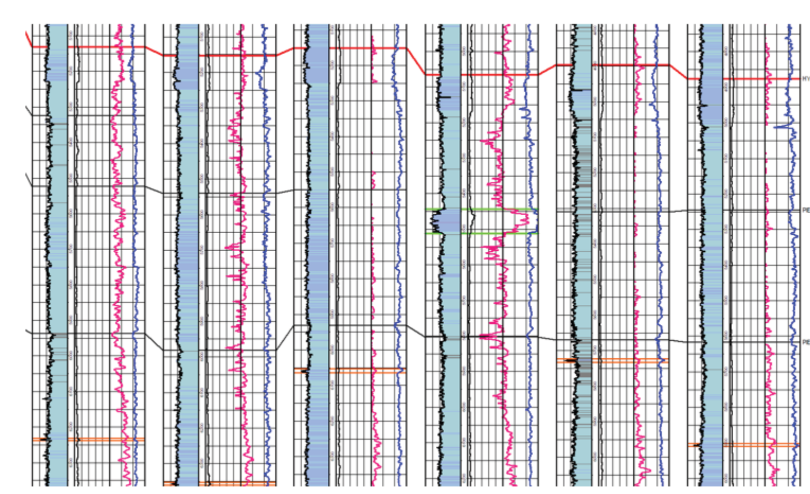
Close up view of Tepee Butte on well log, Wattenberg Field Area



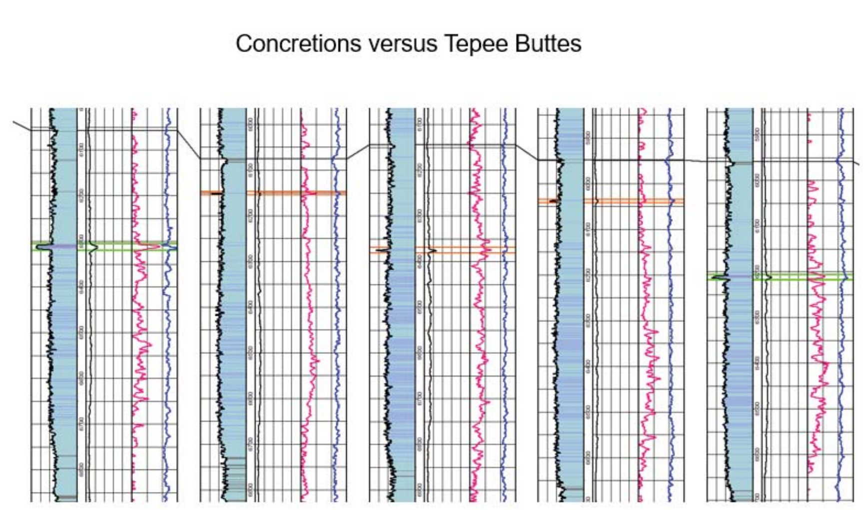
Cross Section examples of Tepee Buttes and/or concretion zones, Wattenberg Field Area.



West to east cross section showing Tepee Buttes and/or concretion zones.



West to east cross section, large circled area from the above cross section. Tepee Buttes green lines; concretions orange lines



West to east cross section, small circled area from the above cross section. Tepee Buttes green lines; concretions orange lines.

Summary

- PFS quite common in Niobrara
  - Compaction dewatering early
- Biogenic gas in Niobrara petroleum system
- Concretions common in Pierre Shale
- Tepee Buttes common in Pierre Shale

∴ Tepee Buttes, methane seeps, PFS!

References Polygonal Faults

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