

PS Tectonic Versus Non-Tectonic Origin of Complex Fault and Fracture Patterns in the Niobrara Formation, DJ Basin, CO*

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Abstract

The Upper Cretaceous Niobrara Formation is emerging as a prolific HC resource play in Colorado. The Niobrara Petroleum System (TPS) is a self-sourced inverted tight HC system producing oil and gas mainly from fractured reservoirs.

The Niobrara Formation forms part of the late Paleozoic through early Tertiary sedimentary sequence of the Rocky Mountain foreland basins that were uplifted during the post-Cretaceous Laramide Orogeny. The Denver-Jules (DJ) Basin and others, are asymmetric basins with a steeply dipping western flank bounded by the Rocky Mountains Front Range and a gently dipping eastern flank.

The Niobrara reservoir rocks consist mainly of interbedded chalks, marls, organic-rich shales, and sandstones that thicken from west to east. The fine-grained tight character of these reservoir rocks, makes them unconventional plays with production depending on development of natural fractures systems.

The structural evolution of the DJ Basin and the Niobrara exhibits Laramide compression, large-scale SW-NE basement-involved right-lateral wrench faults, and Neogene extension characterized by layer-bound small normal faults with varying strike. These faults however vary from random to more organized along basement structures, representing a peculiarity of the Niobrara and subject of debate due to their significance in the HC system. The faults are minor extensional faults with throws of 10-60 m and dips of 30-80 degrees. They are distinct layer-bounded systems concentrating in the brittle calcareous rocks over- and underlain and interbedded with soft ductile marine shales sealing the HCs.

The faults have been interpreted as being listric tectonic faults to polygonal non-tectonic faults. Polygonal faults have been observed in basins worldwide and are commonly interpreted to be formed by mechanisms such as volumetric contraction due to compaction-driven fluid expulsion, shallow overpressure, or differential compaction.

This study takes a structural analysis and balancing approach in order to distinguish tectonic and non-tectonic fault systems and establish the stress distribution in the Niobrara Formation, around the larger regional and basement. Using trishear to model the deformation of the Niobrara above reactivated basement steps in conjunction with mechanical stratigraphy where multi-directional extensional strains in the competent layers create layer-bound faults with varying strike, is suggested as a tectonic model for the Niobrara fault and fracture enigma.

Selected References

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Sonnenberg, S.A., and D. Underwood, 2012, Polygonal Fault Systems: A New Structural Style for the Niobrara Formation, Denver Basin, CO: AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012, [Search and Discovery Article #50624 \(2012\)](#). Website accessed June 2018.

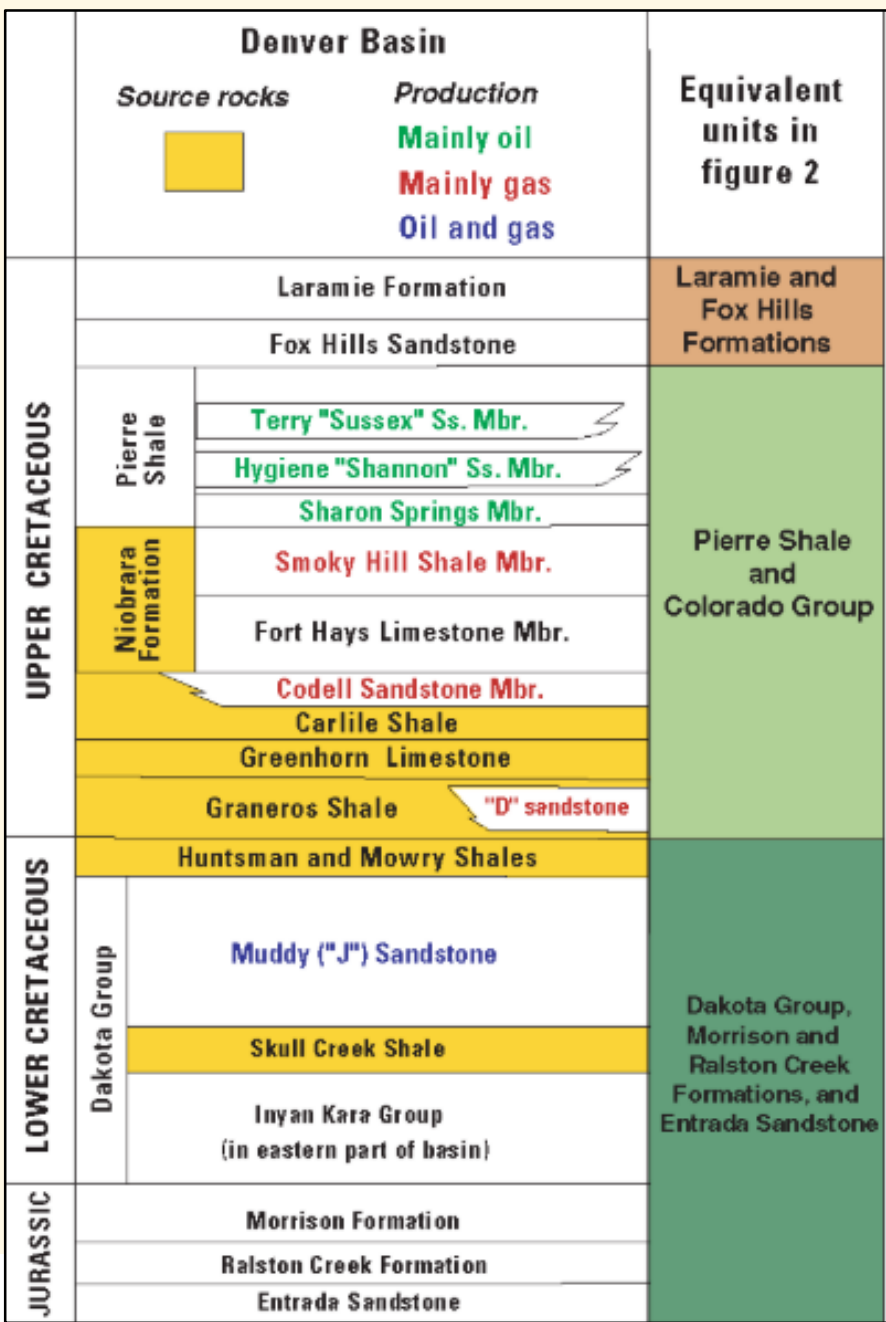
Tectonic versus non-tectonic origin of complex fault and fracture patterns in the Niobrara Fm., DJ Basin, CO

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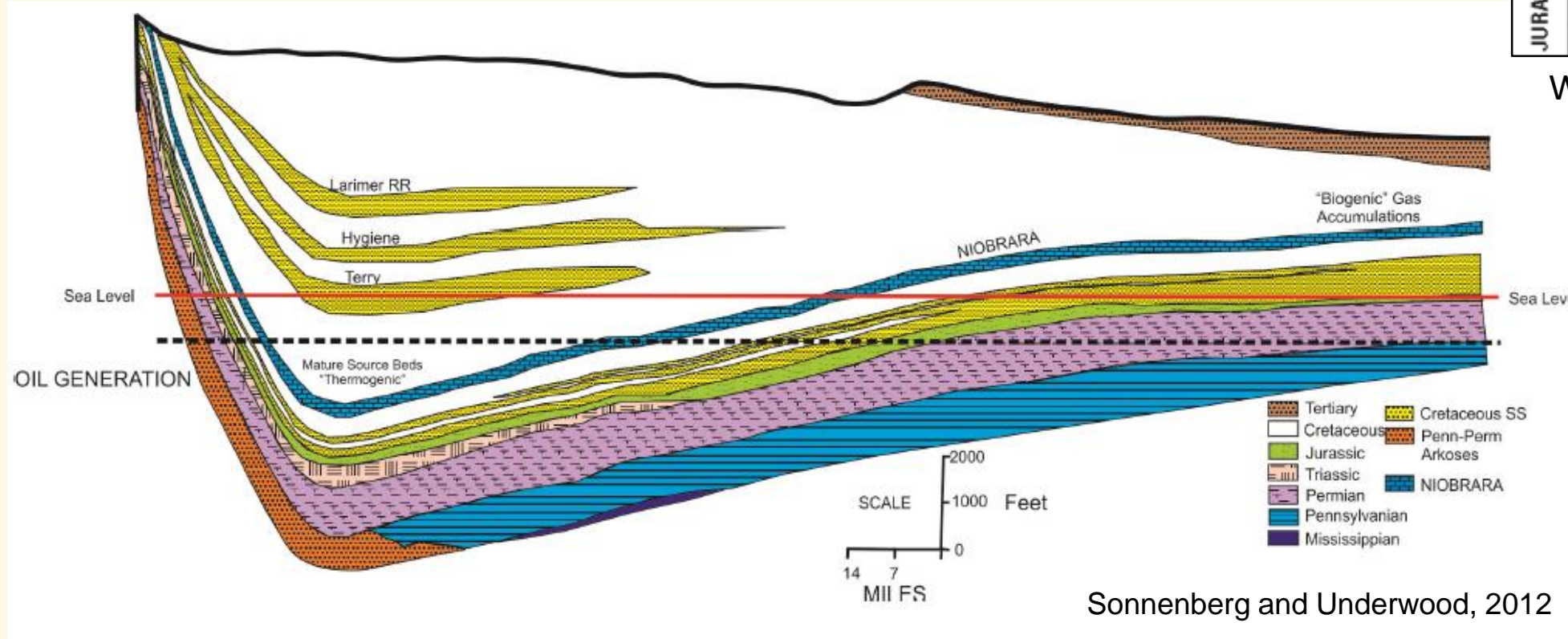
The Niobara Fm. In the Denver-Julesburg Basin, CO

The Niobrara Fm. forms part of the late Paleozoic through early Tertiary sedimentary sequence of the Rocky Mountain foreland basins that were uplifted during the post-Cretaceous Laramide Orogeny. The Denver-Jules (DJ) Basin and others, are asymmetric basins with a steeply dipping western flank bounded by the Rocky Mountains Front Range and a gently dipping eastern flank.

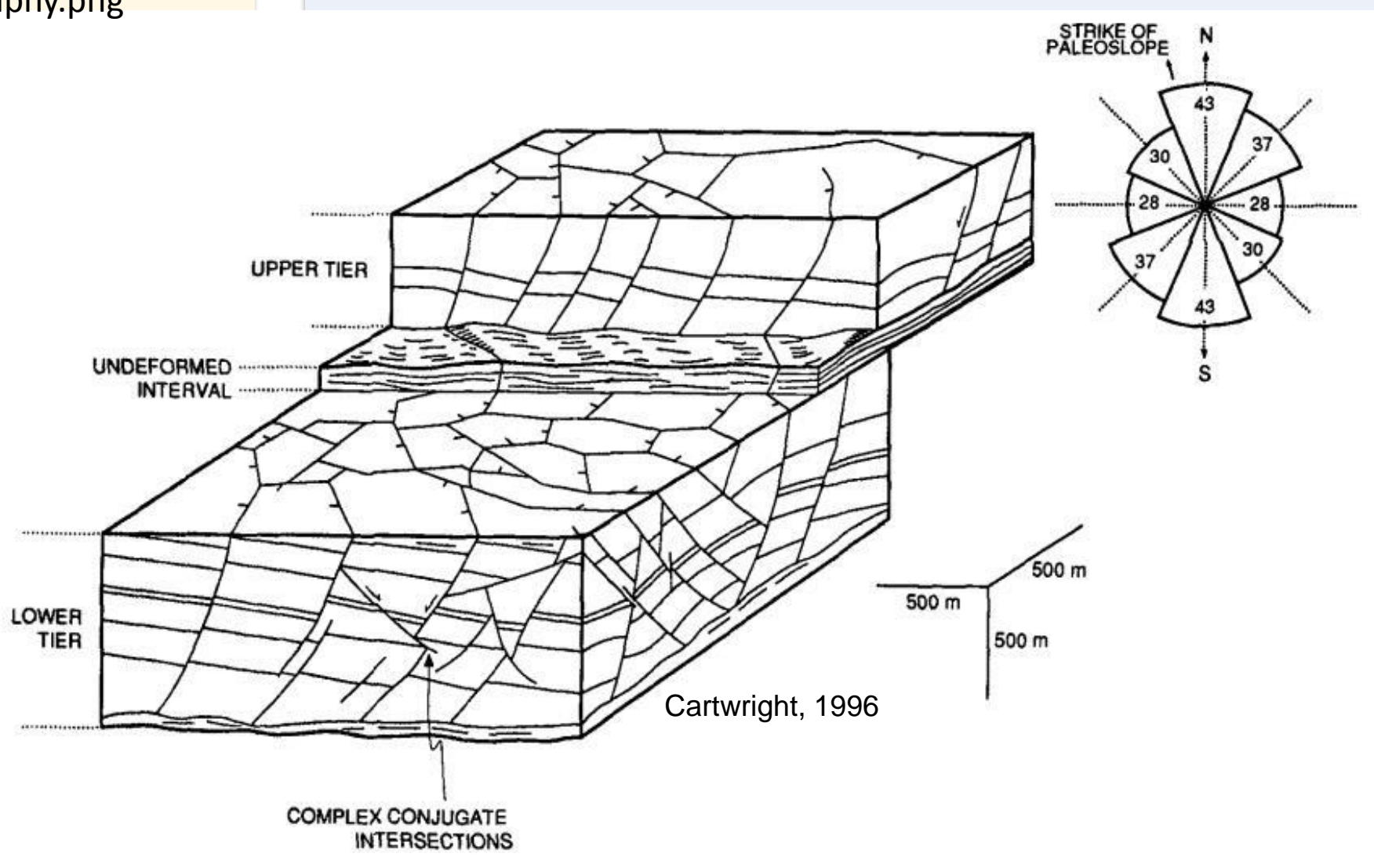
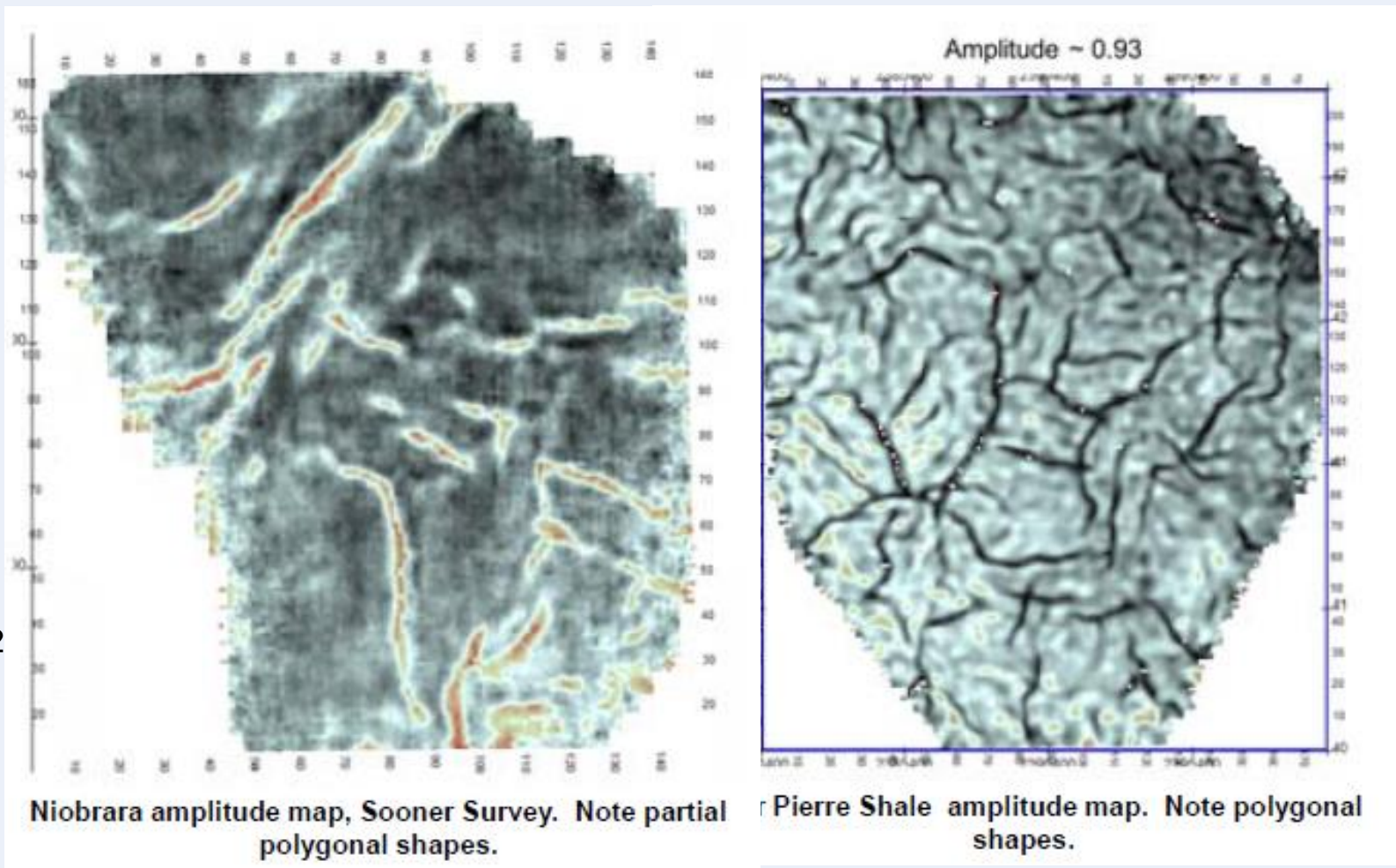
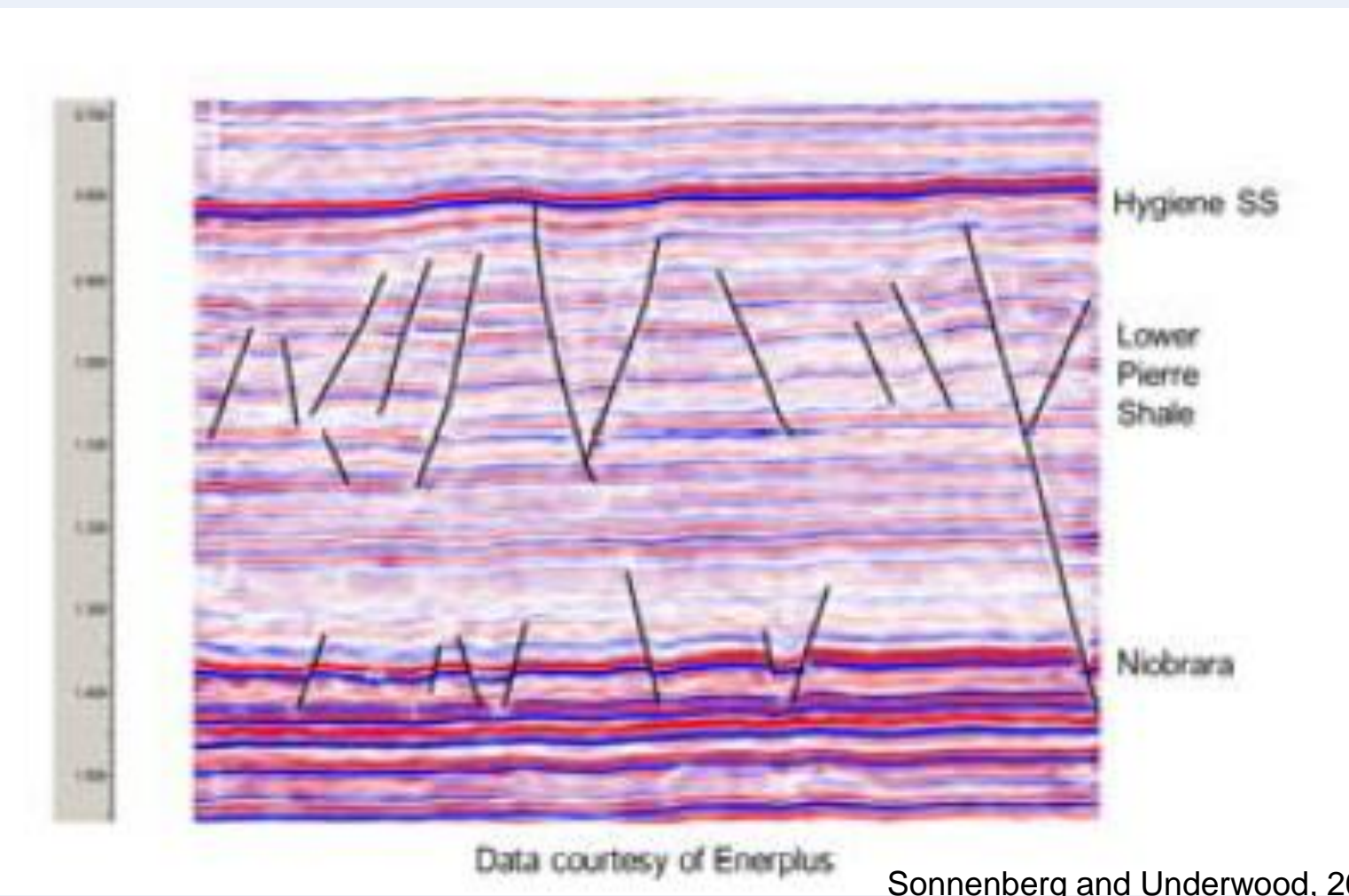
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Wikimedia/Denver_Basin_Stratigraphy.png



Niobrara Faults – polygonal to tectonic

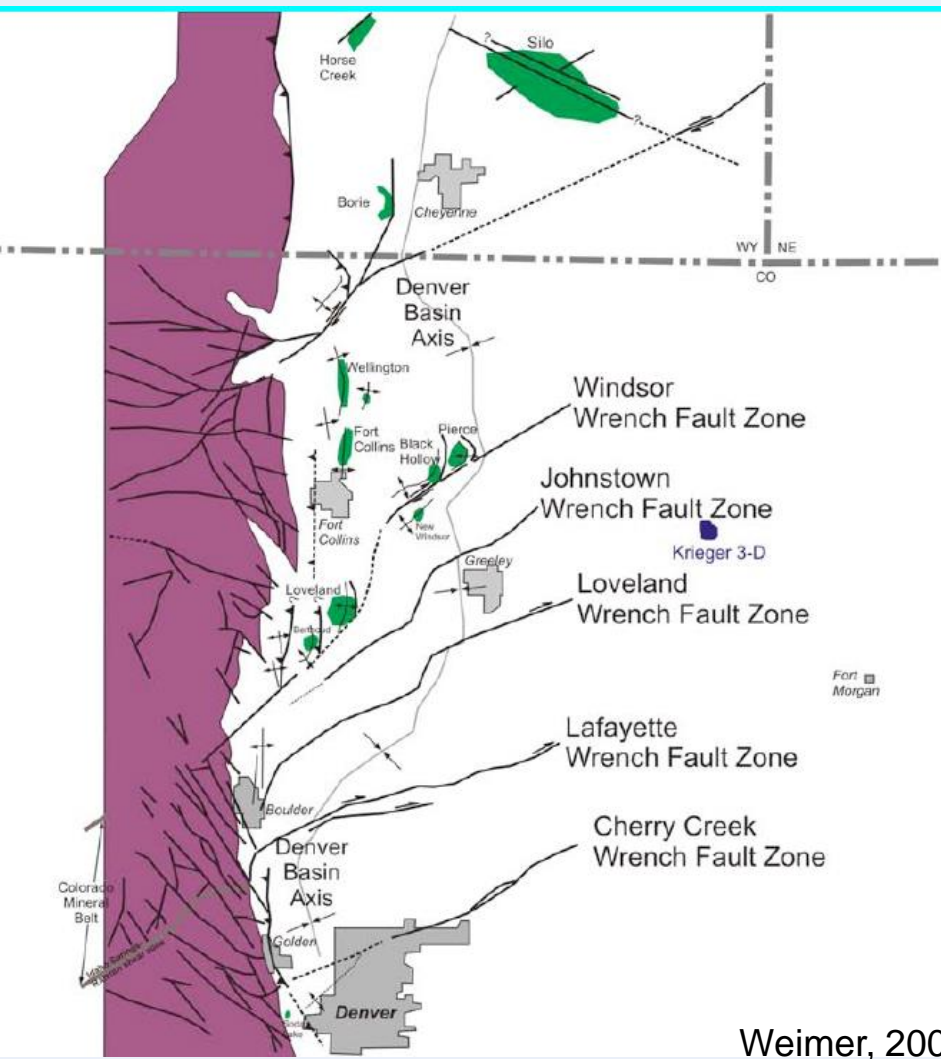


Faults in the Niobrara Fm. are minor extensional faults with throws of 10-60 m and dips of 30-80 degrees. They are distinct layer-bounded systems concentrating in the brittle calcareous rocks over- and underlain and interbedded with soft ductile marine shales sealing the HCs. Although their origin has been debated over the years, the most common recent interpretation is that these are polygonal non-tectonic faults. Polygonal faults have been observed in basins worldwide and are commonly interpreted to be formed by mechanisms such as volumetric contraction due to compaction-driven fluid expulsion, shallow overpressure, or differential compaction.

The faults however vary from random to more organized representing a peculiarity of the Niobrara and raising the question of tectonic versus non-tectonic origin.

Influence of Basement structures and strain cumulation

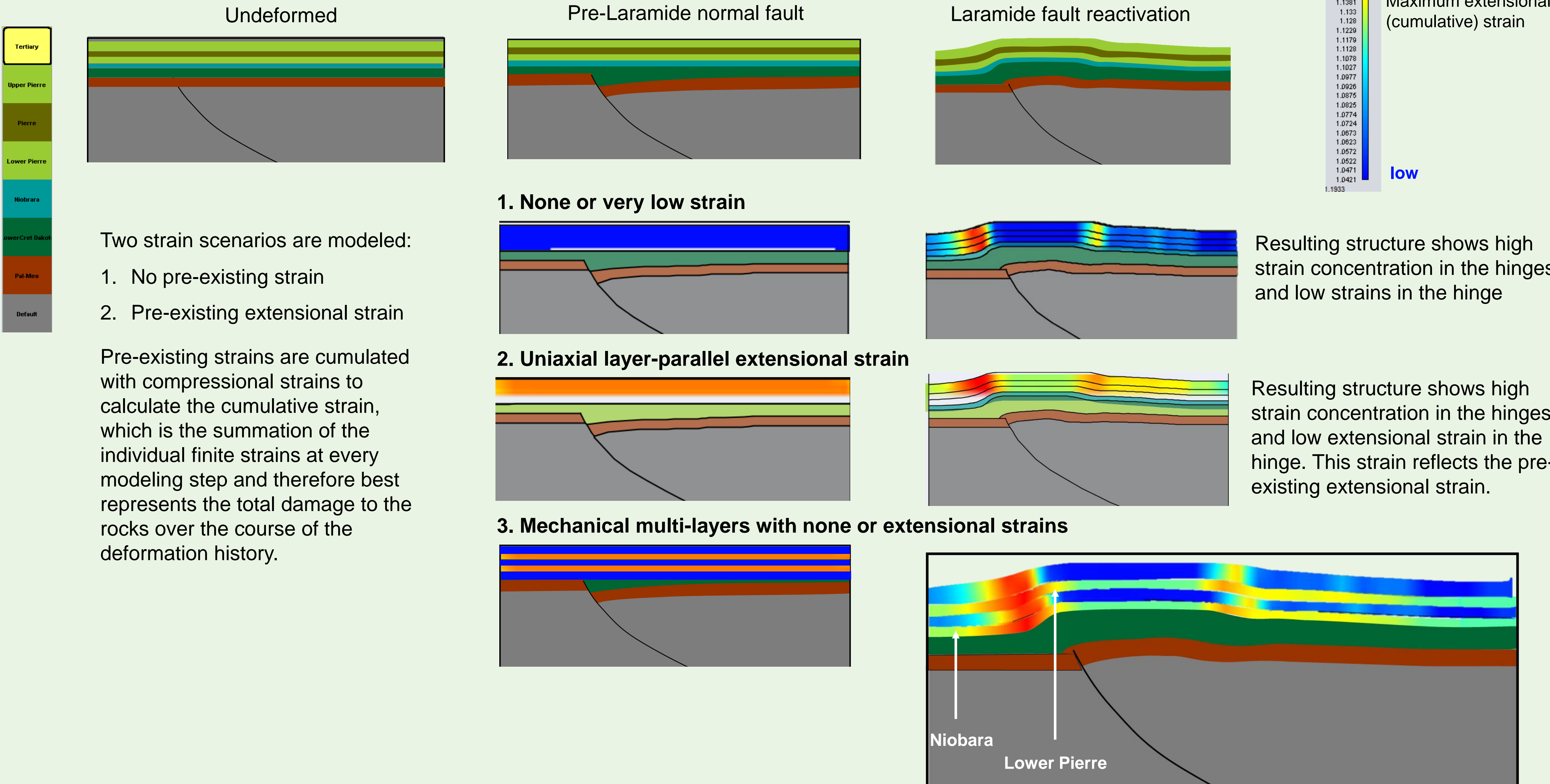
Basement structures often influence the structural architecture and strain distribution of overlying cover sediments by providing a pre-existing geometry or by reactivation. While structural overprinting can be directly observed, the cumulation of strain can have significant influence on the fault and fracture network and geologic scenarios and related HC reservoirs.



Basement-involved faults have been described in the Denver Basin as reverse faults often reactivating older normal faults or strike-slip faults.

Structural Modeling and Strain Tracking

LithoTect Software was used to model the evolution of the Niobrara Fm and related structures. The forward model includes two steps representing pre-Laramide extension and normal faults and Laramide compression and fault reactivation. Since the basement faults are blind, they can be best modeled using trishear, which deforms also the layers above the fault tip.



Two strain scenarios are modeled:

1. No pre-existing strain
2. Pre-existing extensional strain

Pre-existing strains are cumulated with compressional strains to calculate the cumulative strain, which is the summation of the individual finite strains at every modeling step and therefore best represents the total damage to the rocks over the course of the deformation history.

Note that these are schematic models, not to scale or meant to represent a specific regional structure.

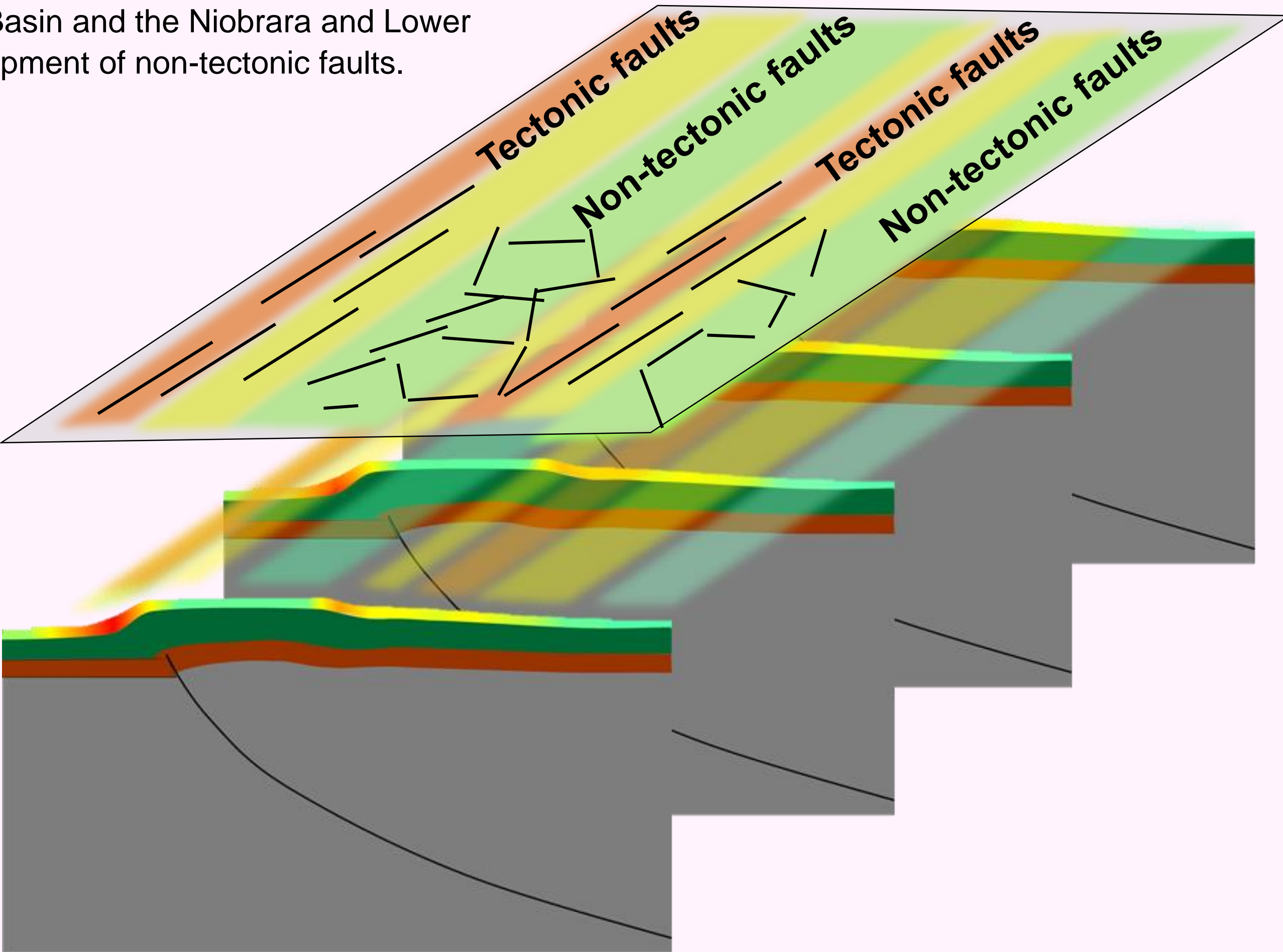
Results and Conclusions

Balancing and forward modeling workflows in combination with tracking of cumulative strains is a powerful technique to understand and predict present-day fault and fracture patterns.

Cumulative strains have been calculated from pre-existing none/low strains and uni-axial layer parallel extension overlap by compressional strains of Laramide deformation.

Mechanical multi-layers mimic the stratigraphy of the Denver-Julesburg Basin and the Niobrara and Lower Pierre Shale development of non-tectonic faults.

Highest strain develop in the fold limbs, where tectonic faults develop with geometrical relationship to deformation directions. Lowest strains develop in the hinges where pre-existing uni-axial extensional strains come through and non-tectonic polygonal faults develop.



Multi-layers with pre-existing none/low and extensional strains, representing Denver-Julesburg Basin stratigraphy.