[PS]Using Structural Restoration Techniques and Strain Tracking to Predict Fracture Distributions*

Catalina Luneburg[1]

[1]Alma Energy, Golden, Colorado, United States (cluneburg@earthlink.net)

Abstract

Structural restorations and forward modeling of the Teapot Dome anticline (Wyoming, USA) show that the evolution of fracture proxies over time can be tracked through the formation of a structure. This allows determining where and when fracture proxies such as curvature, dip, or strain were at their highest values and how these zones of potentially high-density fractures developed over time. Knowledge of the time and boundary conditions for individual fracture sets can then be used to develop predictive 3D models in present-day fractured reservoirs. Strain can be used as a fracture proxy whereby maximum and minimum shear strains as well as the cumulative shear strains may be indicative for different types of fractures and permeabilities. The cumulative strain is calculated as 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 Using the fractured reservoir field of the Teapot Dome anticline (Wyoming, USA) as a case study, the anticlinal structure is restored by trishear on the main fault and then forward modeled in a sequence of time steps while tracking cumulative strain and evaluating fracture formation conditions based on strain intensities and orientations. Tracking maximum and minimum elongations and shear strains reveals the patterns that potentially govern fracture densities. The fracture system at Teapot Dome consists of several sets that typically develop in an anticline with one set parallel and one set perpendicular to the fold axis. A third set that runs oblique to the fold hinge has been described as predating folding. Permeability is most increased in areas close to the fold hinge and along cross faults that transect the fold hinge in a high angle. Most wells have been drilled in a wide zone along the hinge zone following maximum curvature, and wells away from the hinge into the steep western limb are sparse. However, well data in the area of the key section and highest structural culmination shows highest production rates slightly west of the fold hinge and coinciding largely with the highest cumulative shear strain. When comparing the strain modeling results with other studies, there is also a good match with observed seismic average energy maps.

Using Structural Restoration Techniques and Strain Tracking to Predict Fracture Distributions
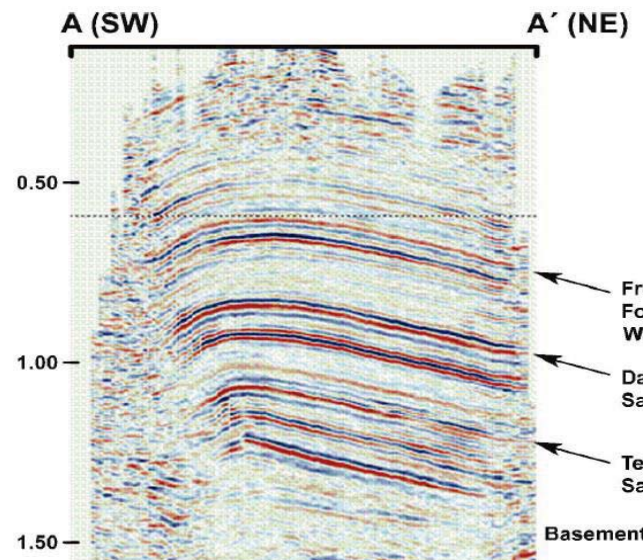
TerraEX GROUP

Catalina Luneburg

The Teapot Dome Anticline

The Teapot Dome anticline, WY is one of the best studied oil and gas fields of fractured reservoir type, worldwide, with large publicly-available data sets from the Rocky Mountain Oilfield Testing Center (RMOTC).
The structure is an asymmetric, doubly plunging, basement cored anticline, of Laramide style The anticline represents a classic 4-way closure structural trap, and has been associated with a large NS trending fault in the western part of the field.
The interpretation of this fault has been debated over the years with interpretations ranging from extensional normal faults to basement-involved blind thrusts
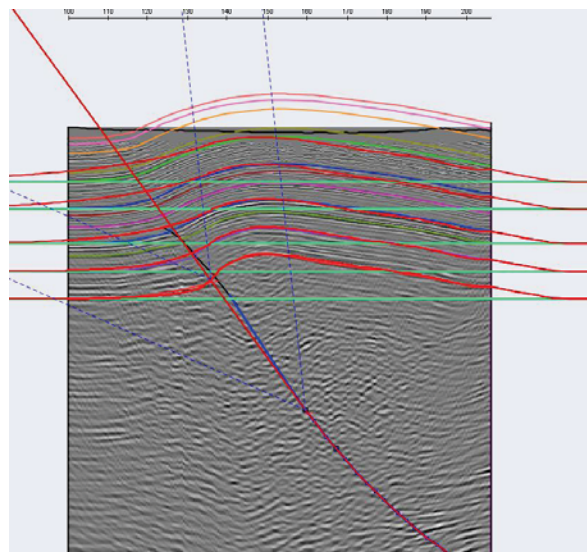
Fox et al. (1991)

Teapot Dome is an unconventional fractured reservoir, located at the southwestern margin of the Powder River Basin WY, Laramide age foreland basin.
The structure is an asymmetric, doubly plunging, basement cored anticline related to a NS trending fault at the eastern limb.

Fracture systems around Teapot Dome Anticline

Stearns and Friedman, 1972

A (SW)   A' (NE)

- 0.50
- 1.00
- 1.50

Frontier Formation Wall Creek
Dakota Sandstone
Tensleep Sandstone
Basement

Depth-converted Teapot Dome Seismic Line D with predicted fault trajectory using initial interpretation of top of basement hanging wall and footwall horizons. Restored section (bedlength and area-balanced) shows perfect match between hanging wall and footwall fault blocks.

Introduction

Predicting natural fracture systems is critical for reservoir development and production fore-casting, as well as optimizing well trajectories, and induced fracture operations.
Natural fracture distributions and intensities are controlled by rock mechanical properties and failure criteria, the regional stress system and the burial and tectonic deformation history. The tectonic history has to be unraveled and analyzed to determine where and when conditions for fracture formation were optimal.
In this study the use of strain as a fracture proxy is investigated by tracking it through the evolution of a tectonic structure. Using the fractured reservoir field of the Teapot Dome anticline (WY, USA) as a case study, the anticlinal structure is restored using restoration software (LithoTect) and then forward modeled in a sequence of time steps while tracking strain and evaluating fracture formation conditions.

Type I fracture set
- Tensional fractures perpendicular to fold axis
- Rotates around plunge of fold
- Mainly along fold limbs

Type II fracture set
- Tensional fractures parallel to gold axis
- Mainly along hinge

shear fractures
Tensional fractures
shear fractures
Tensional fractures

Fractures and proxies

The fracture system at Teapot Dome consists of several sets that typically develop in an anticline with one set parallel and one set perpendicular to the fold axis. A third set that runs oblique to the fold hinge has been described as predating folding.
Permeability is most increased in areas close to the fold hinge and along cross faults that transect the fold hinge in a high angle. Most wells have been drilled in a wide zone along the hinge zone following maximum curvature and wells away from the hinge into the steep western limb are sparse.
However, well data in the area of the key section and highest structural culmination shows highest production rates slightly west of the fold hinge and coinciding to a large extent with the highest cumulative shear strain.
When comparing the strain modeling results with other studies, there is also a good match with observed seismic average energy maps.

ABSTRACT

Structural restorations and forward modeling of the Teapot Dome anticline (Wyoming, USA) show that the evolution of fracture proxies over time can be tracked through the formation of a structure.
This allows to determine where and when fracture proxies such as curvature, dip, or strain were at their highest values and how these zones of potentially high density fractures developed over time. Knowledge of the time and boundary conditions for individual fracture sets can then be used to develop predictive 3D models in present-day fractured reservoirs. Strain can be used as a fracture proxy whereby maximum and minimum shear strains as well as the cumulative shear strains may be indicative for different types of fractures and permeabilities. The cumulative strain is calculated as 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
Using the fractured reservoir field of the Teapot Dome anticline (Wyoming, USA) as a case study, the anticlinal structure is restored by trishear on the main fault and then forward modeled in a sequence of time steps while tracking cumulative strain and evaluating fracture formation conditions based on strain intensities and orientations. Tracking maximum and minimum elongations and shear strains reveals the patterns that potentially govern fracture densities.
The fracture system at Teapot Dome consists of several sets that typically develop in an anticline with one set parallel and one set perpendicular to the fold axis. A third set that runs oblique to the fold hinge has been described as predating folding. Permeability is most increased in areas close to the fold hinge and along cross faults that transect the fold hinge in a high angle. Most wells have been drilled in a wide zone along the hinge zone following maximum curvature, and wells away from the hinge into the steep western limb are sparse. However, well data in the area of the key section and highest structural culmination shows highest production rates slightly west of the fold hinge and coinciding to a large extent with the highest cumulative shear strain. When comparing the strain modeling results with other studies, there is also a good match with observed seismic average energy maps.

Trishear Model

A key section through the highest culmination of the 4-way closure has been balanced and restored. The main fault displacement dies out vertically and the hanging wall deforms over the tip of the fault.
This blind fault can be best restored using trishear, which models a triangular zone of deformation in front of the fault tip. When forward modeling the fault using trishear, an excellent correlation with the present-day folded layers is reached. Starting from an undeformed sequence, the structure is modeled in a number of steps for each of which complex geometry fields such as dip, curvature, and strains are calculated.

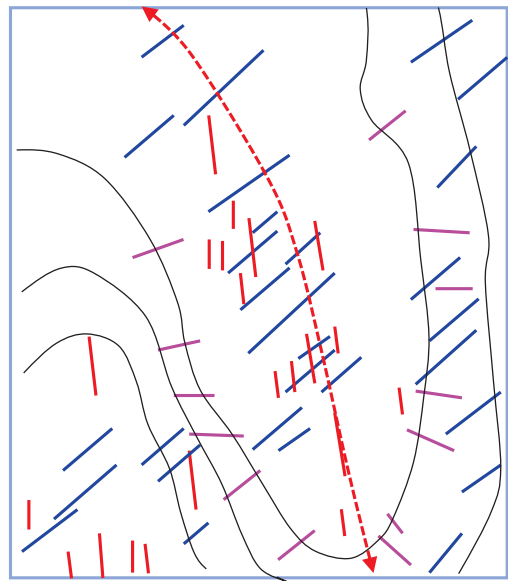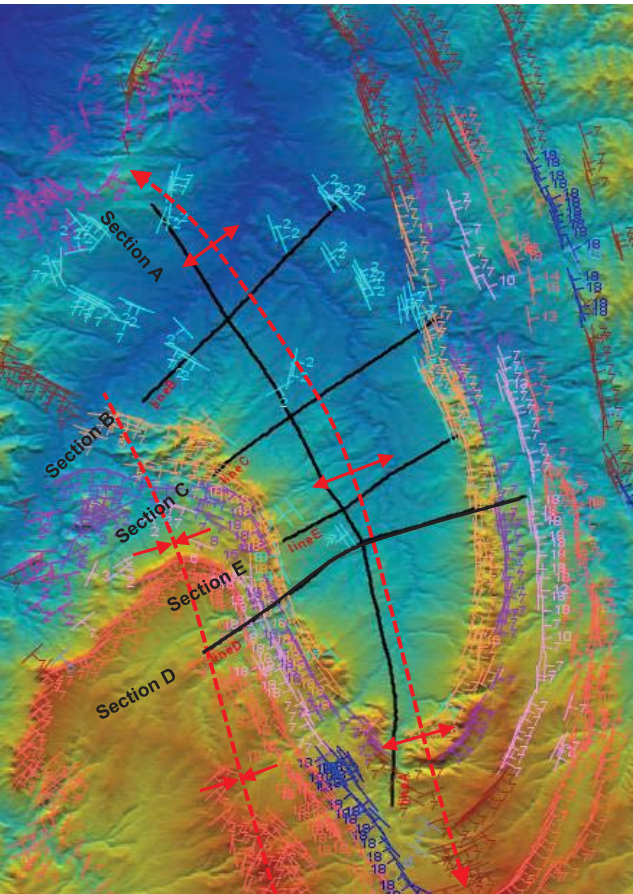
Cumulative Strain development

While highest dips concentrate in the steep forelimb of the anticline, the highest curvature concentrates in the hinge. Over time, the zone of highest curvature widens as the hinge zone develops and the fold amplifies.
The strain pattern is governed by the asymmetry of the fold. The incremental strain remains the same and propagates over time toward the steep limb.
The finite strain shows maximum elongation in the hinge and maximum shortening in the steep limb.
The cumulative strain is highest in steep limb and widens as the structure developed

Incremental Shear Strain

Cumulative Shear Strain

Curvature

Zone of maximum incremental shear strain propagates

Zone of maximum cumulative shear strain propagates and widens
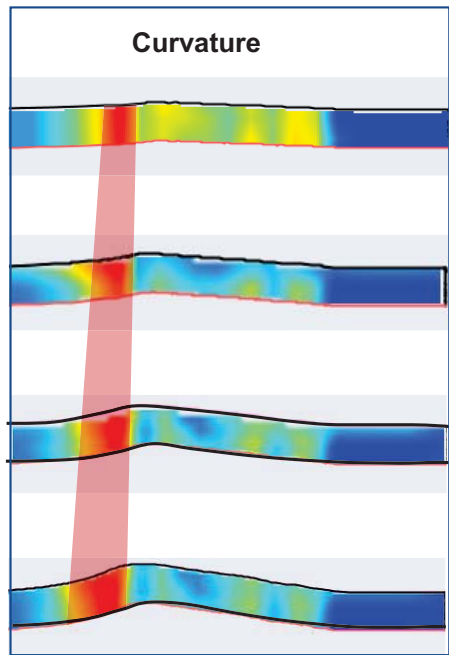
Zone of max curvature propagates with hinge and widens

Conclusions

Structural restorations and forward modeling of the Teapot Dome anticline (WY, USA) show that the evolution of fracture proxies over time can be tracked through the formation of a structure.
This allows to study where and when fracture proxies such as curvature, dip or strain were at their highest values and how these zones of potentially high density fractures developed over time.
Knowledge of the time and boundary conditions for individual fracture sets can then be used to develop predictive 3D models in present-day fractured reservoirs.
Strain can be used as a fracture proxy whereby maximum and minimum shear strains as well as the cumulative shear strains may be indicative for different types of fractures and permeability.

Incremental strain = increments of distortion that affect a body during deformation from one stage to the next
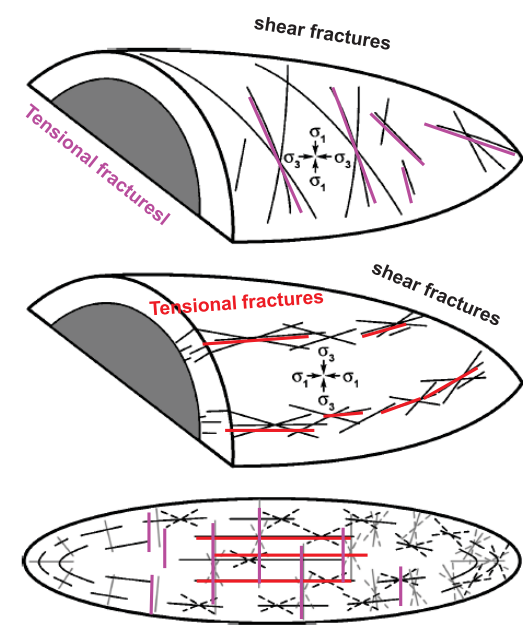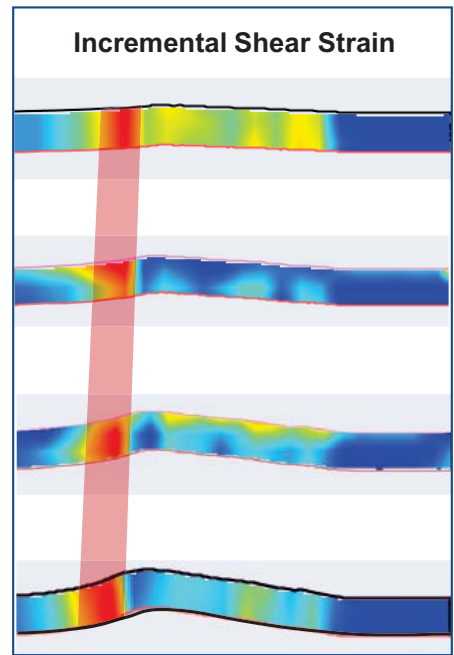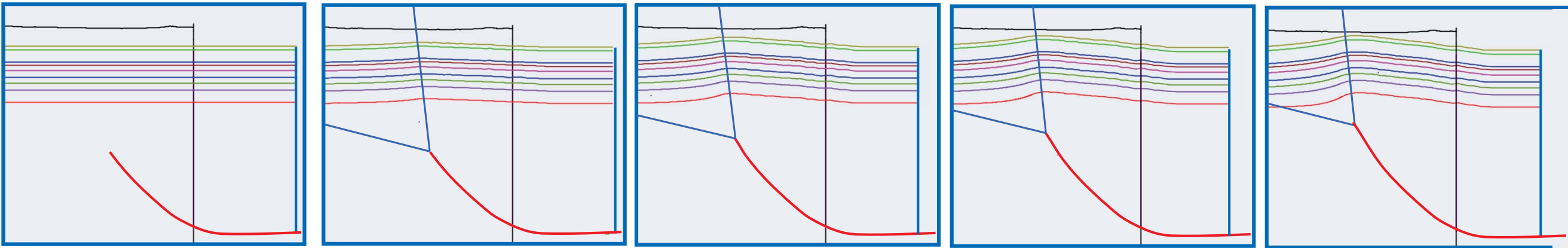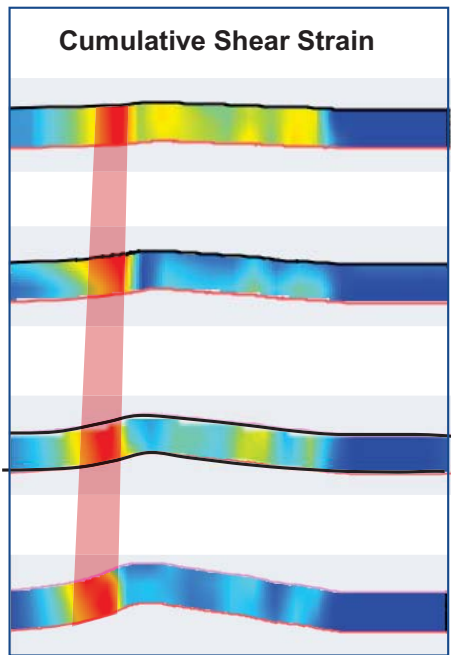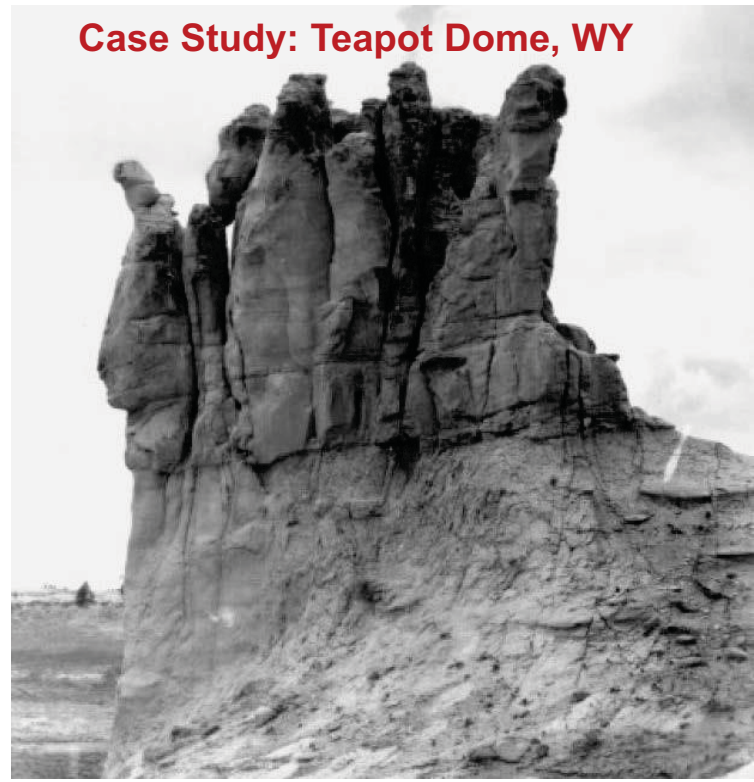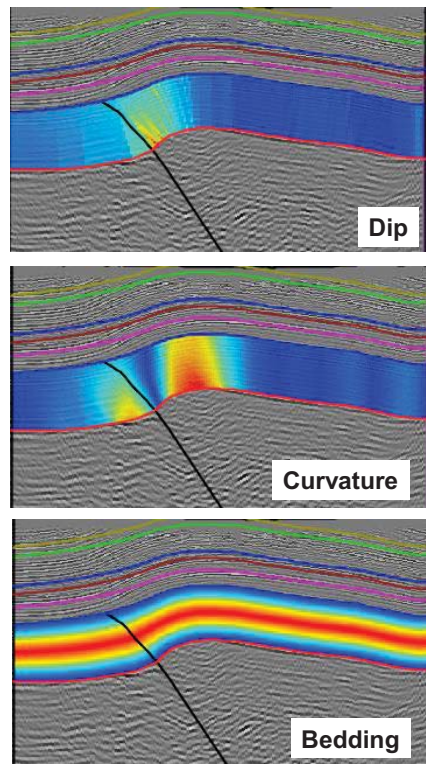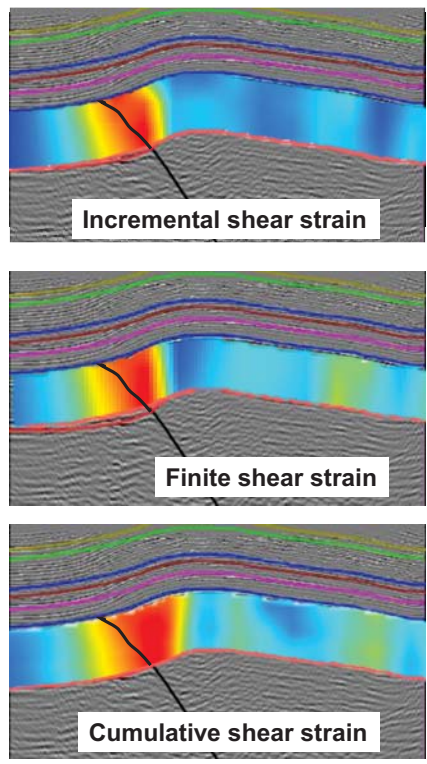
Finite strain = summation of all of the incremental components representing the total distortion (strain) compared to its original shape.

Cumulative strain = summation of all of the incremental components from one step to the next – adding absolute values

>>> YOU HAVE TO KNOW DEFORMATION HISTORY!

Selected time steps of the trishear forward model. For every modeling step complex geometry fields for curvature (lower) and cumulative shear strain (upper) are calculated.

Dip
Incremental shear strain
Curvature
Finite shear strain
Bedding
Cumulative shear strain

Complex geometry fields calculated from the present-day Teapot Dome anticline. Incremental, finite and cumulative strains as well as highest dips are concentrated in the steep limb of the fold whereas highest curvature occurs in the hinge region of the fold.