N169: Structural Geology for Reservoir Characterization: Seismic-scale Outcrop Analogues and Applied Methods *(SW Montana, USA)*

Instructor(s): Lans Taylor and Jim Grant

Format and Duration

Field - 6 Days
Moderate Physical Demand

Summary

This course evaluates techniques that transform seismic-scale structural interpretation into quantitative prediction of reservoir properties for reservoir simulation. Participants learn how to use restoration, curvature analysis and stress modeling to gain insight into the spatial variability of reservoir properties and the orientation of structural anisotropy. Calibration with analog data allows structural heterogeneity to be quantified and incorporated into reservoir simulation, thereby optimizing field development.

Learning Outcomes

Participants will learn to:

1. Evaluate the origin, hydraulic properties and geometric distribution of reservoir-scale structures.
2. Demonstrate how structural heterogeneity can be incorporated into a reservoir simulation model.
3. Evaluate different flow simulation techniques (DFN, effective media, dual porosity) with respect to how structural heterogeneity is incorporated into a reservoir simulation model.
4. Perform manual restoration on outcrop data using line length balancing and vertical and inclined shear.
5. Validate the migrating hinge model using flexural slip.
6. Evaluate the impact of mechanical stratigraphy, rock properties, depth of burial and the magnitude and orientation of applied loads within the context of curvature analysis.
7. Predict production “sweet spots” based on analysis of subsurface stress patterns.

Training Method

A six-day classroom and field course based in Bozeman and Cardwell, Montana. This is an intensive, hands-on course designed to deliver functional knowledge. Participants will engage in field work (60% of course time) and extensive classroom exercises (40%). The exercises use graphical solutions, manual constructions and 2D simplifications that non-specialists can apply quickly and easily. The key techniques are structural restoration, curvature analysis and stress modeling. In each case, software products can facilitate analysis, but the techniques are not dependent on software.

Physical Demand

The physical demands of the field area are MODERATE according to the Nautilus Training Alliance field course grading system. Participants need to be able to walk cross-country on uneven, loose and inclined surfaces for up to 1 mi / 1.6 km. They may be outside for many hours without shade. There are no major ascents or cliff sections.

Please note that a portion of the course is conducted at a university field station with accommodation in rustic cabins therefore some participants may have to share accommodation.

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Who Should Attend

General geologists, geophysicists and engineers engaged in the development of reservoirs that contain joints, deformation bands or faults; or which display stress dependent reservoir properties. Background in structural geology is beneficial but not required. Knowledge of basic seismic interpretation and the principals of petroleum geology is expected.

Course Content

The course covers clastic, carbonate, and shale reservoirs in contractional and extensional tectonic settings. This is not a fault seal course. Determining hydraulic properties of seismically-imaged faults may be part of constructing a simulation model, but this course focuses on features like joints and deformation bands that are widespread across the reservoir.

The first day of the course is dedicated to introduction and context. What are reservoir-scale structures? How do they impact reservoir performance? How are they represented in reservoir simulation?

Following that, we tackle four extended exercises, each lasting a full day. Each exercise begins in the classroom with a lecture that introduces key concepts. Next, we head to the field where participants collect quantitative data across multiple scales of observation. After lunch in the field, we return to the classroom and apply a predictive technique calibrated with the field data. Each day concludes with an example of the technique applied to a subsurface accumulation and discussion of lessons learned.

Where are we going and why? After covering introductory material, we head to the field to look at reservoir scale deformation in outcrop. We will identify several types of reservoir scale structures, and will discuss their origin, hydraulic properties and geometric distribution. Following the field work, we return to class to discuss flow simulation techniques (DFN, effective media, dual porosity) and conclude by introducing the predictive techniques that will be the focus for the remainder of the course.

Extensional Restoration We'll begin with a review of extensional structural styles and then visit an extensional fault propagation fold at the north end of Paradise Valley where the bounding fault of the Basin and Range is exposed. During the afternoon, we introduce restoration and manually restore the outcrop data using line length balancing and vertical and inclined shear. Geometric strain from the restoration is compared to the outcrop data. We conclude with discussion about the strengths and weaknesses of the approach.

Contractional Restoration We continue with a review of contractional structural styles. Then we visit a fault propagation fold at the north end of the Bridger Range where we can compare fracturing in massive and thinly bedded limestones. In class, we discuss kink-band model construction and do an exercise using flexural slip to investigate the migrating hinge model. Again, we conclude with relevant discussion and a subsurface analog.

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Curvature Analysis This is a full day dedicated to curvature analysis. In a combination of field stops and classroom exercises, we will look at plate bending, flexural slip and viscous flow mechanisms. We'll investigate the impact of mechanical stratigraphy, rock properties, depth of burial and the magnitude and orientation of applied loads. We will look at scale dependence, ask what different curvature attributes mean and determine why certain attributes may or may not correlate with reservoir performance.

Stress Modeling We conclude the course with a day dedicated to the analysis of subsurface stress patterns, what controls them, how they are distributed in space, how they can be modeled and, most importantly, how to use them to identify productive sweet spots in continuous, basin-centered or tight gas accumulations.

Daily Itinerary

Day 0
Participants arrive in Bozeman, MT and travel to the Indiana University Geologic Field Station (IUGFS) near Cardwell, MT in the Tobacco Root Mountains.

Day 1
The bulk of the first day will be spent on introductory lectures and covering key concepts that will be used throughout the class, followed by afternoon field work in the Sandy Hollow area. Participants overnight at IUGFS.

Day 2
Morning class work followed by afternoon field work in the Tobacco Root Mountains. Participants overnight at IUGFS.

Day 3
Morning lectures before participants depart IUGFS for field work en route to Bozeman. Participants overnight in Bozeman.

Day 4
Morning class work followed by afternoon field work in the Paradise Valley area east of Bozeman.

Day 5
Morning class work followed by afternoon field work in the Bridger Range North of Bozeman.

Day 6
Morning wrap-up session, followed by a final afternoon field stop, after which participants depart for home or overnight in Bozeman for morning departures.