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Anne H. Covault
University of Texas Dallas

Stratigraphic controls on fault zone architecture in Salina Canyon tunnel, Utah

Introduction

Faults may play a major role in hydrocarbon reservoir compartmentalization. Our ability to predict and understand the effect of faults on the fluid flow within subsurface reservoirs however is highly dependent on knowledge of both the structural and stratigraphic architecture. One of the best approaches to evaluate and advance existing methods and develop new insight and applications for determining the fault zone architecture is outcrop mapping. A recognized limitation of outcrop mapping is that most sections are exposed only in 2 dimensional roadcuts. Consequently, the lithological controls on the distribution of fault gouge or fault rock along the fault surface are poorly understood in three dimensions (Doughty, 2003). We propose a detailed study of a fault zone that is well-exposed in three dimensions cutting a fluvial section with lateral facies changes to investigate the stratigraphic and lithological controls on the development of the fault gouge and damage zone. The fault is exposed in an abandoned railroad tunnel and on an adjoining external cliff near Salina Canyon, Utah, allowing a three dimensional view of the fault within the tunnel and a second perspective within the cliff face outside the tunnel and the surrounding sediments of the Blackhawk and Castlegate formations.

Objectives

The goals of this project are as follows: (1) Describe and map in detail the stratigraphic and structural framework of faulted fluvial sediments and the unfaulted sediments in close to the fault. (2) Analyze samples from the fault and the host rock to determine petrographic characteristics of faulted and unfaulted sediments, the mechanisms of failure within the fault zone, and the petrophysical properties such as permeability and porosity. Evaluate the stratigraphic controls on the fault zone style and fault zone mechanisms. (3) Use a 3D, photorealistic, laser-scanned digital model of the tunnel and outer cliff ([a] as a base for detailed structural and stratigraphic mapping; [b]. as a tool for modeling the 3-dimensional fault zone geometry). (4) Interpret the fault rock distribution along the fault surface relative to existing algorithms.

Background

This fault in question is well-exposed in three dimensions in the Salina Canyon abandoned railroad tunnel in central Utah, providing an ideal location to examine the structural and stratigraphic complexity within the inner core of the fault zone, in the damage zone of small faults around the central core, and in the host rock or undisturbed section adjacent to the fault zone. The formations cut by the fault are clastic deposits of the Cretaceous fluvial Blackhawk and Castlegate Formations deposited in the Western Interior Seaway during the Sevier Orogeny. The Blackhawk formation (of the lower Mesa Verde Group) is made up of marine, marginal marine, and coastal plain sediments. At the study site, only the upper-most mud-dominated fluvial deposits are exposed. The immediately overlying Castlegate formation (of the upper Mesa Verde Group) is composed mostly of fluvial sandstones and conglomerates with rare floodplain and abandoned channel mudstones (Hampson *et al.*, 1999). Juxtaposed and mechanically and diagenetically altered interbedded sands and shales in these formations cut by the fault create the gouge and potential sealing mechanisms along the fault.

The lateral and vertical variation and distribution of these sediments at a macro-scale and the grain and matrix constituents at the grain scale influence the fault gouge and mechanisms by which it forms (Knipe *et al.*, 1998). Detailed mapping and sample analysis of the stratigraphic and faulted section will provide answers to the following questions: (1) What control does the grain size and lithology have on the distribution of sediments in the inner core of the fault zone? (2) How do clays influence the properties and mechanisms of the fault rocks and their distribution along the fault?[2a] What is the mix of detrital vs. authigenic clay and how does their timing impact the fault style? [2b] How are the clay constituents distributed within the fault zone? (3) What additional diagenetic alterations are observed in the host and fault and how are these interpreted relative to the depth of burial and interpreted uplift?

Current methods for predicting the distribution of fault rock properties across a fault rely primarily on simple geometric algorithms, which may not render the best representation of a fault zone with complete exposure. The three-dimensional exposure of the formations in this study allows us to examine both the vertical and lateral variation in stratigraphic architecture, as well as the stratigraphic variation near and farther away from the fault. Such information could prove extremely valuable for the prediction of the behavior and sealing potential of faulted reservoir sediments analogous to the study location (Doughty, 2003; Knipe, 1997).

Methods

Traditional methods of mapping structure and stratigraphy involve tracing observed stratigraphic and fault boundaries onto flat photomosaics. In this study, however, we will transfer the photomosaic interpretation from the field onto a three-dimensional, digital model of the fault over which high-resolution photo images of the stratigraphic and structural features have been draped. The 3D model of the fault zone was acquired by a Riegl Z360i laser scanner that digitally recorded points reflected from the tunnel and outcrop surface by reflectorless laser at a rate ranging between 8,000 to 12,000 points per second. Post processing of the points and GPS reference in space relative to the position of the scanner provides a digital elevation model of the fault surface. Photos draped onto the digital points provide a "virtual" model of the outcrop. The digitized surface of the interior of the tunnel and the external surface of an adjacent cliff face is shown in Figure 1. The digital mapping and 3-dimensional interpretation will test the technology for outcrop mapping and interpretation and answer the following questions: 1) How useful is this model for this particular study? What would improve the utility of the model? (i.e., better pictures?). 2) Did the use of this model in this study reveal any potential applications of the model for other types of geologic studies? 3) Based on the results of this study, what parameters should be considered when applying this technology to other studies?

The high resolution, 30-second exposure digital images captured for the laser-scanned surfaces and draped onto the digital mesh of the model will be used as a photobase for the mapping of the major structural and stratigraphic features in the field. A Global Positioning System (GPS) will be used to georeference the interpretation of the fault and stratigraphy. The georeferenced interpretation will allow us to transfer it onto the digital terrain model with the photodrape of the mapped surfaces. This will provide a unique 3-dimensional map of the faults that can be rotated and displayed with 3-dimensional surface rendering software such as GOCAD, and will facilitate the analysis of the lateral distribution and controls of the stratigraphy across the fault surface.

Additional photos will be taken to record more detailed structures. Detailed mapping onto the photographic base in the field will provide an interpretation at a range of scales. These photographs form the base from which to develop conceptual models for the distribution and fault rock types that develop for a particular lithology.

Measured sections of the stratigraphic intervals provide the detailed description of the stratigraphic variation across the outcrop. The measured sections show the lithology, the grain size, and qualitative mechanical strength contrast between the layers. The mechanical and diagenetic controls, however, are best evaluated by selecting samples from the fault and host to evaluate in the laboratory.

Several methods may be used for the petrographic analysis of the sediments collected from the study site. Examining samples in thin section and SEM provide the porosity, grain size, grain and matrix constituents, as well as the cements and other diagenetic alteration. Crosscutting relationships and mechanical and chemical changes in the faults show the process by which the rocks fail. As clays introduced and mixed into the fault zone are important controls on the fault permeability, X-Ray Diffraction (XRD) analysis will be performed on several samples to determine the types and volume percents of these assemblages. Polished rock slabs can reveal small-scale structures not otherwise seen in outcrop.

The excellent exposure afforded by the Salina Canyon tunnel and the geometry of the fault allow us to study the relationship between the structural and stratigraphic architecture, and how these components vary in three dimensional space. Combining this advanced technology for mapping the fault zone architecture with the sample description and analysis to show the mechanisms of fault rock development has the potential to improve reservoir characterization, understanding, and prediction.

This proposal is for partial funding of fieldwork for a MS degree at the University of Texas Dallas. The work proposed is for the summer of 2005 with sample analysis and interpretation during 2005-2006. This work should generate several meeting technical abstracts for presentations at national meetings and at least one peer reviewed paper.

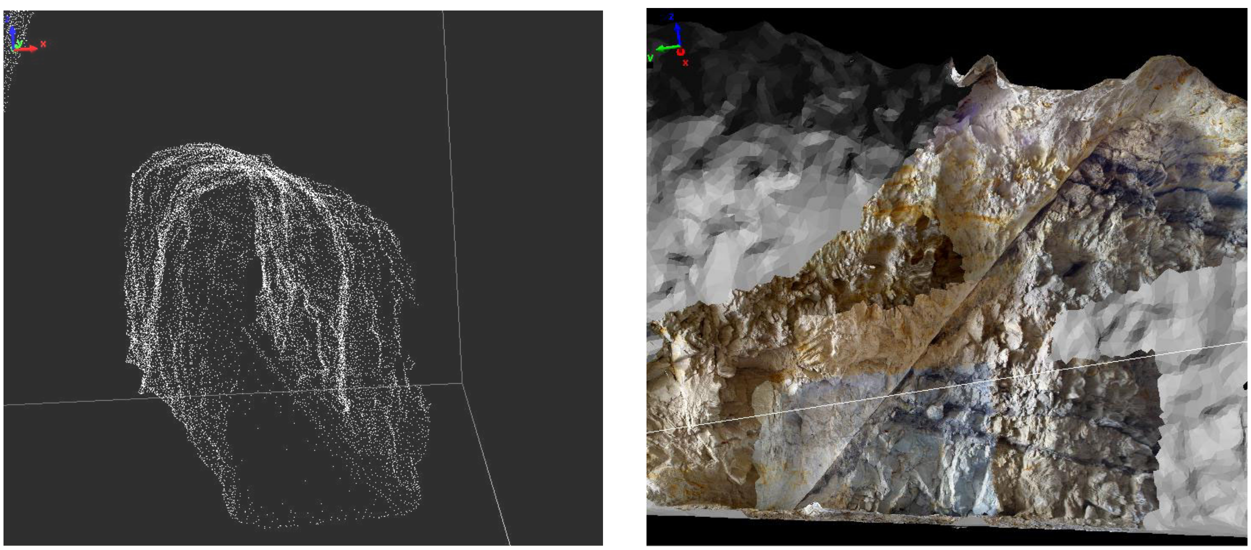

Figure 1. Laser-scanned 3D model of study site. A. The digitized surface of the interior of the tunnel. B. A portion of the 3D model draped with the corresponding high-resolution photo.

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