



Research Paper

Ground-based hyperspectral imaging and terrestrial laser scanning for fracture characterization in the Mississippian Boone Formation

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ABSTRACT

Petroleum geoscientists have been using cores and well logs to study source rocks and reservoirs, however, the inherent discontinuous nature of these data cannot account for horizontal heterogeneities. Modern exploitation requires better understanding of important source rocks and reservoirs at outcrop scale. Remote sensing of outcrops is becoming a first order tool for reservoir analog studies including horizontal heterogeneities. This work used ground-based hyperspectral imaging, terrestrial laser scanning (TLS), and high-resolution photography to study a roadcut of the Boone Formation at Bella Vista, northwest Arkansas, and developed an outcrop model for reservoir analog analyses.

The petroliferous Boone Formation consists of fossiliferous limestones interbedded with chert of early Mississippian age. We used remote sensing techniques to identify rock types and to collect 3D geometrical data. Mixture tuned matched filtering classification of hyperspectral data show that the outcrop is mostly limestones with interbedded chert nodules. 1315 fractures were classified according to their strata-bounding relationships, among these, larger fractures are dominantly striking in ENE – WSW directions. Fracture extraction data show that chert holds more fractures than limestones, and both vertical and horizontal heterogeneities exist in chert nodule distribution.

Utilizing ground-based remote sensing, we have assembled a virtual outcrop model to extract mineral composition as well as fracture data from the model. We inferred anisotropy in vertical fracture permeability based on the dominance of fracture orientations, the preferential distribution of fractures and distribution of chert nodules. These data are beneficial in reservoir analogs to study rock mechanics and fluid flow, and to improve well performances.

1. Introduction

With higher demand for resources, exploration for new oil and gas plays and improving exploitation from current petroleum plays are increasingly important. To understand the source and reservoir rocks, petroleum geoscientists have been studying cores and well logs (Van Wagoner et al., 1990), however, the inherent localized nature of well-bore data cannot account for horizontal heterogeneities (Hewett, 1986; Miall, 1988). Modern exploitation requires in-depth understanding of key source rocks and reservoirs at outcrop scale. In particular, fractures from brittle deformation of rocks provide information on the tectonic history as well as the rock properties. The information is critical to access reservoir fluid flow and fluid storage.

The Lower Mississippian Boone Formation is an actively producing

reservoir in northern Oklahoma and southern Kansas (Manger and Shelby, 2000). Previous studies focused mostly on sedimentology, stratigraphy, and geochemistry (Koch et al., 2014; Lane and De Keyser, 1980; Manger and Shelby, 2000; Mazzullo et al., 2013, 2011; Shelby, 1986). However, not much work has been done on structural and tectonic impacts on the Boone Formation that are important to understand the mechanical characteristics of rocks and to improve hydrocarbon withdrawal (Laubach et al., 2009; Narr, 1991). Structural mapping including fracture orientations and distribution is needed to understand the deformation style of the Boone Formation. Different rock types have distinctive strength, permeability and porosity; consequently, lithology has large impacts on fracture distribution and fluid migration. A detailed fracture analysis requires knowledge of the lithology in which the fractures have developed.

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Ground-based hyperspectral imaging of geological outcrops has been flourishing in recent years (Alonso de Linaje and Khan, 2017; Krupnik et al., 2016; Kurz et al., 2013; Murphy and Monteiro, 2013; Okyay et al., 2016; Okyay and Khan, 2016; Sun and Khan, 2016). This technique collects spectral data with high spatial and spectral resolution, and facilitates detailed spectral analysis to extract mineral information from each pixel and map the lithological variations on the outcrops. Terrestrial laser scanning (TLS) is also widely utilized by geologists (Krupnik et al., 2016; Kurz et al., 2013; Minisini et al., 2014), which collects 3D geometrical information, and allow fast and high resolution 3D mapping of the outcrop. This study combines these two techniques together, and performs an integrated mineralogical and structural modeling of an outcrop of the Boone Formation. With these data we assembled a virtual outcrop model, and use the model as an analog to infer fracture permeability of rocks. This work provides a workflow for applications of ground-based remote sensing in oil and gas exploration and exploitation.

2. Geologic settings

This study analyzes the fracture distribution on an outcrop of the Boone Formation in northwest Arkansas. The Boone Formation consists of coarse-grained fossiliferous and fine-grained gray limestones interbedded with anastomosing and bedded chert deposited in early Mississippian age (Chandler and Ausbrooks, 2010; McFarland, 1998) in a shelf margin environment (Lane and De Keyser, 1980). It is underlain unconformably by the Saint Joe Formation and overlain by the Moorefield Formation (Fig. 1). The Boone Formation is a producing reservoir rock in north Oklahoma and south Kansas; its outcrops are exposed in the Ozark region at northwest Arkansas, northeast

Oklahoma, and southwest Missouri (Manger and Shelby, 2000; Mazzullo et al., 2011).

The outcrop for this study is a road cut along US Highway 71 at Bella Vista, Benton County, Arkansas (Fig. 2). This region is on the Springfield Plateau, which is the southwestern part of the Ozark Plateau. The outcrop is of the lower Boone unit, and is about 120 m wide and 5–9.5 m high. Some chert within the lower Boone unit are soft and highly porous, they are called tripolitic chert and believed to have undergone sub-aerial weathering (Mikkelsen, 1966), while a normal chert is hard with low porosity. This outcrop does not have any development of tripolitic chert, all exposed chert has very high hardness. Chert form nodular shapes and appear in several distinctive beds. The studied outcrop is about 570 m away from the Bella Vista Fault, a normal fault striking northeast–southwest and dipping towards southeast (Gillip et al., 2009; Glick, 1974). Some significant fractures on the outcrop are enlarged to about one meter in width, separating the outcrop into nine blocks.

3. Methods

Specim dual-camera system (Spectral Imaging Ltd., Finland) was used to capture hyperspectral data and determine mineral composition. Hyperspectral imagery were taken at both a large scale to scan the outcrop, and at a fine scale to scan hand specimens in the laboratory. Mixture tuned matched filtering (MTMF) classification (Boardman and Kruse, 2011) is used to match pixel spectra to endmembers. Wavelength range of 2.147–2.391 μm which covers the strong absorption feature of clay minerals and calcite (Clark et al., 2007) is used in the classification. To aid data interpretation, nine hand specimens were collected during fieldwork, and thin sections were prepared and examined. ASD

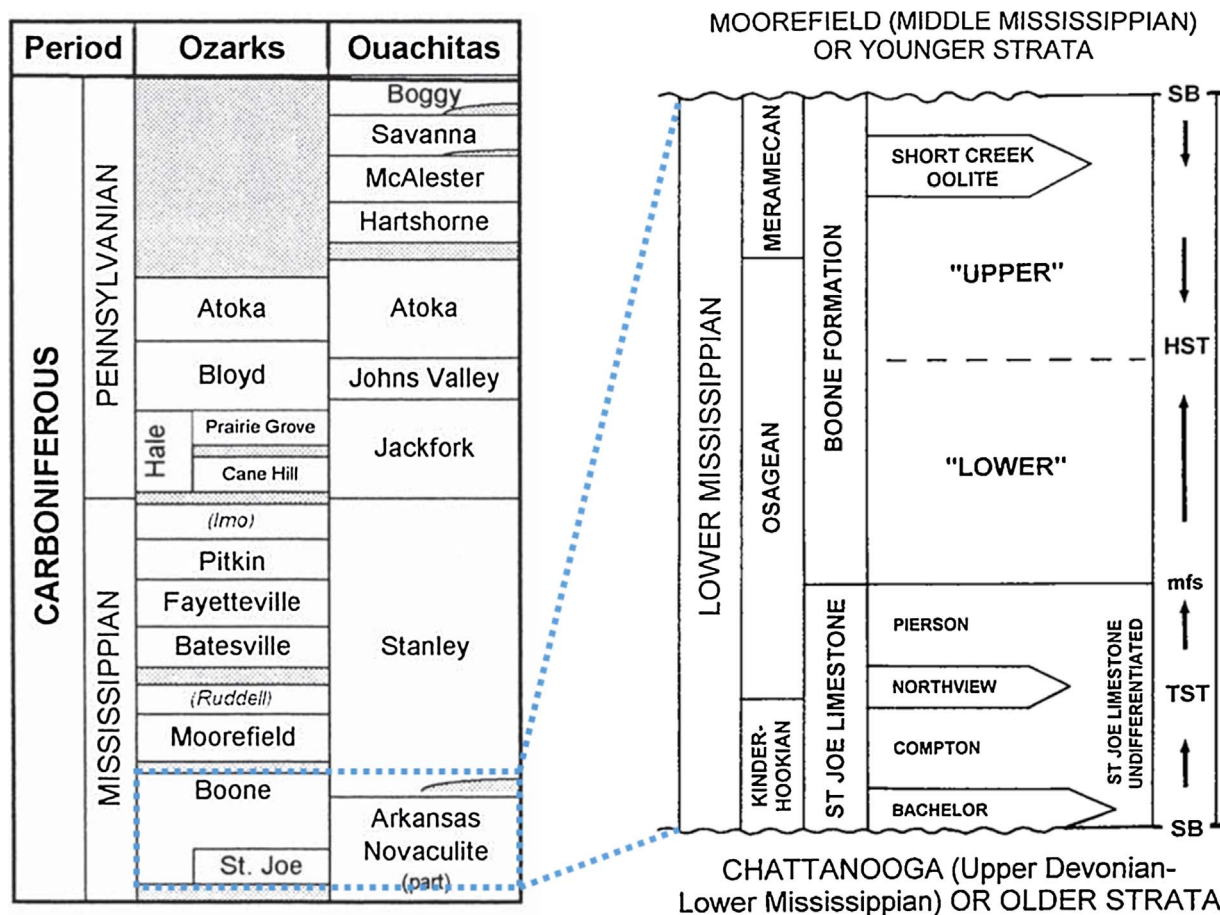


Fig. 1. The stratigraphic column of Ozark region, northwest Arkansas. Modified from McFarland (1998) and Manger and Shelby (2000).

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