Int J Appl Earth Obs Geoinformation 66 (2018) 82–92

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Study of carbonate concretions using imaging spectroscopy in the Frontier Formation, Wyoming

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A R T I C L E I N F O

Keywords:
Diagenetic minerals
Carbonate concretions
Ground-based hyperspectral imaging
Frontier formation

A B S T R A C T

Imaging spectroscopy is applied to study diagenetic processes of the Wall Creek Member of the Cretaceous Frontier Formation, Wyoming. Visible Near-Infrared and Shortwave-Infrared hyperspectral cameras were used to scan near vertical and well-exposed outcrop walls to analyze lateral and vertical geochemical variations. Reflectance spectra were analyzed and compared with high-resolution laboratory spectral and hyperspectral imaging data.

Spectral Angle Mapper (SAM) and Mixture Tuned Matched Filtering (MTMF) classification algorithms were applied to quantify facies and mineral abundances in the Frontier Formation. MTMF is the most effective and reliable technique when studying spectrally similar materials. Classification results show that calcite cement in concretions associated with the channel facies is homogeneously distributed, whereas the bar facies was shown to be interbedded with layers of non-calcite-cemented sandstone.

1. Introduction

Geologists use a variety of methods to determine composition and distribution of minerals, such as; X-ray diffraction, electron microscope, and petrography. These traditional methods can be time consuming. Some methods have scale limitations (i.e. do not generate continuous data), and others are destructive (Zaini et al., 2012). Therefore, geoscientists use interpolation and generalization to estimate diagenetic effects and mineralogical variations.

Post-depositional mineralogical alteration due to fluid-flow can control flow paths by affecting rock porosity and permeability in reservoirs (hydrocarbon and/or groundwater). After deposition, depending on the fluid chemistry, new minerals can fill up pores spaces, reducing the porosity of the rock. Alternatively, the mineral phase can be dissolved, increasing porosity and permeability (Taylor and Merchant, 2011). In reservoir analog studies, high resolution quantitative mineral mapping can be an excellent way to understand complex diagenetic processes and reduce uncertainty. In particular, the presence of calcite concretions and clay cements might change flow dynamics and reduces the quality of the reservoir (Dutton et al., 2000).

In recent years, portable hyperspectral cameras have opened up new horizons for mineralogical characterization at different scales, from hundreds of meters (outcrop) to millimeters (laboratory specimens) (Kurz et al., 2012; Zaini et al., 2014; Krupnik et al., 2016; Sun et al., 2017). Imaging spectroscopy and traditional methodologies can be combined to understand diagenetic processes and reduce uncertainty in reservoir characterization.

For this study, the Wall Creek Member of the Frontier Formation, in Wyoming was studied because of prominent geochemical variations due to diagenetic processes (Nyman et al., 2014). The studied outcrop is located in a gully, locally known as "Raptor Ridge" that was scanned by Visible Near-Infrared (VNIR) and Shortwave-Infrared (SWIR) hyperspectral cameras. Representative samples and core samples were used for laboratory analyses (Fig. 1). In addition, hyperspectral scanning and spectral data were collected in the laboratory for confirmation of remote sensing data.

This study used imaging spectroscopy for high-resolution mapping of diagenetic cements and their secondary-mineral distribution at different scales. Facies distribution and abundance are compared with previous published sedimentological data. Following are the specific objectives of this study; (i) evaluate the accuracy of carbonate concretion detection using imaging spectroscopy in comparison to traditional fieldwork studies (ii) compare commonly-used classification techniques to evaluate the best one for rocks of deltaic facies; (iii) evaluate the accuracy of outcrop classification using spectral endmembers from cores.

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https://doi.org/10.1016/j.jag.2017.11.010
Received 26 October 2017; Received in revised form 21 November 2017; Accepted 21 November 2017

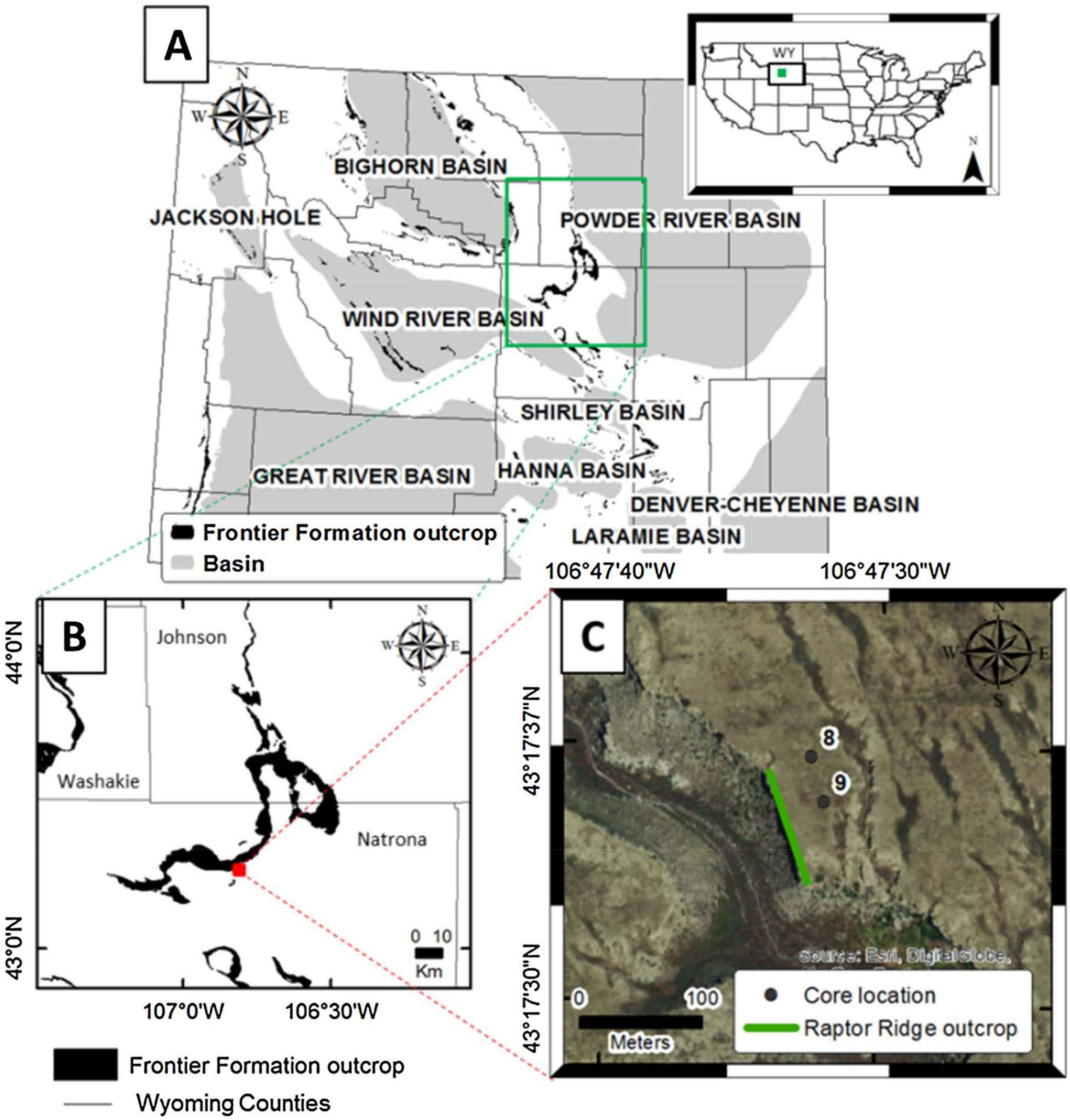

Fig. 1. (a) Location of the study area. General overview map showing studied outcrop distribution of the Frontier Formation and major basins in Wyoming. The study area is located in Big Sulphur Draw, Natrona County. (b) Frontier Formation Outcrop in Johnson and Natrona counties, Wyoming. (c) Map of Raptor Ridge with the locations of studied outcrop in the Parasequence #6 and cores (Wall Creek Member, Frontier Formation). (Map Source: Esri, Digital Globe and Wyoming State Geological Survey).

2. Study area

The study area is located between the Powder River Basin and the Wind River Basin in Wyoming (Fig. 1). The Frontier Formation consists of, at least, three unconformity-bounded members (from oldest to youngest): the Cenomanian Belle Fourche Member, the Emigrant Gap Member of Middle Turonian age, and the Upper Turonian Wall Creek Member (Gani and Bhattacharya, 2007). The Wall Creek Member of the Frontier Formation is Upper Cretaceous (Turonian 93.5 Ma) in age and deposited under fluvial-deltaic conditions. Parasequence #6 of the Wall Creek Member spectacularly crops out at the study area (43° 17′ 30.85″N, 106° 47′ 27.65″W). Parasequence #6 presents a lobate geometry with a shore parallel elongation, interpreted to have a mixed-influence (river and tide) deltaic origin (Gani and Bhattacharya, 2007).

Previous studies at the outcrop scale mapped and described the distribution of carbonate concretions by field and geophysical data (Lee et al., 2007; Gani and Bhattacharya, 2007). Additionally, ten cores, drilled near the outcrop were used to integrate and interpret sedimentological and ichnological characteristics (3D concretion distribution is studied using Ground Penetrating Radar core data, and outcrop description show that concretions are elongated and tabular in shape (Gani and Bhattacharya, 2007). Based on previously published petrographic studies major diagenetic cements are calcite and authigenic chlorite, also kaolinite, iron-oxide, and quartz overgrowth can be found as minor diagenetic cements phases. The concretions are entirely cemented by calcite with minor authigenic, kaolinite, and chlorite coexisting in the margins forming pore-filling and pore-lining phases (Nyman et al., 2014).

3. Data and methods

VNIR and SWIR data were acquired from the depositional dip direction of the Parasequece # 6 at Raptor Ridge. In addition, SWIR images were collected for two cores (8 and 9) in the laboratory. Cores were cut in half which gives a flat and polished section. These specific cores were selected due to their proximity to the studied outcrop and