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Research paper

Ground-based hyperspectral remote sensing of hydrocarbon-induced rock alterations at cement, Oklahoma

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ABSTRACT

Hydrocarbon seepages bring oil and gas from petroleum reservoirs to the surface, these hydrocarbons can generate various kinds of rock alterations, including bleaching of red beds and mineralogical changes. Satellite and airborne remote sensing techniques have been utilized in the detection of rock alterations and hydrocarbon seepages; however, they have limited resolutions and are unable to map vertical outcrops. Ground-based remote sensing techniques hold great potential to characterize rocks with great precisions and resolutions. This study used ground-based Specim hyperspectral data to detect hydrocarbon-induced rock alterations of the Rush Springs sandstone at the Cement field in southeast Anadarko basin, Oklahoma. Hyperspectral data of outcrops and hand specimens were examined, and spectral angle mapper technique was used to compare spectral similarity between image pixels and reference spectra. Laboratory spectroscopy was used to assist with mineral identification and image classification. Remote sensing data detected bleaching of red beds and carbonate cementation. Combining lithological, spectroscopic, remote sensing and geochemical data, this study built a model for petroleum seepage and related rock alterations, and provided a workflow for employing remote sensing techniques in resource exploration.

1. Introduction

Modern hydrocarbon exploration requires the combination of geophysics, geology, and geochemistry, but the oldest way to find oil and gas relies on the usage of near-surface seepage (Jones and Drozd, 1983). Seepage is the escape of oil and gas from petroleum reservoirs and their upward-migration to the surface. As no petroleum seal rock is completely impermeable, every reservoir leaks in various degrees and amounts (Philp and Crisp, 1982). Hydrocarbons have lower density than water and soil/rock, thus they have a potential to migrate upward. Saunders et al. (1999) proposed that buoyant hydrocarbon micro-bubbles can rise through the water-filled network of fractures, joints, and bedding planes, providing a logical mechanism for vertical migration of light hydrocarbons.

Schumacher (1996) summarized that hydrocarbons present at surface can generate various kinds of alterations of soil/rock such as: 1) microbiological anomalies; 2) mineralogical changes; 3) bleaching of red beds; 4) clay mineral alterations; 5) electrochemical changes; 6) radiation anomalies; and 7) biogeochemical and geobotanical anomalies. Surficial expressions of such alterations are distinct from adjacent soil/rock and they can be used to detect hydrocarbon microseepages.

Various methods including field lithological mapping, geochemistry, field spectroscopy, and carbon dioxide and methane monitoring, have been utilized to detect oil and gas seepages (Donovan, 1974; Etiope and Klusman, 2010; Klusman, 2011; Yang et al., 1998). Recently, the applications of remote sensing techniques in detecting microseepages have gained more and more attention as they can provide plenty of geologic information like structure, topography and material chemistry. Various airborne and satellite remote sensing techniques, including Landsat MSS, Landsat TM, ASTER, HyMap, Probe-1, and Hyperion, have been utilized in detection and mapping of hydrocarbon seepages (Khan and Jacobson, 2008; Lang et al., 1985a, 1985b; Malhotra et al., 1989; Petrovic et al., 2008, 2012; Van der Meer et al., 2002). However, there are some limitations to these satellite and airborne remote sensing systems: 1) they are far away from the Earth surface and thus cannot provide high spatial and spectral resolutions; 2) they can only image the ground surface at high angles to the ground, so cannot be utilized to map outcrops with vertical relief, which are

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often excellent geologic targets with optimum exposure. To overcome these limitations, ground-based hyperspectral remote sensing has been used to study the chemistry on geologic outcrops (Kurz et al., 2012b, 2013; Murphy et al., 2014).

In this study, ground-based Specim hyperspectral imagery, are used to detect and map surficial alterations in Cement field, Oklahoma. The purpose of this study is to test the possibility of using ground-based hyperspectral remote sensing techniques to detect surficial rock alterations, and build a geologic model relating rock alterations with underlying hydrocarbon reservoirs. This work proposes a prospecting tool for future petroleum investigation and exploration, especially in areas where field work is difficult.

2. Geologic setting

The Cement field is a giant oil and gas field located in the southeastern Anadarko basin in Caddo and Grady Counties, Oklahoma (Fig. 1). The surface structure is a northwest-trending, doubly plunging, elongate, slightly asymmetric anticline, where accumulations are generally restricted to the structural highs (Fig. 2) (Donovan, 1974). A stratigraphic column of Cement field is shown in Table 1 (Herrmann, 1961; Stanley and Miller, 2005). Hoxbar Group rocks in Missourian Series are the most prolific reservoirs of Pennsylvanian age; and rocks exposed are composed of Whitehorse Group and Cloud Chief Formation of Guadalupian Series (Donovan, 1974). The Rush Springs, a predominantly reddish-brown, fine-grained clayey quartz sandstone, is the uppermost formation of the Whitehorse, which is unconformably overlain by the Cloud Chief Formation, a basal gypsum member. Previous work showed that a south-dipping reverse fault parallels with the anticline and a major normal fault follows the crest (Herrmann, 1961).

Hydrocarbon-induced alterations in the Cement field, Oklahoma were first reported by Reeves (1921). Donovan (1974) performed a comprehensive investigation including surface lithological mapping and isotopic work. He found striking mineralogical and chemical changes, and confirmed the presence of hydrocarbon microseepage at this site. The red-brown sandstone of the Rush Springs Formation is heavily bleached along the anticlinal structure of the Cement field. The red-brown color changes progressively towards the crest of the East and West Cement anticlines to pink, yellow, white and light gray (Donovan, 1974; Reeves, 1921).

Donovan et al. (1979) tried to use Landsat remote sensing tools to detect these surficial alterations, but concluded that the Landsat I and II images had a limited ability to detect microseepage, largely because of the mask by unaltered overlying rock, soil, and dense vegetation, and suggested further experiments with higher resolutions.

3. Methods

Data used in this study were obtained from petrography, laboratory spectroscopy and hyperspectral imagery. Petrographic work provides microscopic observations of sedimentary structures of the rocks and confirms the mineralogy of the rocks. Laboratory spectroscopy assists in mineral identification, and provides reference spectra taken in a controlled environment for hyperspectral imagery. Hyperspectral imagery scans the outcrop and rock samples for mineral mapping, which enables the detection of microseepages.

3.1. Petrography

Five unaltered and eleven altered sandstone samples were collected from the field according to the mapping of Donovan (1974). Standard microscopic thin sections were made from the samples and examined with a Nikon Eclipse LV100POL microscope.

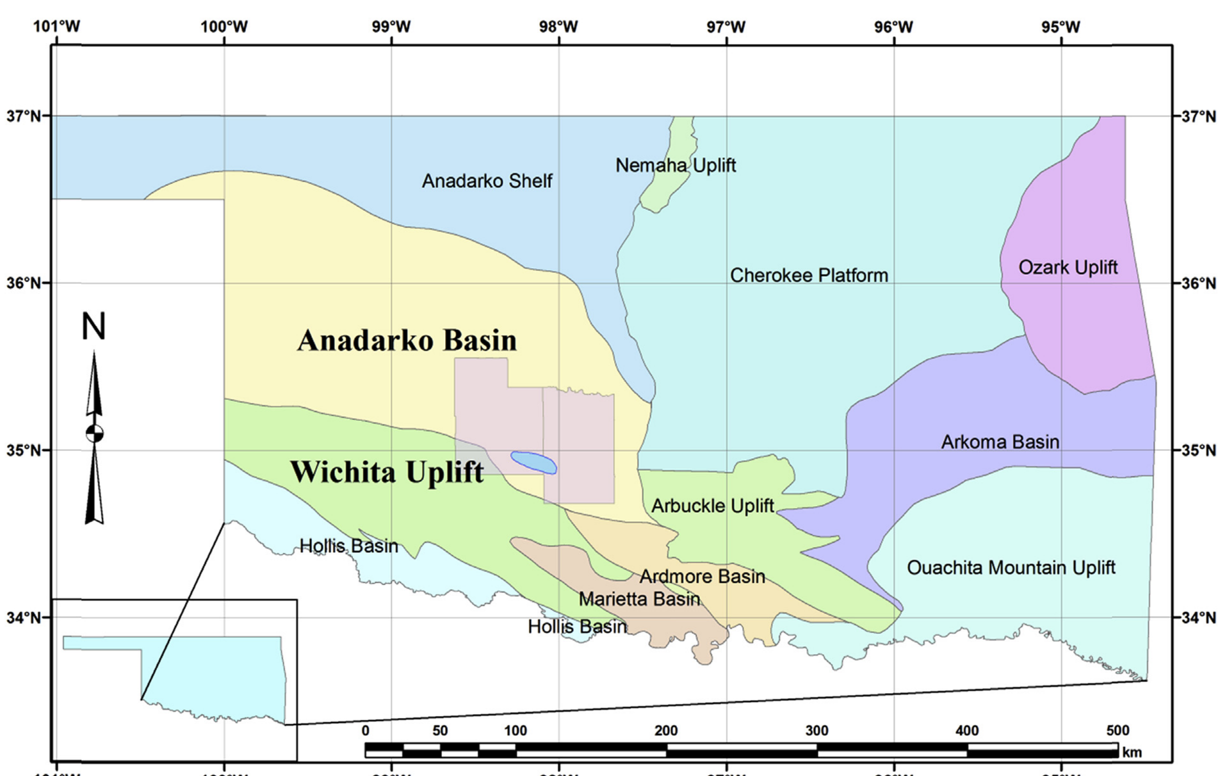

Fig. 1. Location and regional background of the Cement field, Oklahoma, generalized from Northcutt and Campbell (1995).