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Identification of hydrocarbon microseepage induced alterations with spectral target detection and unmixing algorithms

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ABSTRACT

Hydrocarbon micro and macro seeps alter chemical and mineral composition of the Earth's surface, providing prospects for detection with remote sensing tools. There have been several studies focusing on mapping these anomalies by utilizing ever evolving multispectral and hyperspectral imaging instruments, which has proven their capacity for mapping both hydrocarbons and hydrocarbon-induced alterations so far. These studies broadly comprise of methods like calculating band ratios, spectral angle mapping, spectral feature fitting, and principal component analysis as detection techniques. However, there is a lack of concentration on advanced signature based detection algorithms and unmixing methods for mapping surface manifestations of hydrocarbon microseeps. Signature based detection algorithms utilize target spectra to correlate with each pixel's spectrum in order to allocate possible target locations. Unmixing methods, on the other hand, require no input spectra beforehand, aiming to resolve each pixel's spectral constituents and their corresponding abundance fractions. In this paper, the potential of all these methods in mapping microseepage related anomalies are evaluated by implementing and comparing them for Gemrik Anticline, one of the prospective hydrocarbon exploration fields in Turkey. Hence, it provides a complete knowledge on determination surface manifestations of hydrocarbon microseeps with the help of well known supervised target detection algorithms and hyperspectral unmixing algorithms. The study area is located in the Southeastern Anatolia, between the cities of Adıyaman and Şanlıurfa. The spectral signatures were collected with Analytical Spectral Devices Inc. (ASD) spectrometer during the field studies conducted by Avcıoğlu (2010), to be utilized as an input to the signature based detection algorithms as well as a reference to select the related abundance map among the outputs of unmixing methods. Advanced Space Borne Thermal Emission and Radiometer (ASTER) image of the study region, with an atmospheric correction before running the algorithms, is selected for the applications. Among the applied algorithms, Simplex Identification via Split Augmented Lagrangian (SISAL) is selected as a base of comparison, as it possess minimum calculated error metrics in the experiments. Another unmixing method, the Minimum Volume Simplex Algorithm (MVSA), and signature-based techniques, Desired Target Detection and Classification Algorithm (DTDCA) & Spectral Matched Filter (SMF) follow the success of the SISAL, respectively. The Crosta technique, which is performed as a conventional approach for experimental comparisons, has also shown its capability, succeeding these algorithms. The study provides an overall assessment for methodologies to be used for hydrocarbon microseepage mapping, which also serves guidance for further exploration studies in the region. The potential of ASTER data for hydrocarbon-induced alterations is also emphasized as a cost effective tool for the future applications.

1. Introduction

Tracing the micro- and macro- seepages has been an invaluable approach for the exploration of oil and gas reservoirs so far. The alterations of surface sediments overlying the gas/oil reservoirs due to in situ long-term seeps along the migration pathways exhibit surface anomalies which facilitate the exploration of the reservoirs (Shi et al., 2010). The hydrocarbon-induced anomalies are vastly recognized in remote sensing literature, indicating the existent absorption features of hydrocarbon bearing minerals in electromagnetic spectrum. Knowing the common hydrocarbon absorption characteristics at 1.73 µm and 2.31 µm, the target region of the hydrocarbon microseeps is considered to be differentiated from the background with the spectral signatures of the reference valley (Kühn et al., 2004). Band ratio of the images of

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specified altered minerals, the feature oriented principal components, and the false color composites with original bands or band ratios are some of the mostly utilized techniques in remote sensing studies for hydrocarbon microseepage mapping (e.g. Salati et al., 2014; Shi et al., 2010; Kühn et al., 2004; Crosta et al., 2003; Petrovic et al., 2008; Freeman, 2003). However, utilization of only a few bands in these techniques contradicts the idea of handling the most possible information that can be obtained from the hyperspectral image for target detection (Kruse et al., 1993). The high dimensionality of spectral data can provide significant evidence for the identification of mineral of interest, as in signature based algorithms, or even better in unmixing techniques (Khan, 2006).

In this study, it is aimed to map hydrocarbon microseepage regions utilizing two main sets of algorithms, signature based algorithms and unmixing algorithms. Signature based algorithms require a prior knowledge about the spectral characteristics of the target, which can either be a single spectrum or a subspace defining it, in order to determine the possible locations. Unmixing algorithms, on the other hand, are unsupervised techniques that are used to identify the components in each observation pixel of a data cube, their spectral signatures with the corresponding abundance fractions. In this paper, ASD spectrometer data collected from the field (Avcıoğlu, 2010) and an ASTER image of the study area located in the Southeastern Anatolia, are compiled for the analysis. After the atmospheric correction of the image, the spectral signatures collected from the field are resampled to be used for running the algorithms. As a baseline for the comparisons, first the well-known traditional technique for hydrocarbon-induced alteration mapping called Crosta technique is implemented. The Crosta technique utilizes principal component transformation to obtain eigenvectors to highlight the target material in consideration with its spectral properties. This baseline method is compared with signature based target detection methods which are selected as vector correlation, normalized correlation (NC), spectral matched filter (Hwon and Nasrabadi, 2004) and desired target detection algorithm (DTDCA) (Ren and Chang, 2003). From the simplest to the most sophisticated, while correlation and normalized correlation is calculating vector similarities between the ASD signatures and captured pixel spectra, spectral matched filter and DTDCA utilize also the background information by using the covariance and the spectral signatures of the background. In addition to the supervised signature based methods, four different hyperspectral unmixing algorithms are applied to the data cube for hydrocarbon induced alteration mapping. As an unsupervised approach, unmixing algorithms result in several abundance maps together with their spectral signatures (i.e. endmembers), providing another measure to evaluate the performances of the resultant maps. N-FINDR (Winter, 1999), Vertex Component Analysis (VCA) (Nascimento, 2005), Minimum Volume Simplex Algorithm (MVSA) (Li and Bioucas-Dias, 2008) and Simplex Identification via Split Augmented Lagrangian (SISAL) (Bioucas-Dias, 2009) are the hyperspectral unmixing methods applied in this research.

Not only applications of advanced spectral signature algorithms but also hyperspectral unmixing techniques in the context of microseepage induced anomaly detection contribute to the literature significantly with this novel methodology. The comprehensive and comparative elaborations enable to assess the capability of algorithms both individually and collectively with regard to frequently used, traditional techniques. That is, the in-group and between group evaluations of these methods serve as an improvement of hydrocarbon microseepage mapping on the designated site in South Eastern Turkey, offering overall performance evaluations between the state of art algorithms and existing methods. Similarly, the study extends the hyperspectral detection applications on multispectral images for pixel-wise and sub-pixel applications. The implementations uncover the capacity of multispectral sensors to differentiate alterations via state of art hyperspectral algorithms with the novel methodology it presents.

In the rest of this paper, the geochemical and geophysical anomalies related to the hydrocarbon microseeps along with the microseepage formation mechanisms are presented in Section 2. The remote sensing literature for detecting hydrocarbon-induced anomalies is detailed consecutively in the same section, starting from the early applications to the latest methodologies. This is followed with the description of the lithology of the study area in Section 3. The applied algorithms for this research are explained in the Section 4, followed with the experimental results and comparisons in Section 5. Finally, the derived conclusions are given in the last section.

2. Hydrocarbon microseepage induced alterations: their formation and detection with remote sensing

Comprehension of the geochemical and geophysical processes resulting in the microseepage systems and their indicators on the Earth's surface is required to identify the abnormalities regarding with macro/microseepage systems using earth observation satellites. In this section, the mechanisms of hydrocarbon microseepage process and the related anomalies are summarized. The literature survey reveals that the alterations on surface sediments and soils overlying the oil/gas reservoirs are traceable with remote sensing techniques due to the fact that these variations have particular spectral signatures. The remote sensing applications and their capability for detection of hydrocarbon microseeps are elaborated in the second part of this section (Fig. 1).

2.1. Mechanisms of hydrocarbon microseepage

Bacterial or microbial activities are accounted as one of the main reasons of hydrocarbon microseepage alterations generating surface oxidation-reduction zones, which also facilitate both mineralogical and chemical changes (Avcıoğlu, 2010). Schumacher et al. (1996) indicates that oxidation of hydrocarbons is mostly related to bacteria or microbe activities with the reaction of the free oxygen or chemical bound oxygen (i.e. sulfates, nitrates). In addition, to the alteration of the redox potentials, soil alkalinity and acidity changes are reported as other reasons for evident mineral alterations. In his study, Schumacher et al. (1996) refers carbonate cementation, bleached red zones and pyrite mineralization as main alteration variations due to hydrocarbon microseepage process, especially for red beds or sediments overlying the oil fields. Carbonate minerals, sulfide minerals, bleached red beds, clay alteration, existence of some trace elements, change in electrochemical characteristics and finally the magnetic minerals are the main headings dwelled on regarding with the alterations due to hydrocarbon micro/macro seeps. Methane oxidations, interaction of hematite with sulfide minerals, removal of hematite and alterations due to the reducing environment can be appointed as the leading reasons of the prominent alterations stated earlier, which are simply illustrated in Fig. 2 (Schumacher et al., 1996).

The migration of hydrocarbons through the rock columns is described in Khan and Jacobson's study as the movement of light hydrocarbons vertically through the connected fractures or micro fracture

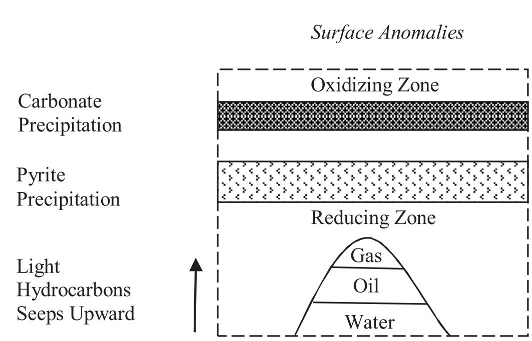

Fig. 1. Generalized form of soil and sediment geochemical alterations (Modified from Schumacher et al., 1996).