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Micro-FTIR Hyperspectral Imagery: A New Method for Identifying Aragonite, Calcite, and Dolomite in Carbonate Rocks and Assessing their Formational History on the Micron Scale

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Summary

Hyperspectral imaging combines digital imaging with reflectance spectroscopy, and allows for the in-situ identification of minerals in rock samples in a non-destructive manner. The project presented here focuses on the collection and analysis of hyperspectral images from carbonate rocks for the purpose of developing a technique to identify aragonite, calcite, and dolomite on the micron scale. The information gathered using this technique will serve to better understand the microscopic alterations taking place in minerals throughout diagenesis, and the results are intended to help interpret the paragenetic history of the carbonate rocks. In summary, this presentation will showcase a new analysis method that will aid in the assessment of the quality of carbonate rocks as oil reservoirs.

Long-wave infrared (LWIR) hyperspectral images were collected from polished thick sections using a Micro-FTIR instrument with a Focal Plane Array (FPA) detector, which collects hyperspectral images at a pixel size of 2.7 x 2.7 µm. Each hyperspectral image was processed and analyzed to produce a compositional map that shows the location of each mineral and/or the crystallographic orientation of individual mineral grains. Textural analyses were then performed on the compositional maps to extract grain size and textural information. The samples used in this study originated from the Western Canadian Sedimentary Basin and the Austrian Alps, and this work will serve as a foundation for subsequent studies, which will examine the feasibility of using LWIR hyperspectral imagery as an automated drill core logging tool for carbonate rocks.

Introduction

For a mineral to produce a diagnostic reflectance spectrum, it must possess molecular bonds that change their orientations or dimensions when electromagnetic radiation of a specific wavelength is absorbed. For carbonates, the CO_{3-}^{2} functional groups are the main absorbers of electromagnetic energy in the LWIR spectral range. This bond is sensitive to the abundance of cations such as magnesium and calcium, and as a result, LWIR spectroscopy can be used to unambiguously identify different carbonate minerals in a rock. Furthermore, LWIR spectra collected at high spatial resolutions also contain information about the orientation of the minerals. This means that LWIR reflectance spectroscopy is one of the few analytical techniques that is sensitive to the subtle compositional changes observed in carbonate minerals, but it also provides additional information about the crystal orientation of each grain.

Diagenesis of carbonate rocks can profoundly affect the quality of carbonate reservoirs (Tucker and Wright, 1990; Erhenberg and Nadeau, 2005). Changes in rock composition through diagenesis can result in the rearrangement of crystals through recrystallization, occlusion of porosity due to cementation, or porosity enhancement associated with a change in crystal structure in the formation of a new mineral such as dolomite. These changes can be evaluated in carbonate rocks through petrography and geochemical analyses, but the techniques currently used are time consuming, costly, and destructive. This study aims to develop a new non-invasive technique for collecting information from carbonate rocks that can be used to precisely and accurately identify mineral phases and characterize the arrangement of crystal packing at a much finer scale than is currently possible using conventional techniques. Understanding these changes and the resulting configuration of the constituent minerals will aid in the development of better predictions regarding the enhancement or depletion of porosity and permeability in carbonate reservoirs that have undergone diagenetic alteration.

Materials and Methods

For this project, we used carbonate rocks from two locations with distinct diagenetic histories. The first set of samples were fossil-rich carbonaceous marls from the Triassic (Carnian) Raibl beds of Zirl, Northern Calcareous Alps, Tyrol, Austria. The second set of samples came from a dolomitized reef in the Leduc Formation of the Western Canadian Sedimentary Basin, Alberta, Canada.

Hyperspectral images were collected from ten polished thick sections (~500 µm) using a Bruker Vertex 70 FTIR spectrometer coupled with a Hyperion 3000 IR-Microscope, which was mounted with a Focal Plane Array (FPA) detector. The FPA detector collected spectra in a 64 x 64 pixel grid between 6 and 14 µm. This resulted in a pixel size of 2.7 x 2.7 µm. The incident radiation (angle of incidence = 0°) was un-polarized, and each spectrum was comprised of 100 scans.

These images were spectrally smoothed and de-noised using an Iterative Spatial Filtering (IAS) tool, which was designed to use both spectral and spatial information to reduce random noise and intra-class variability (Rogge and Rivard, 2010). The resulting images were processed using the Spectral Analysis in Wavelet domain (SAW) tool (Rivard et al., 2008), which isolates mineral spectral features from the background spectral continuum. Spectral endmembers were obtained using the successive projection algorithm (SPA) endmember extraction tool (Zhang et al., 2008), which locates endmembers by searching the data volume using convex geometry and orthogonal projection in an iterative fashion. Representative endmembers were assigned a mineral chemistry, and these endmembers were then merged into a single spectral library, which was used to classify the hyperspectral images using the Spectral Angle Mapper (SAM) tool, which classifies each pixel by calculating the similarities between a reference endmember and the given pixel spectrum using the spectral angle. All representative endmembers were assigned a mineral composition and/or crystal orientation. We refer to the final output of the classified hyperspectral image as a compositional map.

Compositional Maps

For each sample, a compositional map was created to show the spatial placement of the minerals identified in the sample. In the marl from the Triassic Raibl beds, different carbonate and non-carbonate minerals were identified, including aragonite, calcite, quartz, and a matrix composed of siliciclastic mud (Figure 1A). Aragonite was restricted to the bivalve shells, whereas calcite occurred as isolated grains and within foraminiferal tests. The dolomite from Alberta consisted exclusively of dolomite. However, the mineral orientation information contained within the LWIR reflectance spectra revealed that different generations of dolomite (~different grain sizes with different grain orientations) were present in this sample (Figure 1B).

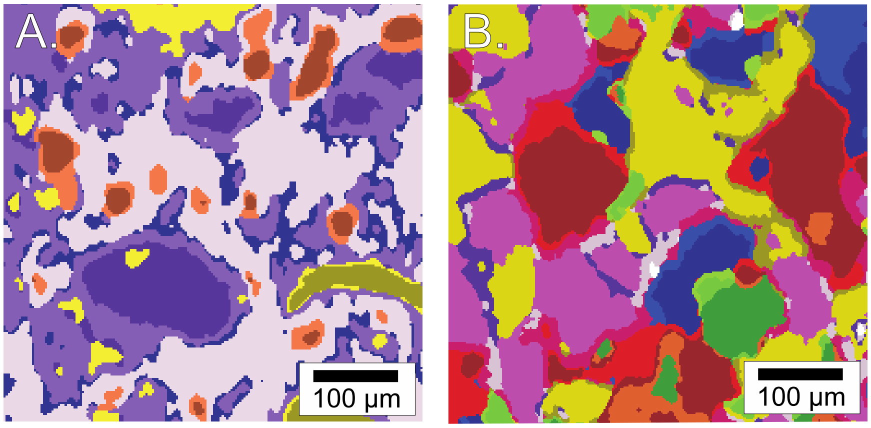

Figure 1. Two compositional maps: (A) The Raibl marl contains aragonite (dark and light yellow), calcite (dark and light purple), siliciclastic mud (pink), and quartz (brown and orange), and shows how this method can be used to identify different minerals; (B) The sample from the Leduc Formation is comprised entirely of dolomite with different crystallographic orientations (variable colors), and this example shows how this method can be used to analyze rocks consisting of a single mineral.

Conclusions

Preliminary research conducted on polished thick sections of carbonates show that LWIR hyperspectral imagery can be used to identify carbonate minerals at very small spatial resolutions. The compositional maps produced by this technique can be used to draw conclusions about the formational histories of these samples, which can have important implications for the enhancement or depletion of porosity and permeability in carbonate reservoirs. This technique may also be used to identify the configuration and orientations of individual crystals in rocks comprised of a single mineral, which highlights the importance of crystal packing and/or arrangement in the creation or destruction of porosity and permeability in carbonate rocks that have undergone diagenetic changes.

This work is of particular importance because obtaining this type of information at these scales can be very difficult using other techniques. This technique is non-destructive, and the results are digital, which allows for quantification of the results and easy data transference. Although this work was focused on hyperspectral images collected at very small spatial resolutions, the results will be used to build a foundational body of knowledge that will be used in subsequent studies, which will examine the feasibility of using LWIR hyperspectral imaging techniques to log drill core from carbonates in an automated, objective, rapid, and non-destructive manner.

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