The application of IR spectroscopy for real time mineralogical analyses of core and cuttings

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ABSTRACT

The use of infrared spectroscopy for mineral identification dates back several decades, and is complementary to other mineral analytical techniques, such as XRD or point counting. However, a major drawback of these techniques, including the older point sampling IR spectrometers, is that they require sample preparation – an expense in both time and money. More importantly they cannot provide continuous quantitative mineralogical data to aid reservoir characterisation.

The most recent advance in IR spectroscopy is the use of real-time imaging reflectance spectrometers. These are non-contact and non-destructive, and acquire continuous mineral data from core and cuttings in a detailed image format. The first of these introduced to the UK oil industry in 2008 is the portable SpecCam imaging spectrometer.

The current SpecCam design accurately discriminates and quantifies different polytypes of the swelling and non-swelling clays, carbonates and sulphates. In addition, the spatial distribution of solid and liquid hydrocarbons and their compositional changes can be mapped. Thus, the SpecCam can provide a unique, spatially-detailed image dataset that allows the impact of clay and carbonate mineralogies on hydrocarbon distribution and permeabilities to be studied and assessed. Several examples from the Brent and other North Sea Formations are presented.

The SpecCam technology addresses 3 major limitations of point sampling techniques – low productivity, inability to show detailed spatial distribution of minerals and low data density. These limitations have direct implications for the reliability and use of these data. The SpecCam imaging IR spectrometer can overcome these limitations and generate near continuous data, which provides a link between point sampling methods and continuous logs.

INTRODUCTION

Short wave infrared (SWIR) imaging reflectance spectrometry is a semi-quantitative mineral logging technique that can rapidly analyse core, cuttings or any other material without the need for sample preparation. The first of these introduced to the UK oil industry in 2008 is the portable SpecCam imaging spectrometer. Its compact dimensions mean that it is well suited for routine analyses of core in core stores - to produce detailed mineral abundance images and mineral logs - or at the well site to provide real-time mineral information from cuttings. Importantly, its continuous measurements of a core surface eliminate sampling biases associated with point sampling techniques.

Spectra-Map's SpecCam infrared imaging spectrometer collects high spatial resolution scan lines at regular intervals - consisting of 140 * 0.5mm square pixels – to create an infrared image over core or cuttings (Fig 1). The image represents a hyper spectral data cube of mineral information, where each pixel can be interrogated for its infrared reflectance spectrum. Typically 28,000 sample (pixel) points are acquired from a metre of core using the SpecCam.

Each reflectance spectrum contains the diagnostic wavelength information that allows different minerals to be identified. Automatic processing and spectral matching of each pixel reflectance spectrum to a spectral library, allows a variety of minerals and their relative abundances to be mapped in an image format (See Capabilities below).

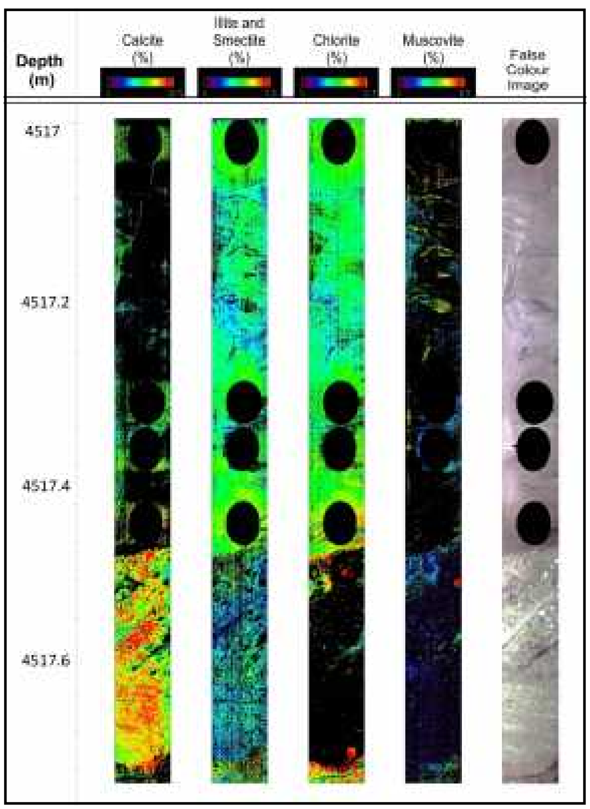

Figure 1: Example of SpecCam mineral maps from clastic sediments. The infrared images allow the mineralogical and hydrocarbon data to be visually compared in the core.

CAPABILITIES

SWIR reflectance spectroscopy is a non-destructive, molecular-vibrational analytical technique that measures the absorption and reflection of infrared light at narrow and discreet wavelengths off a sample surface (Fig 1). Many minerals have their diagnostic molecular (overtone) vibrations in the SWIR; the most common vibrations are associated with subtle changes between the hydroxyl and cation molecular bonds common to the clays and phyllosilicates[1].

These wavelength-specific vibrations can be recorded by IR spectrometers as reflectance lows or absorption features in each reflectance spectrum (Fig 3). Changes in the wavelength position and shape of these absorption features can be used to ‘fingerprint’ different mineral groups and polymorphs, e.g., kaolinite and dickite as well as hydrocarbons and some other organic molecules.

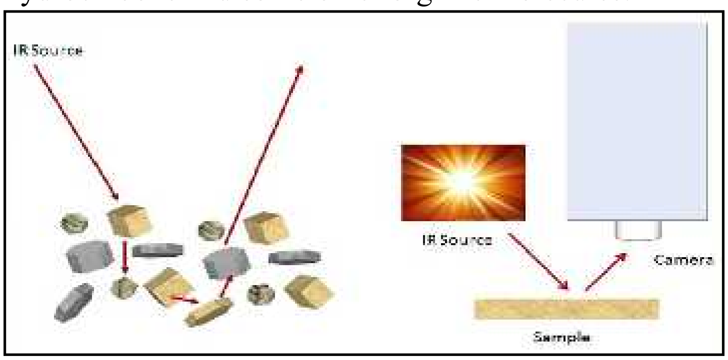

Figure 2: Reflectance spectroscopy light pathway.

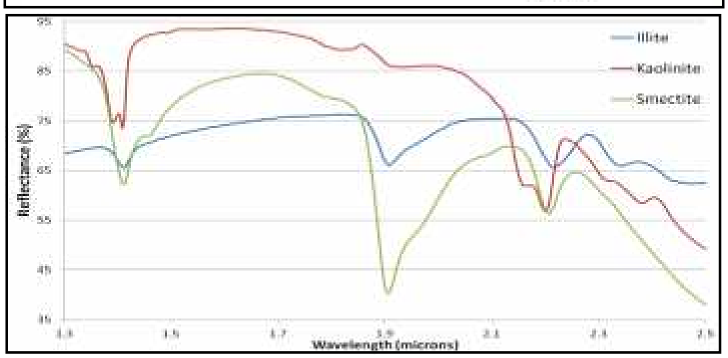

Figure 3: Example mineral reflectance spectra

By using this principle IR spectroscopy is able to identify clays (illite, smectite, chlorite, kaolin polymorphs), micas, carbonates, sulphates, borates, hydrocarbons and more, in core and cuttings. The only constraint is that the mineral must have a diagnostic spectral reflectance signature within the 1.3-2.5 micron spectral range that the instrument operates, so tectosilicates such as quartz cannot be uniquely identified.

Reflectance spectroscopy does not provide whole-rock data and is therefore a semi-quantitative technique, using a combination of the strength of the IR-active absorption features and a modal count procedure. Increased accuracy and precision in mineral quantification can be achieved using other data to calibrate, such as XRD or point count, but these data are also considered to be semi-quantitative. No calibration is possible for the unique hydrocarbon data supplied by the SpecCam.

APPLICATION CASE STUDIES

Well to well stratigraphic correlations - Northern North Sea, UK:
The client had unresolved stratigraphic correlation problems in the Jurassic reservoir units of a mature oil field. In particular a lack of core in more recent wells located in downthrown compartments off the crest was hampering the interpretation of the 10m thick sand units at the top of the reservoir.

Traditional core analytical methods, such as XRD, had been unable to resolve these long-standing problems. imaging infrared spectroscopy was carried out on core and cuttings from 11 wells to identify variations in clay types and assist in a better understanding of the correlations between units. The spectroscopy study had two phases:

Phase 1. Define and correlate spectrally-derived mineralogy with well-understood drill core stratigraphy. Spectral measurements were made on some core and on cuttings from a nearby sidetrack over the same depths. This gave the client confidence that the cuttings provided consistent data.
Phase 2. Apply SpecCam-derived mineralogy to problematical cuttings stratigraphy.

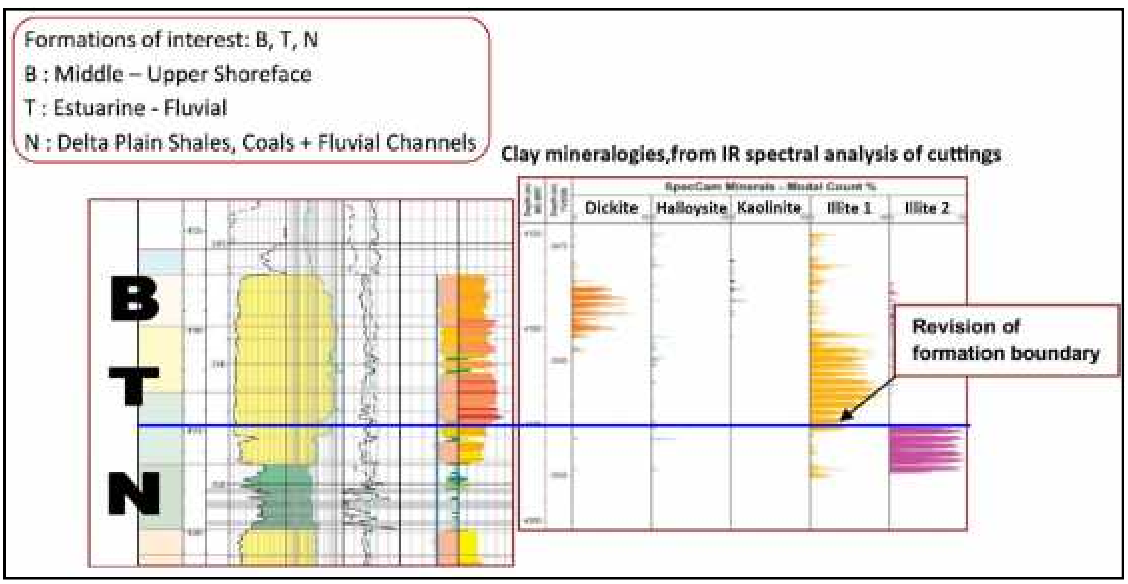

Figure 4: Differences in the clays between units B, T and N

The results showed clear differences in the clays in the three formations (Fig 4). Whereas the XRD did not differentiate the kaolin and illite types (cost rather than technical limitations), the spectrally-derived mineral information identified unique mineral assemblages; Formation B was characterised by dickite, while formations T and N showed subtle changes in the type of illite – something not previously detected.

On the basis of new spectroscopy data and supporting information the client was able to make significant revisions to formation boundaries and well to well correlations.

Mineralogical controls on permeability - Southern North Sea gas basin, UK:
A significant problem in this Rotliegend gas reservoir is the presence of clay 'baffles' which reduce permeability and gas flow. The client has historically used the costly method of thin section work to get % volume and XRD for clay differentiation and quantification. However, the sparse sampling of core for these techniques has meant that the results have not been representative.

The data derived from IR spectroscopy - highlights how small-scale mineral changes control permeability. Figure 5 shows the inverse relationship between illite content and permeability. Above the baffle illite is the dominant clay, and average permeability is about 6 mD. Illite values are lower below the baffle, yet average permeability is low at around 0.1 mD, suggesting that the presence of chlorite is significant in reducing permeability in this part of the reservoir.

The client was able to use the mineral data to identify core intervals that had mineralogical controls on permeability, and subsequently plan for a more focussed well fracturing programme.

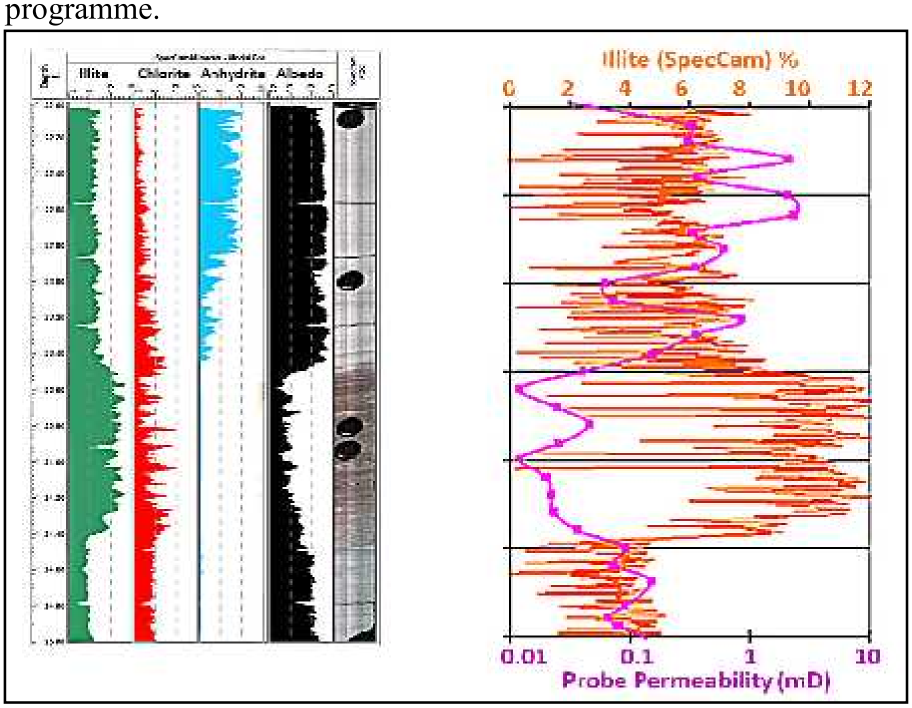

Figure 5: Profiling the negative impact of illite on permeability

IR spectroscopy can be used to identify and quantify the clays present, and display these data as near continuous logs. Where subtle variations in illite and other clay chemistry exist they can be identified and their impacts on reservoir quality highlighted.

Hydrocarbon variation with depth:
Hydrocarbons have distinct spectral features that can be identified using imaging infrared spectroscopy (Fig 6). These features relate to the presence or absence of certain functional groups (e.g. CH3, OH) and may be used to indicate compositional variations with depth, and whether these are step changes or gradual. Biodegradation and changes in the maturity of oils may also be evident, as can the invasion of oil base drilling mud.

Because crude oils are mixtures of many complex hydrocarbons and other organic compounds, the information derived from the short wave infrared region provides only part of the picture. However, since extracted oils can be measured directly by infrared spectroscopy it is possible to make direct comparisons with the *in-situ* oil in the core and improve understanding of charging episodes, source rock correlation, influence of minerals and compression features on oil distribution (e.g. barriers to vertical migration).

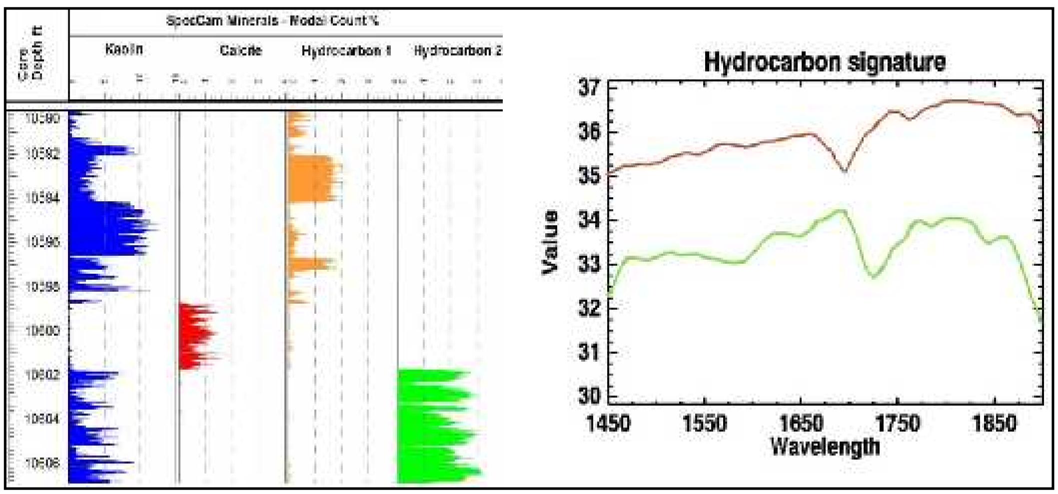

Figure 6: An example from 28 year old Brent reservoir core. A calcite seal separates hydrocarbons showing distinct spectral features. The client identified these oils as having different charging episodes and maturity.

CONCLUSION

The comprehensive, spatially continuous data from SWIR reflectance spectroscopy often reveals trends that other techniques are unable to gauge, due in part to the techniques ability to discriminate clay polytypes in great detail and map subtle compositional changes in both clays and hydrocarbons. In doing so it provides the geologist with a more thorough knowledge base from which dependable interpretations can be made. With the advent of real time analysis, SWIR spectroscopy is becoming an ever more viable solution, and can now be applied to time critical projects.

[1]Clark, R. N., Chapter 1: Spectroscopy of Rocks and Minerals, and Principles of Spectroscopy, in *Manual of Remote Sensing, Volume 3, Remote Sensing for the Earth Sciences*, (A.N. Rencz, ed.) John Wiley and Sons, New York, p 3- 58, 1999.