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Graphical Approach to Determination of Hydrocarbon Maturation in Overthrust Terrains

With current exploration efforts in areas of overthrust tectonics, it is important to evaluate efficiently and effectively the effects of thrust-related thermal perturbations on hydrocarbon maturation. Because of the transient nature of the temperature field during and after thrusting, the simple assumption of constant geothermal gradients is inappropriate in most cases. A simple graphical technique that combines Lopatin diagrams with thermal models for thrusting allows the explorationist to develop relatively detailed models for the timing of hydrocarbon maturation in overthrust terrains. The thermal regime that exists after thrusting may be calculated by solving the equation for the one-dimensional conduction of heat. Geothermal gradients after thrusting can then be derived from solutions to the heat conduction equations that have been plotted on depth versus temperature diagrams. By superimposing the appropriate geothermal gradients on the Lopatin diagram for a given sedimentary unit, the theoretical vitrinite reflectance can be calculated at any point along the burial history of that sediment.

It is critical in these models to modify the geothermal gradients used in the Lopatin diagrams according to the perturbations in the normal gradient caused by the thermal effects of thrust faulting. The effect of thrusting is to cool the overriding sheet and heat the sediments being overridden. The sheet being thrust from deep within the earth's crust to a shallower level will cool and lose heat to the sediments below. Consequently, the overridden sediments will become warmer as they attain equilibrium with the new thermal conditions imposed by burial beneath the thrust plate. The thermal effects due to thrusting can be quite pronounced. A calculated example demonstrates that the same stratigraphic unit located in the hanging wall of a 21,000 ft (6,400 m) thick thrust sheet in the Overthrust belt is still in the liquid window while the equivalent unit in the footwall of the thrust is overmature.

The graphical approach developed here is applicable not only to cases of simple overthrusting, but can also be modified to include the effects of multiple thrusting events, subsurface thrust planes, and post-thrust erosion. All of these models can provide critical constraints on the timing of maturation and migration as well as information on the degree of maturity of potential source rocks. Integration of maturation data generated from the Lopatin diagrams with the structural history of the region can help predict prior to drilling whether a prospective structure may contain hydrocarbons or if it is more likely to be a dry hole.

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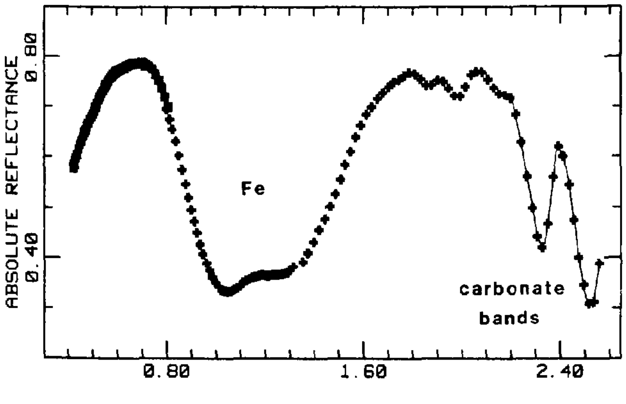
Spectral Reflectance of Carbonate Rocks and Minerals

Spectral reflectance in the visible and near infrared (0.35 to 2.5 μ) offers a rapid, inexpensive, nondestructive technique for determining the mineralogy and minor element chemistry of the hard-to-identify carbonate minerals, and can, in one step, provide information previously obtainable only by the combined application of two or more techniques.

When light interacts with a mineral, certain wavelengths are preferentially absorbed. The positions, intensities, and widths of these absorption bands are diagnostic of the sample's mineralogy and chemical composition. Absorption bands in the 1.5 to 2.5 μ region are due to vibrations of the carbonate radical, and their

Reflectance Spectrum of Ferroan Dolomite



precise positions are used for mineral identification. At shorter wavelengths, absorption features are due to electronic processes within the partly filled d-shells of transition metal ions such as Fe^{+2} and Mn^{+2}. Positions, intensities, and widths of these bands allow determination of the chemical composition of the mineral. Studies indicate detection limits for these cations are less than 0.5 mole %. The figure shows a typical carbonate spectrum and the sources of the absorption bands.

Absorption bands caused by water also occur in reflectance spectra. The exact shapes and positions of these bands indicate the form in which the water occurs (i.e., as bound water in clay minerals, or as liquid water in fluid inclusions), and relative band intensities indicate the amount of water present. Fluid inclusions appear to be nearly ubiquitous in carbonate rocks and are particularly abundant in skeletal material. Diagenesis of skeletal material results in loss of a large percentage of these inclusions, and spectral studies can be used to monitor these changes.

Reflectance spectra may be obtained from powders, sands, rock surfaces, and thin sections.

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VSP Fundamentals that Improve CDP Data Interpretation

This paper emphasizes the fundamentals of the vertical seismic profile (VSP) that improve the interpreter's confidence and understanding in its use as an exploration tool. The areas covered are VSP acquisition, critical points of the processing sequence, and applications to borehole information in depth and CDP data in time.

Correlating reflection character to the stratigraphic section is done typically with synthetic seismograms computed from sonic logs and check shot traveltimes. Problems often make this task difficult, even in areas where the synthetic or surface seismic data are of good quality. The VSP provides an alternative approach and a valuable link between the synthetic and CDP data.

A VSP extends check shot surveys from first break traveltime analysis to reflection analysis by recording the complete seismogram at a fine depth interval in the borehole (at least two depths per seismic wavelength). The unique feature of a VSP is the simultaneous measurement of downgoing and upgoing seismic waves as they propagate at depth.

A repeatable source such as Vibroseis and the fine depth sampling make it possible to separate the VSP downgoing waves from the upgoing reflections by f-k filtering. The downgoing wave field can be used as signatures to deconvolve the upgoing wave field as the best estimate of the primary reflections in the vicinity of the borehole. VSP processing preserves the polarity and amplitude of reflections, and after deconvolution, a trough corresponds to a positive reflection coefficient. These reflections can be shifted to their two-way traveltime and stacked to produce a VSP extracted trace (VET), which is used to correlate to the CDP data.

An important application of a VSP is to correlate the reflection character to depth and the stratigraphy observed in the borehole. The direct downgoing arrival contains the two-way time to depth relationship and the enhanced primary reflections contain the reflection character. Any formation top in the VSP survey can be correlated to time using these features.

VSP reflection character indicates the significant features in the sonic log velocities that produce the reflections observed in the surface seismic data. Sonic logs and VSPs attempt to measure the same velocities and reflectivity near the borehole but with significantly different resolution. The sonic log only penetrates a short distance into the formation but provides detailed velocity information vertically. A VSP, however, has poor vertical resolution (50 to 100 ft [15 to 30 m] intervals) but samples a large area around the borehole similar to CDP data. Therefore, the VSP correlates well with CDP data because they have the same resolution. It also correlates well with the synthetic seismogram because they both contain primary reflections without multiples.

Finally, multiples in the CDP data are easily identified utilizing the VET and synthetic seismogram. In addition, the depth of origin and periodicity of multiples in the processed VSP can be observed directly because they are generated by downgoing multiples and not by the direct arrival.

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Iodine—A Pathfinder for Petroleum Deposits

The relationship between oil and gas fields and high concentrations of iodine in water is well known. Iodine is a good, indirect surface indicator of areas favorable for oil and gas accumulations. Humic substances are the main initial source of iodine in subsurface waters. At the high temperatures achieved during burial, structural degradation of large molecules of unsaponified organic matter and of insoluble residues and bitumens also provide a source of iodine. Although the iodine background content in formation waters of different geologic ages varies widely, it has no apparent effect on the use of iodine as a pathfinder for potential oil and gas prospects.

Samples are taken from the top 2 to 4 in. (5 to 10 cm) of the soil and are analyzed for total iodine content. In the analysis for iodine, the total iodine content—iodine that is firmly retained by humic soils and iodine that is contained in soluble iodide form—is expressed in weight percent. Depth appears to influence the extent of iodide fixation by clay soils. For example, in arid and humid-temperate soil clays, the extent of iodide fixation increases with the decrease of soil depth. Clays obtained from different depths of soils located within the water table do not record any difference in iodide fixation; however, identification of the sand/clay ratio in the 170 mesh soil sample is important.

High iodine concentrations occur about the perimeter of a surface geochemical anomaly. This surface expression of the reduction chimney, the so-called halo effect, is associated with oil and gas anomalies. A typical anomaly exhibits values greater than two standard deviations above the statistical mean.

Iodine is an effective pathfinder in surface prospecting because of: (1) the simplicity of taking and non-critical handling required of the surface samples, (2) the ability to integrate a detailed survey into an earlier reconnaissance survey, and (3) relatively low-cost analysis permits a greater sampling density, which provides better identification and definition of anomalies.

Iodine, as all geochemical parameters, should not be used by itself, but rather in combination with other geochemical techniques, and the results should be cross-correlated for an optimum confidence level. Iodine analyses are a good cross-check on the validity of radiometric anomalies or magnetic anomalies. They are also a good geochemical tool to use in the reconnaissance mode prior to using more expensive hydrocarbon analyses in the detailed phase of an exploration program.

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Depositional Architecture and Reservoir Characterization of Late Paleozoic Submarine Slope and Basin Depositional Systems—Midland and Delaware Basins, Texas

Upper Pennsylvanian and Lower Permian slope sandstones of the Eastern shelf (Midland basin), Permian Spraberry and Dean fan sandstones and siltstones (Midland basin), and Delaware Group basinal sandstones (Delaware basin) were deposited by slope-accelerated density currents and illustrate a spectrum of intracratonic submarine slope and basin depositional styles. Each depositional system also contains several large reservoirs (cumulative production exceeding 10 million bbl) and numerous smaller reservoirs constituting three prolific oil plays.

The Eastern shelf submarine-slope fan system was deposited along the margin of an actively prograding clastic shelf. Downslope sediment transport was by turbidity currents, and deposits are scale-models of larger oceanic submarine fans. Spraberry/Dean reservoirs were largely deposited by relatively nonturbid, saline density currents flowing off of shallow, restricted shelves and platforms. Reservoir geometries reflect the increasing importance of channelized flow across the basin floor. Delaware sandstones were deposited by saline density currents originating on surrounding broad, evaporitic reef-barred platforms. Elongate, lenticular geometry and textural maturity characterize Delaware Sand reservoirs. Despite the variations in specific sand-body genesis, reservoirs of each system display numerous similarities. (1) Reservoir facies are embedded in organic, oil-prone source rock basinal mudrocks. (2) Entrapment is largely by the updip or uplap pinch-out of porous fan facies that is inherent in the depositional architecture of submarine slope systems. (3) Porosity and permeability range from fair to poor, and proximal-to-distal variations decrease as saline density currents assume the dominant role in sediment transport. (4) Water saturation and residual oil saturation are high. (5) Solution gas drives dominate reservoirs; consequently, waterflood and pressure maintenance are necessary for efficient recovery. (6) Great internal facies complexity of the slope channel and suprafan deposits, combined with low to moderate permeabilities, results in low recovery efficiencies. Because of the internal and external stratigraphic complexity of these slope system reservoirs, the potential remains for discovery of new reserves and significant improvement in recovery of the 12 billion bbl of known oil-in-place.

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Deep-To-Shallow Carbonate Ramp Transition in Viola Limestone (Ordovician), Southwest Arbuckle Mountains, Oklahoma