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Brines, Clay Minerals, and Equilibria: Predicting Diagenetic History and Reservoir Quality in Oligocene Frio Formation of Texas

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Effect of Bulk Composition on Clay Mineralogy: Examples from Jurassic Sandstones of North Sea

ABSTRACTS

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Clay Mineral Identification by Remote Sensing

In the past three years there have been major advancements in our ability to identify clay minerals by remote sensing. Two different technologies have been used—imaging broad-band multispectral scanners and non-imaging narrow-band radiometers and spectrometers.

Multispectral scanners, including NASA's Thematic Mapper Simulator (analog for Landsat-D Thematic Mapper) have had several broad-band channels in the wavelength region of 1.0 to 2.5 μm. In particular, the wavelength region 2.0 to 2.5 μm contains diagnostic spectral-absorption features for most layered silicates. Computer processing of image data obtained with these scanners has allowed the identification of the presence of clay minerals, without, however, being able to identify specific mineralogies. Studies of areas with known hydrocarbon deposits and porphyry copper deposits have demonstrated the value of this information for rock-type discrimination and recognition of hydrothermal alteration zones.

Non-imaging, narrow-band radiometers and spectrometers have been used in the field, from aircraft, and from space to identify individual mineralogical constituents. This can be done because of diagnostic spectral absorption features in the 2.0 to 2.5 μm region characteristic of different clay types. The Shuttle Multispectral Infrared Radiometer (SMIRR), flown on the second flight of the space shuttle Columbia in 1981, had 10 narrow-band channels specifically chosen to evaluate the ability to identify directly clay minerals and carbonates. Preliminary analysis of SMIRR data over Egypt showed that kaolinite, carbonate rocks, and possibly montmorillonite, could be identified directly.

Plans are currently under way for development of narrow-band imaging systems which will be capable of producing maps showing the surface distribution of individual clay types. This will represent a major step in remote sensing, by allowing unique identification of minerals rather than the current ability only to discriminate among materials. Applications of this technology will provide geologists with a powerful new tool for resource exploration and general geologic mapping problems.

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K/Ar Dating of Illitic Clay in Sandstone Reservoirs and Timing of Petroleum Migration

Illite and illite/smectite, which occur as authigenic pore-fill in some sandstones, are excellent argon-retentive clocks. Dating their mean time of growth in conjunction with other basin information may add to predictive understanding of illitic cement distribution. Paragenesis and distribution of authigenic clay in the sandstone body with respect to hydrocarbon occurrence may allow the measured age to be related to time of hydrocarbon emplacement. For certain petroleum-source shales, the mean age of illite/smectite burial metamorphism, and thus petroleum maturation, can be measured directly and then compared to the age of clay authigenesis in reservoir sandstones to see if the two phenomena are related.

Three sandstones have been examined: the Cretaceous Muddy on the eastern flank of the Powder River basin; the Jurassic Nugget of the Wyoming Overthrust belt; and the Permian Rotliegendes of northern Europe. For the regressive poorly sorted Muddy, logistic problems arise because of the low abundance of authigenic illite/smectite compared to kaolinite and the common occurrence of old detrital illite. The age of illite/smectite authigenesis thus is asymptotically derived from analyses of a series of progressively finer (and authigenically purer) clay size fractions down to $<0.05\mu$. Over a broad region, this derived age is about 40 m.y., excluding Bell Creek which is anomalous. This age may associate illite/smectite growth in the reservoir with the early Tertiary deep burial of the basin interior. Because similar ages occur in both oil and water zones, illite/smectite growth may either have preceded or accompanied oil emplacement.

Logistic problems are minimized for the abundant, high-K_2O, discrete illite cements of the well-sorted aeolian Nugget and Rotliegendes. For both of these, precise sets of ages have been obtained for individual fields in both water and hydrocarbon zones, implying cementation may have been a relatively short-lived "event." The Nugget samples, all from the Absaroka sheet, give late Mesozoic ages. In the Rotliegendes, complex block faulting has led to unique post-late Jurassic burial and gas generation histories for adjacent fault blocks. However, thus far the three areas of the Rotliegendes examined indicate illite growth largely preceded this history.

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Silica and Metal Release During Clay Mineral Diagenesis and Shale Overpressuring

Mud sidewall cores from the northwest Gulf of Mexico, extending down to the upper portion of the overpressured zone (OPZ), were examined mineralogically (XRD) and chemically. The resultant data is limited, but provides some clues on the 17A→ 10A clay transformation and related shale processes.

Squeezed interstitial water concentrations, corrected for temperature effects and evaporative loss during processing, show little deviation from seawater, other than major K and Mg decrease in the upper 3,300 ft (1,000 m). As the upper OPZ dilution is encountered (water release from 17A→ 10A transformation), K, S, and organic C increase markedly relative to C_1.

Increased Na_2CO_3-leachable Si in the upper OPZ suggests that Si released in the 17A→ 10A transformation may reside in part as weakly absorbed material or, as suggested by a broad 5

to 7.5A XRD band, in a poorly crystalline silicate phase. Concentrations of B in squeezates, water leachates, and different size fractions closely parallel Si, supporting this hypothesis.

Transition metals show decreases with depth in the -0.1 μm (clay mineral-dominated) fractions and equal or lesser increases in the coarse fractions. This trend becomes more marked as the OPZ is encountered. Comparison of total metal with that freed by reducing and oxidizing leach solutions, plus XRD and petrographic observations, suggests removal of some transition metals from the altering 17A phase and their incorporation into coarser sulfidic and possibly carbonate phases.

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Relation of Illite/Smectite Diagenesis and Development of Structure in the Northern Gulf of Mexico Basin

Water expelled from smectite into the pore system of the host shale during the process of diagenesis may migrate out of the shale early or may be totally or partly trapped and released slowly through time. In areas such as the northern Gulf of Mexico basin, where much of the water is partly trapped, clay diagenesis data indicate a close relation between high fluid pressure buildup and the smectite-illite transformation process.

Abnormal pressures affect, in part, the type and quantity of hydrocarbons accumulated since pressure controls the direction of fluid flow and partly controls the geometry of structures formed in basins where shale tectonism is the primary mechanism for structural development. In basins of these types, contemporaneous faults and related anticlines are the most common types of productive structures found. The depth to which faults can penetrate and the angle of dip that faults assume at depth is dependent largely upon fluid pressure in the sedimentary section at the time of faulting. Some faults formed in the overpressured Tertiary section of Texas have been observed to flatten and become bedding plane types at depths near or above the temperature level required for thermal generation of hydrocarbons. This observation suggests faults of these types play a minor role in draining hydrocarbons from deep shales within basins where thick overpressured sedimentary sections are present at shallow depths and where shale tectonism is the primary mechanism for structural development.

Microfracturing resulting from increased fluid pressure is indicated to be a primary mechanism for flushing fluids from deeps basins where thick abnormally pressured sedimentary sections are present. This flushing process would be enhanced by clay diagenesis since water supplied from smectite would cause the process to continue for longer periods of time and to extend to greater depths than could be attained if only remnants of the original pore water were present in the section. Large volumes of diagenetic water present within the microfracturing interval could also act as a vehicle for primary hydrocarbon migration provided hydrocarbons are present in a form and in sufficient quantities to be transported.

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Illite/Smectite Diagenesis and Hydrocarbon Generation in Cretaceous Mowry and Skull Creek Shales of Northern Rocky Mountains–Great Plains Region

The Lower Cretaceous Mowry and Skull Creek Shales and their equivalents are among the major source rocks in the northern Rocky Mountains–Great Plains region. They are the major source of hydrocarbons in the Lower Cretaceous Muddy Sandstone of the Powder River basin. This sandstone has a geographic distribution similar to that of the Mowry and much of the Skull Creek.

Illite/smectite mixed-layer clay in the Mowry and Skull Creek Shales of eastern Montana and western North Dakota is unaltered. No significant amounts of hydrocarbons have ever been found in the Muddy Sandstone of this area. Hydrocarbons in the Muddy Sandstone occur within or immediately adjacent to areas in which the smectite component of the illite/smectite in the Mowry and Skull Creek Shales has undergone alteration to illite during burial diagenesis. Anomalous decreases in the total organic carbon content of the Mowry and Skull Creek Shales lie within areas of illite/smectite alteration and coincide with the deeper parts of structural basins which developed after deposition of the Mowry and Skull Creek. These regional variations in illite/smectite alteration and total organic carbon content reflect thermal maturation and are not provenance controlled. They are useful indicators of areas where the potential source rocks have been subjected to temperatures adequate to generate hydrocarbons. The degree of illite/smectite diagenesis in the Mowry and Skull Creek of the northern Rocky Mountains–Great Plains region is thus of exploration significance in the search for hydrocarbons in this area.

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Catalytic Effect of Smectitic Clays in Hydrocarbon Generation

Smectites or three-layer expanding clays promote the thermal decomposition of long-chain aliphatic hydrocarbons to produce hydrocarbons of lower molecular weight. Smectites are believed to act as acid catalysts through the dissociation of water, thus promoting carbonium ion reactions. When sedimentary organic matter, isolated as kerogen from suspected petroleum source rocks, is pyrolyzed in the laboratory, long-chain aliphatic hydrocarbons are in the pyrolyzate, commonly in abundance. When the source rock contains smectite and is pyrolyzed, the pyrolyzate has significantly less high molecular weight aliphatic hydrocarbons and more lower molecular weight hydrocarbons.

Mixtures of kerogens with quartz, silica, alumina, calcium carbonate, kaolin, or illites not containing smectite-illite mixed layer clay, yield pyrolyzates more similar to those of the kerogen alone, i.e., the range of hydrocarbons in the pyrolyzates is broad including those of high molecular weight. This is interpreted to be due to a lack of catalytic activity of these minerals as compared with the catalytically active smectite. The catalytic effect of smectite is observed particularly when the concentration of sedimentary organic matter in the source rock is relatively low, amounting to less than about 2% total organic carbon. Smectites in sediments with a modest or low amount of organic matter are critical regarding the type petroleum generated, exemplified by the gas condensates of the northern Gulf of Mexico basin and Indonesia. Consequently, it is concluded that smectitic argillaceous sediments containing less than approximately 2% organic carbon are poor sources of oil, although they may be productive of gas and gas condensate.

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Probable Interactions Between Stevens Sandstone (a Miocene Deep-Water Turbidite) and Surrounding Siliceous Shales in San Joaquin Valley, California

The upper Miocene Stevens Sandstone deep-water turbidite