

shales are in the range of  $10^{-7}$  to  $10^{-12}$  cm/sec. The change in permeability, with void ratio is expressed as  $\Delta \log k = \Delta e/C_v$ . The parameter  $C_v$  is directly related to the void ratio. For clays, values of  $C_v$  range from 0.5 to 4. For shales, the  $C_v$  values are in the range of 0.02 to 0.5.

Permeability of fissile shales is expected to be highly anisotropic as compared to massive shales that have a more random fabric. However, permeability anisotropy in shales has not been extensively investigated. At shallow depth, the permeability of shale formations is strongly influenced by discontinuities such as fissures and joints.

PEVEAR, D. R., Western Washington Univ., Bellingham, WA (present address: Exxon Production Research Co., Houston, TX)

#### Illite/Smectite Diagenesis: Relation to Coal Rank in Tertiary Sediments of Pacific Northwest

Bentonite partings formed by alteration of air-fall tephra interbedded with coal in three Eocene coal basins (Tulameen, British Columbia; Chuckanut and Centralia, Washington) record the nature of arc volcanism and subsequent diagenesis and metamorphism. Euhedral feldspar phenocrysts, embayed quartz, and relict glass shards demonstrate volcanic provenance, whereas the absence of muscovite, microcline, and other nonvolcanic minerals indicates lack of epiclastic detritus. At Tulameen, abundant sanidine and biotite indicate rhyolitic tephra; at Centralia, plagioclase and absence of quartz and K-spar indicate dacite. Absence of K-spar from Chuckanut deposits may be due to its destruction by metamorphism, since quartz phenocrysts are present, suggesting rhyolite.

Alteration of glassy tephra to bentonite has taken place in two or three steps. (1) Leaching (weathering) in the swamp may have formed allophane or halloysite, but much glass remained unaltered. (2) Early diagenesis at temperatures below 60°C (suggested by vitrinite  $R_o = 0.40\%$ ) formed, by reaction of non-phenocrystic components with pore fluids within individual partings, one of five assemblages depending on degree of prior leaching: zeolite-smectite-cristobalite, smectite-cristobalite, smectite, smectite-kaolinite, kaolinite. Na-smectite at Centralia inherited interlayer Na from original glass. Delicate vermicular kaolinite may also have formed during this stage. (3) Thermal metamorphism has transformed smectite in some Tulameen and all Chuckanut partings to regularly interlayered illite/smectite (I/S). At Tulameen ( $R = 1$  ordered I/S with 55% I + kaolinite), the source of potassium for the reaction was solution of phenocrystic sanidine and mica;  $R_o = 0.9\%$  suggests 130 to 200°C. The Chuckanut bentonites ( $R = 1$  and  $R \geq 3$  ordered with 65 to 90% I + chlorite) show  $R_o = 3\%$  suggesting temperatures exceeded 300°C; some potassium may have been derived from outside the parting, and more complete illitization may have been inhibited by lack of potassium and by calcium released during albitization of plagioclase.

QUIREIN, J. A., J. S. GARDNER, and J. T. WATSON, Schlumberger Well Services, Houston, TX

#### Combined Natural Gamma Ray Spectral/Litho-Density Measurements Applied to Clay Mineral Identification

The utilization of well log data to provide a lithologic description of complex formation is well-evidenced. Historically, however, most approaches assume fixed, known, and distinct lithologies for analyst-specified zones. The proposed approach attempts to alleviate this restriction by estimating the

"probability of a model" for the most likely models suggested by the reservoir geology. Lithologic variables are then simultaneously estimated from response equations for each model and combined in accordance with the probability of each respective model.

The initial application of the proposed approach has been the recognition of clays in the presence of calcite, quartz, dolomite, feldspar, anhydrite, or salt. This application has been realized through utilization of natural gamma-ray spectra, photoelectric effect, bulk density, and neutron porosity information.

For each specified model, response equations and parameter selections are obtained through utilization of the thorium versus potassium crossplot and the apparent matrix density versus apparent volumetric photoelectric cross-section crossplot. The thorium and potassium response equations are used to estimate the volumes of clay and feldspar. The apparent matrix density and volumetric cross-section response equations can then readily be corrected for the presence of clay and feldspar. However, a test is applied to ensure that the clay correction lies within limits consistent with the assumed lithology model. If inconsistency is detected, either the estimate of clay volume or the lithology model, or both, are changed.

A computer program has been written to test the proposed approach. Initial field testing in the U.S.A. and Canada has been completed and the program appears to recognize, with minimal analyst intervention, illite, chlorite, and a third clay which is considered to be a kaolinite-montmorillonite mixture. Results from the field are presented for an assortment of wells with varying lithologies.

ROBERSON, HERMAN E., State Univ. New York, Binghamton, NY, and BRUCE SASS, State Univ. New York, Binghamton, NY (present address: Washington State Univ., Pullman, WA)

#### Al-Hydroxy Smectite: An Intermediate Between Smectite and Mixed-Layer Illite/Smectite Formed in Burial Diagenesis of Pelitic Sediments?

Reaction mechanisms for the reaction smectite → mixed-layer illite/smectite are proposed based on experimental results. Pure smectite (100% expandable) in NaCl-Na<sub>2</sub>CO<sub>3</sub> solutions was heated in sealed gold capsules to 180 and 350°C for periods of 7 and 28 days. The solutions used for this initial hydrothermal treatment were kept  $K \pm$  free to prevent the formation of non-expanding illite layers, a condition which would have made it difficult to characterize the exchange properties of expanding layers undergoing transition.

A series of cation exchange experiments using chloride solutions of Na<sup>+</sup>, K<sup>+</sup>, and Mg<sup>++</sup> were carried out at 25°C to determine the effect of the heat treatment described above on  $K \pm$  selectivity and total cation exchange capacity. Data obtained from these experiments show that the hydrothermally treated clays become *less selective* for K<sup>+</sup> with increasing temperature and length of run. Data also show that the total CEC *appears to decrease* with increasing temperature and length of run. We suggest that this apparent decrease in total CEC as well as the difference of  $K \pm$  selectivity is caused by the inability of the exchange cation (Ba<sup>++</sup> in these experiments) to replace tightly held Al, which diffused to exchange sites from tetrahedral and octahedral positions when the clays were heated.

These results lead us to propose that a smectite-interlayer Al-hydroxy complex may be an important intermediate in the smectite → mixed-layer illite/smectite transformation often observed in buried pelitic sediments. Further study of the rate and mechanisms involved in the formation and ultimate destruction of the Al-hydroxy interlayer material should be