set and opening on fractures, factors very important to production in fractured reservoirs.

The appropriateness of a numerical model depends completely on the specified input which consists of: (1) the boundary condition that produced the structure, and (2) the material behavior of the rock. Consequently, it is possible that a model with improper input may produce the desired fold geometry yet provide inaccurate information pertinent to fracture prediction. Thus, debate over the nature of boundary conditions, such as exists in thrust terrane, has implications even in the realm of fracture prediction.

JOHNS, W. D., Univ. Missouri, Columbia, MO

Clay Mineral Catalysis and Petroleum Generation

Kerogen, the major organic component of sediments and sedimentary rocks, is the immediate precursor of petroleum hydrocarbons. Recent studies of kerogen maturation during burial diagenesis show that decarboxylation of fatty acid constituents and C-C bond cleavage of hydrocarbon groups, both attached to the kerogen polymer, lead ultimately to petroleum-hydrocarbon formation. The low temperature range over which this occurs (60 to 110°C, 140 to 230°F) has suggested that the clay mineral matrix may play a role in catalyzing these important reactions.

Kinetic studies of clay-organic reactions have demonstrated the effectiveness of clay catalysis in organic acid decarboxylation and cracking reactions and suggest the mechanisms involved.

Kinetic constants deduced for these reactions from the natural maturation of kerogen during diagenesis reveal a further complication in sediments. Because kerogen is a solid, relatively immobile polymer, structural rearrangement is necessary to bring reacting groups in contact with catalytic sites. Mechanical movement plays a role in promoting catalytic activity.

JOHNSON, R. C., U.S. Geol. Survey, Denver, CO

Stages of Eocene Lake Uinta, Piceance Creek Basin, Colorado

Recent stratigraphic studies have greatly improved our knowledge of the relation between the facies of the Green River Formation in the Piceance Creek basin, thus allowing for a more precise interpretation of the development of Eocene Lake Uinta through time.

In general, the evolution of Lake Uinta can be divided into six main stages. During the first stage, which is represented by almost half of the preserved Green River section in the central part of the Piceance Creek basin, there were two lakes, one located in the Uinta basin and one in the Piceance Creek basin. Freshwater mollusks occur throughout the stratigraphic section representing this period of time, suggesting that the lake was at least periodically fresh. These two lakes should probably not be rightfully called Lake Uinta, since a single lake did not exist. The second stage begins with the Long Point transgression in which the lake in the Piceance Creek basin transgressed across the Douglas Creek arch and connected with the lake in the Uinta basin. The area under water was quadrupled, and Lake Uinta, as envisioned by Bradley, came into being. During the following stages, Lake Uinta extended unbroken between the two basins. Low-grade, clay-rich oil shale is the dominant lithology from this stage, with the exception of some nearshore areas where shallow shelves began to form. Freshwater mollusks are found in rocks of the second stage, but are not common in rocks of later stages of Lake Uinta in the Piceance Creek basin. The third stage began with an abrupt increase in the kerogen content of the offshore oil shales. In the marginal lacustrine areas, however, there was no noticeable change. Here, marginal shelves, which began to form immediately after maximum Long Point transgression, continued to prograde into the lake. Large fluctuations in water level are suggested by rapid changes in facies on the marginal shelves. Thick, ripple-laminated sandstones were deposited during rising water, and deep meandering channels formed when water level dropped.

The water level appears to have been much more stable during the fourth stage. Thick stromatolites and tufa mounds interlayered with laminated carbonate-rich mudstone are the dominant lithologies found in the marginal shelf deposits. Laminated, kerogen-rich, dolomitic oil shale was deposited in the center of the lake. Carbonate content increased in all Lake Uinta sediments during this stage; and for the first time, the saline mineral nahcolite is found associated with oil shale. At the beginning of the fifth stage, water level gradually rose, bringing intermitted oil-shale deposition over about the outer half of the marginal shelves. Nahcolite deposition in the offshore oil shales ceased during transgression but began again once water level stabilized. In fact, most of the nahcolite and halite in Lake Uinta sediments were deposited during this comparatively long stage. This higher lake level brought some peculiar changes to the marginal shelves. Oil shale is commonly interlayed with ripple-laminated siltstones and fine sandstones, ranging in thickness from a few inches to as much as 70 ft (21 m). These clastic sequences can be traced toward the center of the lake where they form lean zones in the oil-shale section.

The final stage of Lake Uinta in the Piceance Creek basin begins with a major transgression, represented approximately by the base of the Mahogany Ledge, a rich oil-shale sequence. Lake Uinta expanded to its maximum extent in the early part of this stage, possibly expanding to near the limits of the sedimentary basin. Infilling of the lake began at maximum transgression when a rapidly prograding shelf complex, composed largely of volcanoclastic sediments, started at the north shore of Lake Uinta and reached the southwest corner of the basin before halting. Lake Uinta evidently persisted in this limited area considerably longer than elsewhere in the basin.

The stratigraphic model presented here demonstrates that Lake Uinta evolved with time, and that each succeeding stage represented an accumulation of characteristics acquired during the preceding stages. Geochemical models that have been proposed to explain the unique oil shale and saline deposits from Lake Uinta should be reexamined in light of this more complete stratigraphic picture.

JOHNSON, RONALD C., and VITO F. NUCCIO, U.S. Geol. Survey, Denver, CO

Structural and Thermal History of Piceance Creek Basin, Colorado, in Relationship to Hydrocarbon Occurrence in Mesaverde Group

The purpose of this study was to reconstruct the structural and thermal history of the Piceance Creek basin to try to predict the occurrences of hydrocarbons in the Upper Cretaceous Mesaverde Group. A vitrinite reflectance map of basin-wide coal zone and several coal rank cross sections using vitrinite data was constructed. Isopach maps were used to reconstruct the burial history. In general, the Mesaverde Group can be divided into two parts: a lower mixed marine and nonmarine part, and an upper, largely nonmarine section. Vitrinite reflectance values range from R_o .50 to R_o 2.1, and indicate that both the nonmarine and marine Mesaverde are within the range of thermal gas generation throughout the basin, with the possible exception of the upper part of the nonmarine Mesaverde along the extreme west and southwest margins of the basin. The occurrence of gas correlates reasonably well with this finding. Both the marine and nonmarine Mesaverde are within the window of oil generation for most of the basin, except in the deeper parts where the upper limit of oil stability has been exceeded. Oil, however, is seldom encountered in the basin, probably because of a lack of abundant source beds with oil-generating capabilities.

The vitrinite values are much too high to have formed under the present geothermal gradient, which averages about 1.7°F/100 ft (3°C/100 m), and appear to reflect a paleothermal gradient of between 2.2 and 3.5°F/100 ft (4 and 6.3°C/100 m), with the highest gradients in the southern part of the basin. It is suggested that this high gradient occurred during Oligocene time when the southeastern part of the basin was extensively intruded by magmas of intermediate composition.

Overpressuring has thus far only locally been encountered in the basin. The lack of a well-defined overpressured area may be a combination of: (1) a decrease in the geothermal gradient since Oligocene time, and (2) uplift and removal of overburden during the last 10 million years. As much as 5,000 ft (1,500 m) of overburden has been removed in some parts of the Colorado River drainage.

JOHNSON, SAMUEL Y., Washington State Univ., Pullman, WA

Eocene Chuckanut Formation of Northwest Washington—Sedimentation in a Large Strike-Slip-Fault Controlled? Basin

The Eocene Chuckanut Formation of northwest Washington comprises as much as 6,000 m (20,000 ft) of alluvial strata and is one of the thickest nonmarine sequences in North America. It is exposed in several disconnected outcrop belts that are probably remnants of a regionally extensive fluvial system. Four distinct periods of sedimentation are represented in the main (50 × 20 km, 31 × 12 mi) Chuckanut outcrop belt near the town of Bellingham. These include: (1) early Eocene: rapid sedimentation in west-southwest-flowing fine-load meandering rivers; (2) early-middle Eocene: sedimentation in braided rivers draining northern fault blocks in the western part of the outcrop belt, synchronous with continued fine-load meandering-river sedimentation to the east; (3) middle Eocene: sedimentation in a south-flowing, coarse-load meandering river system in the western part of the outcrop belt, synchronous with continued sedimentation in west-flowing, fine-load meandering rivers of reduced size and competence to the east; and (4) middle to late(?) Eocene: sedimentation in alluvial fans and braided rivers in the eastern part of the outcrop belt draining uplifted pre-Tertiary basement north of the Boulder Creel fault. Following period 4, but still in the Eocene, the Chuckanut was first folded and then truncated by faulting.

It is proposed that the Chuckanut basin formed in an extensional zone of right lateral shear between major strike-slip faults. Consistent with this interpretation are: (1) rapid sediment accumulation rates; (2) rapid facies changes; (3) an irregular basin margin characterized by dip-slip faults and intraformational unconformities; (4) deformation consistent with predicted structural patterns; (5) rapid changes between extensional and compressional tectonics; and (6) interbedded and intrusive relationships with extension-generated(?) volcanic rocks. The Chuckanut basin is considerably larger than most pull-apart basins generally associated with strike-slip faulting, yet shares many of the same attributes. Similar large basins might be found in other continental margins characterized by strike-slip faults.

JONES, DONALD R., American Exploration Co., Houston, TX, and MICHAEL D. SMITH, Michael Smith and Assocs., Inc., Houston, TX

Ranking South Louisiana Trends by Probability of Economic Success

Hydrocarbon exploration is an economic and a probabilistic enterprise. Especially in mature provinces, where the giant discoveries have mostly already been made, we must incorporate probability and economics into exploration if our efforts are to be successful. Not even the largest companies have the resources to be active in all the exploratory plays possible; we find ourselves concentrating on only a small number of the available plays.

This choice of where to explore should be made by defining the objective of exploration and then concentrating on those plays which have the highest probability of achieving that objective. For a limited partnership drilling fund, the objective was formulated as a 3:1 present worth return on the money risked by the investors. A trend analysis process was developed which combines the probability of making a discovery with the probability distribution of reserves found to determine the probability of obtaining a desired return.

The industry's performance was analyzed for the years 1970 through 1981. For the foreseeable future we will be using the same technology as the 1970s and can reasonably expect the continuation of the trends of physical results (success ratios and the size distribution of discoveries). These physical results were combined with price and cost forecasts for the 1980s to obtain a realistic projection of expected exploratory success.

The steps in the analysis are as follows. (1) Geological Classification—A data base was developed containing the well information on 4,800 new-field and other exploratory wells drilled in south Louisiana. Each well was classified as to the objective formation and as to the producing formation(s) if successful. Twenty-nine separate trends were identified and analyzed. (2) Exploratory Drilling Data Analysis—A computer program was written to sort the well data by trend, project and exploratory success ratios for oil and gas, and prepare depth and cost analysis. (3) Reserves Added Analysis—Reserve estimates were made for 858 (557 gas, 301 oil) discoveries by projecting rate-cumulative production decline curves. Discovery sizes for the trends exhibited the expected log-normal frequency distributions. (4) Economic Projections—Using projected costs and product prices, a profile was developed for each trend of present worth profit as a function of discovery size. As usual, many discoveries can be expected to be "geologic successes but economic failures." (5) Probabilistic Analysis—Utilizing the Monte Carlo technique, a computer program was written to realistically simulate an n-well exploration program. The result for each trend was a cumulative frequency distribution of the return per exploration dollar. Using the same exploratory budget for all trends allowed us to rank trends based upon the probability of achieving the desired present worth return or better. Examples are presented for trends of varying rank.

In summary, computer data banks were used, along with thorough geologic analysis and some common sense, to provide a sound basis for concentrating exploration effort on those trends where we are most likely to achieve our objective.

JONES, R. W., and G. T. MOORE, Chevron Oil Field Research Co., La Habra, CA

Frontiers in Organic Geochemistry

During the past 20 years, an explosion has occurred in both the