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.

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## 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.

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## 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.

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## Frontiers in Organic Geochemistry

During the past 20 years, an explosion has occurred in both the analytical sophistication of organic geochemistry and the application of organic geochemistry to better evaluating risks when making exploration decisions. Unfortunately, the applications available from present technology have not been fully exploited. Thus, a major frontier exists in the increased exploitation of presently available technology. This frontier can best be exploited by placing an experienced exploration geologist, with an interest in organic geochemistry and basin analysis, between the chemist in the lab and the exploration manager.

Meanwhile, technology improves and new opportunities appear, although we will probably be dealing with incremental improvements, not the conceptual breakthroughs of the past 20 years. Anticipated developments include the following. (1) Finer tuning of the "generation window" for different types of organic matter, generation products, and rock matrices. (2) Better generation, migration, and accumulation models. Many numbers are multiplied together in these models, thereby leading to large uncertainties in the final prediction. Geochemistry will help better define such models in several ways; however, its major contribution will probably be in the increased accuracy and numbers of measurements of the actual distribution of hydrocarbons and other organic compounds in the subsurface. More such data are sorely needed to increase our ability to quantitatively evaluate migration mechanisms. Most of the oil and gas remains in the potential source rock. Better understanding of when, how, and why some of it does move is clearly an important frontier. (3) Improved prediction of source rock distribution, type, thickness, and maturity. This will be accomplished by integrating organic geochemistry with modern and paleo-oceanography, paleoclimatology, and plate tectonics. By better understanding why source rocks are where they are, we will better predict where others might exist, and conversely, where they are not to be expected. (4) Increased efforts to apply "biomarker" geochemistry to exploration problems. (5) More sophisticated, non-"biomarker," methods for characterizing oils. These will lead to better oil-oil and oil-source correlations for use in exploration, but will also be increasingly applied to a variety of development and production problems. (6) Increased studies of interactions between organic matter, rocks, and fluids. In the past, the prime interest was in the effects of different rock matrices on organic maturation rates. Results have been disappointing, perhaps because the major effects are in the other direction. Organic matter and its decomposition products can have a major effect on rock diagenesis and sedimentary ore deposits. (7) The geochemistry of deep, hot, gas accumulations.

This list is not exhaustive. Opportunities abound for the application of geochemistry to exploration problems. The technology exist, or soon will. The frontier is how well the resourcefulness of our profession will be used to apply the available technology to our problems.

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### A Discussion of Crude Oil Production Potential in Alaska and California

Nearly half of the proved oil reserves in the United States are located in Alaska and California. In 1980, production from this 14 billion bbl reserve base averaged nearly 2.6 million BOPD or roughly 30% of total United States production. Although there is little doubt that Alaska's and California's future contributed to total United States production will increase, a great deal of uncertainty exists concerning the magnitude of this contribution.

A range of forecasted production values is presented for Alaska and California. The forecast reveals that there is a 67% spread between the high and low boundaries of California's production potential during the mid 1990s; this range is even greater (167%) in the case of Alaska.

The forecast is accompanied by a comprehensive discussion of factors that will determine actual production. These factors are organized into three groups: exploration success, market conditions, and regulatory environment. The first, exploration success, is described in terms of geologic prospects, lease sale timing, technology performance in harsh frontier environments, and economic risk in comparison to other regions. The second group comprises factors affecting petroleum company perception of future West Coast market conditions. Forecasts of refined product demand, crude supply potential, and refinery configuration are presented to help define this perception. The third group, future state and federal regulatory environments, is discussed from the perspective of conflicts between state and federal outer continental shelf operational jurisdiction, potential governmental responses to serious accidents, and policies concerning taxes, royalties, and crude exports.

This information will help petroleum companies formulate crude exploration, development, production and processing plans based on personal perceptions of the future.

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

Sandstone reservoirs of good quality, displaying abundant deep secondary porosity, exist on the upper Texas coast, whereas secondary porosity and permeability in sandstones of the lower coast are occluded by authigenic ferroan calcite and chlorite. This difference in regional reservoir quality is controlled by bulk mineralogy, temperature, pressure, and pore-fluid chemistry. Concentrations and activities of major species show depth dependent trends that correspond to pore pressure gradients and associated thermal gradients. Salinities decrease near the base of hydropressure, but increase at intermediate pressure gradients between 0.465 and 0.7 psi/ft (10.5 and 15.8 kPa/m). At higher pressure gradients salinities decrease with depth. The Ca/Na ratio is lowest at top of geopressure. Predictions from solution-mineral equilibria using approximately 130 analyses of Frio brines add new insight on relative mineral stabilities and in-situ pH, and are consistent with the diagenetic sequence developed from petrographic data. Kaolinite is stable in geopressured waters relative to Ca-montmorillonite and plagioclase; it is abundant on the upper coast as a late stage cement. Lower temperature and in-situ pH (high $P_{CO_2}$) explain the general absence of chlorite on the upper coast; its formation on the lower coast is promoted by higher temperature, a mineralogy rich in volcanic and carbonate detritus, and inferred higher pH. The key to predicting reservoir quality at depth is the deep hydropressured waters. Activity indices are indicators of reservoir quality. Waters of the lower coast plot more deeply into the stability field of chlorite than do those of the upper coast.

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### Egyptian Exploration: Background, Models, and Future Potential

Egypt has proven to be an area with excellent exploration