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Dealing with Risk and Uncertainty in Exploration: How Well Do We Predict? How Can We Do Better?

Risk and uncertainty are inherent aspects of investing in exploration ventures. Risk, the weight of investment with respect to budget and consequence, is a subtle, variable, but important factor that is intrinsically difficult to apply consistently. Uncertainty, the perceived range of probabilities that a given situation may exist, lends itself more readily to systematic consideration. Professionals may be able to improve their ability to assess uncertainty more reliably. Judgments of both risk and uncertainty are highly susceptible to psychological influences and biases of which most explorationists are unaware.

Two of the most influential considerations involved in exploration decisions are (1) the likelihood that a postulated hydrocarbon accumulation is present, and (2) the probable volumes of oil or gas contained in the prospect if it exists. Both lie within the geotechnical purview. Such exploration predictions are made routinely, and they have enormous financial impact. Nevertheless, few public data have been available as to actual performance records of explorationists' predictions: many organizations do not examine predictive performance, and the few that do are reluctant to publicize their records. The reasons are mostly human and understandable, relating to the forward press of exploration events, individual chagrin, corporate politics, proprietary advantage, and even professional modesty.

Limited data on predictive accuracy in exploration began to be available in 1979 and suggest the following general patterns.

1. Accuracy of hydrocarbon-volume forecasts ranges widely, based on predrilling and postdrilling estimates; there may be roughly a 90% chance that a given volumetric forecast will be accurate within about one order of magnitude (power of ten), plus or minus the actual volume of the accumulation.
2. Forecasts of hydrocarbon volumes tend to be overly optimistic. The chief technical reason has to do with erroneous predictions of hydrocarbon recovery factor. Other nontechnical forces also appear to contribute to this trend, including motivational bias.
3. Analysis of various geological risk factors (such as structure, reservoir, trap, or charge) may help improve assessment of discovery probability; however, prior to drilling a prospect, explorationists commonly do not identify which geological factors constitute the primary exploratory hazards. Also, many explorationists confuse "exploratory success" and "commercial success."
4. The dedicated technical intellect is loath to recognize and accept the large uncertainties and biases actually involved in his/her professional predictions and, therefore, may encourage exploration management to make unwarranted expenditures for data prior to drilling. This tendency is reinforced by the natural corporate inclination to reduce exploratory uncertainty to a minimum prior to drilling.

Growing evidence exists that professional exploratory performance can be improved through the following.

1. Training to minimize heuristic biases inherent in estimating uncertainty, as well as decision-making in risk ventures.
2. Postmortem analysis of exploration predictions and decisions.
3. Evaluation of tactics versus declared strategy, by comparing various exploration parameters (e.g., discovery probability, predicted target volume, actual discovered volume, finding rate, working interest, and prospect origin).

Discerned performance trends can then be used to discount or enhance new prospects, to highlight areas for future improvement, and to modify corporate stances and strategies. Such analysis may best take the form of individual professional progress, rather than imposed management inspection.

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Predictive Models for Sandstone Diagenesis

The maturation of organic material in hydrocarbon source rocks and inorganic diagenetic reactions in reservoir sandstones are a natural consequence of the burial of a prism of sedimentary rocks. The distribution of porosity/permeability enhancement in potential hydrocarbon reservoirs can be predicted by integrating the reaction processes characterizing the progressive diagenesis of a reservoir/source rock system.

A variety of observations suggests that the organic solvents necessary to increase aluminosilicate and carbonate solubilities in sandstones can be generated either by thermal or oxidative cracking of carbonyl or phenolic groups from kerogen in adjacent source rocks. For example, nuclear magnetic resonance (NMR) spectra of kerogen show that peripheral carbonyl and phenol groups are released from the kerogen molecule prior to the generation of liquid hydrocarbons.

Experimental data indicate that these water-soluble organic solvents can significantly affect the stability of both carbonate and aluminosilicate minerals. Water-soluble organic acids (carboxylic) have been observed in oil field waters in concentrations up to 10,000 ppm, and they commonly dominate the alkalinity in the fluid phase over the 80°-120°C temperature range.

The integration of the organic and inorganic diagenetic reactions can be modeled conceptually by constructing a series of potential reaction pathways with increasing temperature, for a system that includes aluminosilicate minerals, carbonate minerals, organic solvents (carboxylic and phenolic), and carbon dioxide. The important chemical divides in these diagenetic flow diagrams are dependent on temperature, the nature of the buffer in the carbonate system (internal or external), and the relationship between organic acids and P_{CO_2}. Forward predictive capabilities result when this general diagenetic model is placed in a time-temperature framework. The detailed organic and inorganic geochemistry and the general thermal scenario used in the time-temperature analysis must be basin-specific. Casting the diagenetic history of a sandstone into this type of process-oriented model enables one to make the transition from a conventional descriptive mode to a predictive mode of analysis.

Predictive models have been developed for several tectonic settings, including rift or "pull-apart" basins, and intermontane or "Laramide" basins. From these reconstructions, two types of information result: (1) general optimum conditions for porosity/permeability enhancement in sandstones are delineated, and (2) specifically, the degree and potential for porosity/permeability enhancement are determined. Forward prediction of the porosity-enhancing potential of a diagenetic system is possible based on an understanding of the reaction processes in a time-temperature framework.

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Paleogeographic Evolution of China

China presents a challenge to the paleogeographer because all but 9% of this huge country has been tectonically deformed between the Jurassic and the present. Even the undeformed areas—the Sichuan basin of south China, the Ordos basin of north China, and the Tarim and Dzungarian basins of west China—have thrust-loaded margins. The present geometry of China resulted from the accretion to Asia during the late Paleozoic to the early Cenozoic of three moderate-size continents (Yangtze, Sino-Korean, and Tarim) as well as numerous smaller continental fragments in the region of the Tibetan Plateau. As might be expected, the present collision pattern of India with Asia and the resultant thrusting of western China and "continental escape" of eastern China by transtensional systems became manifest during some of these earlier collision episodes.

Is there any hope of "untying the Gordian knot" and reconstructing this complicated history with any confidence? Chinese geologists have been able to date the collisions of the constituent microcontinents by studying the ophiolite and flysch sequences. Their biogeographic studies would point to Gondwana as the most likely source of these continental elements. Also, Chinese geologists have been assiduous in describing the rich stratigraphic record of their country, so it is possible to deduce from the distribution of the climatically sensitive sediments the approximate paleolatitudes of the microcontinents during their transits of Tethys. This information can be compared with paleomagnetic results that are just becoming available. The sea-floor-spreading history of the Indian Ocean provides some constraints, but prior to the collision of India in the Eocene, China was completely surrounded by subduction zones and therefore detached from the ocean floor.

The general picture then is the accretion in succession, from north to south, of microcontinents, of which India is the most recent arrival. Left-lateral deformation between and within these elements was a recurrent