BASIN ANALYSIS AS AN EXPLORATION TOOL—PARADIGMS LOST, INSIGHTS GAINED

Advances in geology, as in all sciences, result from the testing and overturning of paradigms and the replacement of old theories with new. Paradigms are useful in seeking solutions to complex geologic problems because 'we have to start somewhere' in our analysis, and existing theory provides a convenient point of departure. Moreover, paradigms provide a framework within which to place what might otherwise be random observations. For example, a relatively new paradigm in geology is sequence stratigraphy, which provides a more systematic way to organize stratigraphic observations.

A problem with paradigms is that we become increasingly dependent upon the ready explanations they offer and find ourselves searching for data in support of the paradigm rather than treating the paradigm as one of many working hypotheses. The more a paradigm is cited in the literature, the more 'correct' it becomes, and in the process the more difficult it is to overturn. So, although science advances by the overturning of paradigms, in practice our reliance on paradigms leads us to become increasingly reluctant to relinquish them even when faced with contradictory data. As a consequence, paradigms are more commonly applied than tested: what begins as hypothesis evolves into unalterable truth. This is in spite of the fact that the creators of new paradigms commonly are the most cautious in the extrapolation of their models and warn readers against indiscriminate application. The proponents of sequence stratigraphy, for example, urge us to use the concept as a 'tool rather than a template' (H. Posementier, *oral commun.*, 1989).

With these caveats, why do we still have the tendency to apply paradigms without questioning them? In large measure, this tendency stems from the need to interpret an increasingly bewildering amount of data from diverse specialities in which we have limited or no expertise and must rely on prevailing thought to narrow the number of possible interpretations. Also, the propensity of scientists to hold tenaciously to conventional wisdom is understandable in light of new knowledge of the partitioning of brain functions. The analytical and organizational left hemisphere of the brain seeks explanations for random information already in storage. Although this ordering is an important and necessary function, the left hemisphere becomes reluctant to give up a model that it sees as a satisfactory explanation for otherwise random information. With time, a paradigm can become deeply rooted and virtually ineradicable, even in the face of new data that may be contradictory to the paradigm. Moreover, paradigms stored in the left hemisphere filter new observations that enter the visual right hemisphere of the brain, a process that also hinders formulation of new concepts. In light of this inclination to override the implications of new observations, our objectivity as scientists is questionable. This coloring of our thought processes comes through in the humorous admission, 'I would never have seen it if I hadn't believed it myself.'

In the study of sedimentary basins, the basin analysis approach forces rigorous testing of scientific paradigms because the multidisciplinary nature of the approach necessitates the integration of data from diverse specialties. Feedback from diverse specialties provides numerous constraints so that no conclusion can be drawn about one aspect of a basin's history without affecting the interpretation of other aspects. Thus, when a conclusion from one line of evidence is at variance with a conclusion

drawn from several other lines of evidence, we must challenge the assumptions that led to the different conclusions—which usually involves examining cherished theories or paradigms. The reluctance to relinquish paradigms is more easily overcome when several lines of evidence point toward new concepts that have exciting implications of their own. Basin analysis, by its integrative nature, pushes us toward new perspectives and thus serves to promote new discoveries in geoscience.

A case study in the San Juan Basin of New Mexico serves as an example of the basin analysis approach to a geologic problem. It also points out that answers to questions not initially posed can sometimes be the most significant (and surprising) outcome of a basin study. The original goal of the San Juan Basin study was to develop a genetic model for sandstone-type uranium deposits in the Jurassic Morrison Formation. Tectonic, geophysical, sedimentologic, petrographic, hydrologic, and geochemical studies were drawn together so that mineralization could be evaluated in the context of the entire depositional, structural, and diagenetic framework. The result was not only a model for uranium mineralization, but also, somewhat unexpectedly, the overturning of several paradigms and their replacement with new concepts. Many of these new developments were unrelated to the solution of the original problem.

One new result of the San Juan Basin study is that it was possible to document that authigenic illitic mixed-layer clays in the Upper Jurassic Morrison Formation formed at near-surface conditions in the absence of elevated temperatures. This finding contrasts with the 'Gulf Coast model' for illite formation, in which temperatures of at least 90°C are thought to be required. The 'Gulf Coast model,' in which composition of illite/smectite mixed-layer clays is attributed to increasing temperatures attendant with increasing burial, had become a paradigm throughout the petroleum industry. In the San Juan Basin study, because the basin analysis approach was used, formation of authigenic illite was not viewed as an isolated event. The process instead was constrained by other lines of evidence, including inferences from associations with other authigenic minerals; vitrinite reflectance data; petrographic constraints; paragenetic relationships; reconstructions of burial and thermal history; and hydrogeochemistry. Thus, the 'Gulf Coast' paradigm, requiring elevated temperatures, did not provide a valid model for illite formation in this study. It became apparent that, in certain instances, pore-water chemistry alone can facilitate formaiion of authigenic illite, and thus that illite is not always a reliable geothermometer. Therefore, the 'Gulf Coast model' offers one, but not the only, mechanism by which authigenic illite can form. This example serves to illustrate that a paradigm cannot be generalized to include all cases. The paradigm was correct, yet did not provide a unique solution to the problem. In other cases, a paradigm is invalid because the underlying assumptions are incorrect. In either case, basin analysis provides internal checks on the validity of paradigms and highlights inconsistencies that would not be evident if only the constraints within individual sub-disciplines were considered.

R. K. Matthews stated in a letter to the editor of *Geology* in 1985, 'A paradigm is the framework within which we attempt to solve problems,' not necessarily the solution to the problem itself. The integrative nature of the basin analysis approach allows a synoptic rather than a myopic view of specific geologic problems, and the multidisciplinary nature of the approach forces us to scrutinize each paradigm because each paradigm has consequences for the whole, beyond the solution of an isolated problem. The approach can be applied to any geologic problem and will

serve to advance science by continuing to lead us away from current paradigms, as multiple lines of evidence force us to question our most cherished beliefs.

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ENVIRONMENTAL PROBLEMS

The real solution to environmental problems is not preservation of conditions as they are, nor it is simply to clean up the intolerable messes that were created by human ignorance of or indifference to natural systen processes. Something more is needed to solve the problem because the solution must accommodate growth until the growth can be controlled. I believe that basic education is the key element in the solution to environmental problems, and engineering geologists can play a critical role in the education process. This is a call to all engineering geologists: Go educate the public about geologic aspects of environmental problems and the problems will go away. But, of course, it is not that simple.

This idealistic call leads me to the story of the Grasshopper and the Owl which goes something like this: One cold, gray day in late autumn the Grasshopper, who had given no thought to how he would survive through the winter, was shivering in a cold wind as snow began to fall. The Grasshopper was rather smart and had lived through the summer and early fall in grand style. He took whatever he felt like taking with never a thought that the abundant leaves and stems he was enjoying might not last forever. The cold wind and blowing snow gave him a starling view of the reality that the green leaves of summer were, indeed, brown bits of dry, broken waste. What to do now, now that it was cold and he had nothing to eat!

The Owl! Everyone knew the Owl was the wisest of all the animals. He would visit the Owl and ask for advise. So the Grasshopper set out to find the Owl, and when he finally found him, he asked.

'Mr. Owl, everyone knows you are the wisest of all the animals; I need your advise.'

'Well, Grasshopper, I can see that your situation it requires some appropriate action. What is it that you would like to ask?', the Owl said.

'Mr. Owl, here it is late autumn and I have made no plans for the winter. I am already cold and hungry. What should I do?', pleaded the Grasshopper.

'That's simple!' replied the Owl. 'Change yourself into a bear and hibernate for the winter.'

'What a wonderful idea!', responded the Grasshopper. 'That way, I won't have to do anything except sleep in a nice dry cave all winter. What a great idea, Mr. Owl, thanks!'

And with that, the Grasshopper turned away from the Owl and began to look for a suitable cave. But reality descended upon the Grasshopper before he had taken more than a few shivering steps.

'Wait a minute!'. cried the Grasshopper, as he turned back to the wide-eyed Owl. 'How am I supposed to do that? How do I change myself into a bear?'

'Hold it! Hold it!', replied the Owl firmly, holding up the ends of his wings as though they were palms of outstretched hands. 'I just make policy; I don't implement it.'

In this fable, the Owl could be viewed as federally or locally promulgated environmental regulations; well-meaning, but some-times not totally practical or even possible. The Grasshopper clearly is Society; unaware of the gravity of the situation until it is almost too late to do anything except try to figure out how to change a grasshopper into a bear.