 Frontier Hydrocarbon Exploration: The Importance of Tectonic Models

Advances in understanding the dynamics of modern tectonic processes have transformed scientists’ interpretations of ancient tectonic environments and regional deformation regimes and have led to radical conceptual changes about the tectonic evolution of basins in continental, marginal and oceanic environments. These new concepts are making a significant impact on operators’ exploration strategies and on the discovery of hydrocarbon plays in regions that were previously unknown, poorly explored, difficult to access or quickly dismissed. Tectonic insights suggest that there may be significantly more hydrocarbon resources to be found in places that were once deemed valueless (see “Basin to Basin: Plate Tectonics in Exploration,” page 38).

For example, high orogenic plateaus, while typically set in the heart of mountainous regions, are now understood as mosaics of internally drained basins rather than as coalescent mountain ranges. Dynamic surface processes consisting of erosion, sediment transport and deposition by large rivers interacted with tectonically rising mountain rims to shape the high, flat and smooth morphology of these plateaus. This creates “cold” basins of a novel type, best represented within and to the north of the Tibet plateau. The basins filled rapidly with great thicknesses of Tertiary clastic sediments from internal drainage. The sediments likely host potential reservoirs and seals on top of source rocks in Mesozoic marine and Tertiary lacustrine limestones or shales, adding to new leads in the high plains south of the long-producing basins in western China.

On the Lebanese stretch of the Levant basin margin, recent seismic and bathymetric offshore surveys, coupled with onshore tectonic studies, have also brought new insight. They show that this passive margin has experienced inverted folding since about 13 Ma. To the west of Mount Lebanon, which rises 4,800 m [15,700 ft] above the Levant basin floor, is a 150-km [93-mi] active thrust fault and an underwater fold-and-thrust belt that deforms Tortonian carbonates, Messinian evaporites and Pliocene-Quaternary turbidites. This submarine, thin-skinned, foreland-migrating thrust wedge is worthy of modern exploration. Many structures are sealed by the Messinian salt, which may trap large reservoirs, as it might do elsewhere in the Mediterranean region. Since 2009, discoveries of large gas accumulations in subsalt Miocene strata offshore Israel and Cyprus have demonstrated the importance of the Levant basin for significant natural gas resources.

In the early opening stages of both the Cretaceous South Atlantic and the Miocene Red Sea, thick salt deposition was controlled by a peculiar tectonic framework in which the marine environment was restricted between fissural “floodgates” formed through volcanism and transform faulting. Much of the evaporitic deposition likely resulted from precipitation in deep sags above oceanic crust during seafloor spreading, a characteristic once attributed to hyperextended continental crust. The existence of the Red Sea central trough, Angola escarpment and São Paulo plateau are most easily accounted for by incorporating seafloor spreading in the early evolution of the margins. The floodgate models may preclude simple extrapolation of onshore or shallow near-shore stratigraphy far beneath the deep salt. However, the existence of deep offshore hydrocarbon plays in a still largely unexplored environment was proved in 2007 by the discovery of the presalt Lula—formerly Tupi—oil field in the Santos basin offshore Brazil and by the discoveries in 2012 of the presalt Azul and Cameia oil accumulations in the Kwanza basin offshore Angola.

The odds are that vast oil reserves exist on top of the deep basaltic seafloor. Thick salt forming in a restricted anoxic environment resulting from tectonic activity is the key; the presence of prerift or synrift source rocks might not be required. The North American and West African margins of the central Atlantic also may harbor such plays, sealed deep beneath thick salt. Scientists will gain a better understanding of these phenomena by developing tectonic models with overlapping spreading centers that isolate continental slivers rather than models that rely merely on crustal hyperextension.

In understanding the tectonic evolution of basins, geoscientists may change classic perspectives and develop new paradigms for oil and gas exploration. The most important lessons from tectonic studies are that no environment should be considered beyond the bounds of exploration and that current models should be revisited. It seems certain that coherent, dynamic tectonic models, based on the well-constrained kinematics of active analogs, will be essential to the future of hydrocarbon exploration.

Paul Tapponnier
Professor and Group Leader, Tectonics and Earthquakes Group
Nanyang Technological University
Singapore

Paul Tapponnier is Professor and Group Leader of the Tectonics and Earthquakes Group at the Earth Observatory of Singapore at the Nanyang Technological University in Singapore, where he has worked since 2009. Previously, he worked at the Tectonique, Mécanique de la Lithosphère group at the Institut de Physique du Globe de Paris. His contributions to geology, tectonics and geophysics span more than 40 years and his research interests include continental dynamics and tectonics, particularly in Asia and the Mediterranean region; active faulting and seismotectonics; earthquake hazard assessment; quantitative geomorphology; rates of active deformation processes; and rock mechanics and rock deformation physics. He is a member of both the French and US National Academy of Sciences and a Fellow of the American Geophysical Union, Geological Society of America and Geological Society of London. Paul holds an ingénieur des mines degree from Ecole Nationale Supérieure des Mines de Paris and a doctorat d’etat degree from Université Montpellier 2 Sciences et Techniques, France.