A geotectonic model for petroleum exploration

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The recent period of high oil prices provided us with evidence to suggest:

- All the major, low-cost oil has been found and it exists in the Middle East and other OPEC countries. Thus we must suspend traditional exploration efforts to a large degree and concentrate on enhanced recovery of already found oil. Or,
- All low-to-moderately priced oil within reach of current geologic concepts has been found but new geologic concepts might lead to additional substantial discoveries of new, low-cost oil. Therefore the next round of petroleum exploration, done in conjunction with new tools and techniques, should be based on new prospect models.

This article describes such a model, an empirically derived geotectonic model, which I believe is geologically sound and should interest all explorationists because it forecasts large, low-cost prospects even in basins now considered mature.

Since the seminal idea grew out of personal preoccupation with basement tectonics as a precursor of basin development, much of the model is built upon the work of nonexploration-oriented geoscientists such as volcanologists and oceanographers. These were integrated with my personal observations (covering nearly four decades in exploration) and measurements from a wide range of exploration techniques—aerial photography and sensing, surface and subsurface geology, seismic reflection and refraction (including Moho shots), gravity and magnetics.

A key factor in the development of the model was the assumption that structure in the earth's crust represents a record of the release of forces which originated in, and emanated from, the planet's interior regions. This assumption evolved, to a considerable extent, from the recognition of similar orogenic occurrences on diverse continents, separated by large bodies of water, in correlative geologic time periods. If this were true, then the oldest observable rocks should be examined for clues. Since these

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*(**Geotectonic model** continued from p. 25)*

rocks are generally found under the modern oceans (especially in the abyssal plains), curiosity was naturally focussed on the explorations of the oceanographers for rocks and on the work of the astrophysicists for forces.

(Why astrophysicists? Because of the application of the currently evolving chaos theory and fractal geometry. But specific discussion is more appropriate a bit later in this article.)

Physical models/theories of nature's behavior commence as ideas which can be simply expressed either mathematically, graphically, or verbally. In this case, a drawing was made to illustrate a series of mechanical events which explained why a certain structural shape was being observed in seismic data. This interpretation hinges upon the inexplicable movement of substructural or basement blocks. Such movement is presumed to be primarily articulated by deeper forces which issue upward (or outward) along essentially vertical force vectors. This release of internal forces, as expressed in the oldest rocks, produced an intense pattern of rift faulting in the area of the modern sea floors—a predictable occurrence given the petrology of those incompetent rocks.

This concept leads to the conclusion that rift faulting is the trigger mechanism for sedimentary basins, and the behavior of the attendant fault blocks determines basin shape and internal structure.

Continued study revealed a repetitive shape in the initial phase of basin development. The occurrence and appearance of this shape was so regular that it is now recognized as the "analyzable factor" in an otherwise chaotic tectonic field—a requirement in the new chaos dynamics. Furthermore, this shape (Figure 1) was found to range in scale from very small to very large, in conformity with what is now known as fractal geometry and scaling; this from local structure through subbasinal, basinal, continental, and extracontinental scales.

(For those unfamiliar with chaos theory, the "analyzable event" is the complete model as we observe it today in its "final" form for this is the summary of the mechanical necessities required to form it. Although it may be intersected and thereby defaced by other manifestations of it, all the elements of the model must be there in some form. For example, a powerful and strikingly useful observation of fractal geometry and scaling recognizes that when a piece of fabric is torn—paper, cloth, metal, and perhaps space—a microscopic examination of a torn edge anywhere along the tear will reveal a shape identical to the main or largest manifestation of that tear. That shape, once it is recognized, becomes the analyzable event and that is what I claim my model is in a chaotic tectonic field. This is obviously a key to interpretation because, if chaos is produced by the interaction of analyzable events or forces as the physicists postulate, then these events must be recognized and isolated if the chaos is to be usefully quantified.

And that brings us back to the astrophysicists. For, when we hypothesize that fractal upscaling from the microscopic or even submicroscopic occurs, then that geometry—or shape—retains its fidelity throughout the whole scale-ranging process. So if we are justified in looking as far downward—or back in age—as possible, then we should also look upward to the forces forming and moving the whole universe.)

The "rift fault trigger" caused a ramp, in one of two adjacent fault blocks, to drop down from the basement plain to form what is classically known as a half graben or, sometimes, fault wedge structure (Figure 2). Thus initial sedimentation came from the ancestral granites surrounding such depressions and prograding of the sediments was controlled by the seminal shape, at least until the irregularities in the floor were infilled or erased and the local provenance rocks were covered.

After infilling was completed, a period of widespread (usually shallow water) deposition occurred. Such deposits are now

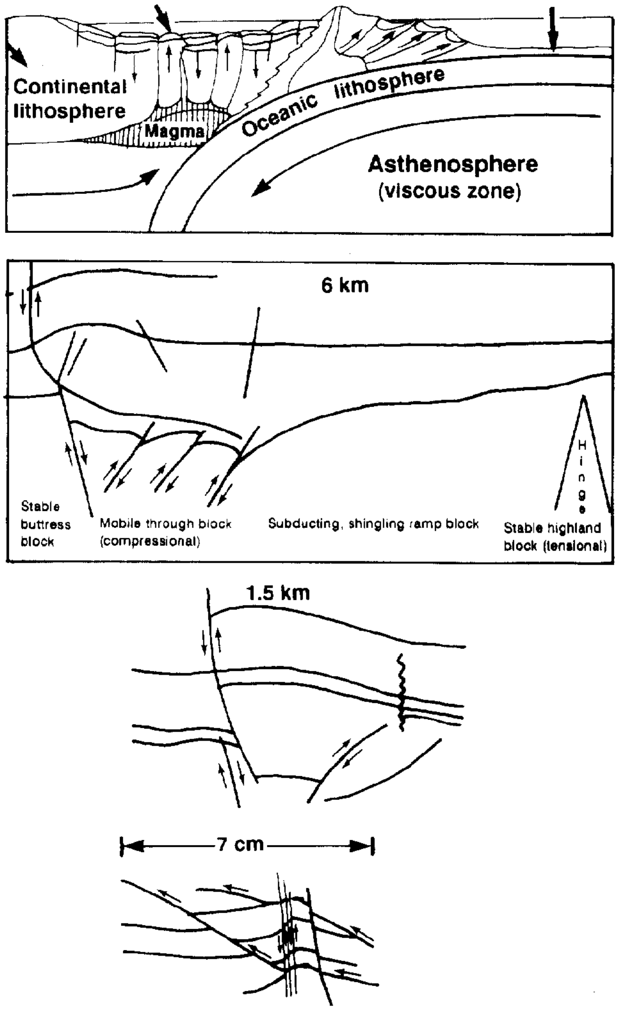

Figure 1. The drawing at the top was made by Tommy Thompson of the University of Oklahoma. The drawings in the center were made by the author from seismic sections. The bottom part of the figure was drawn to scale from banded iron stone by P. Purcell.

recognizable in basins around the world; they are characterized by shallow water limestones, interdigitated limes, sands, shales, silts or muds, and by coal measures or by salts. All of these sedimentary phenomena are notorious for absorbing seismic energy. That, in turn, has hampered exploration of these basins and preserved a new frontier for petroleum exploration—one that awaited the development of tools and techniques as well as new concepts of basement and plate tectonics.

Because this phase of the model is a relatively quiescent "rocking around" between two periods of major upheaval, it has been termed "transitional." It is followed by a phase of orogeny which forms the basins and structure constituting our present or "conventional" play in petroleum exploration (see Figure 3). The dominant force in this phase is compression (expansion or uplift), as in inflation of a balloon. (The qualifying term dominant is used because, in a closed-loop system such as we appear to exist in, it is doubtful compression can exist in one place unless accompanied by tension somewhere else—somewhat as we envision at the leading and trailing edges of tectonic plates.) Several periods of orogeny of varying intensity may occur in this phase and it is notable that the resulting uplifts may occasionally contribute their

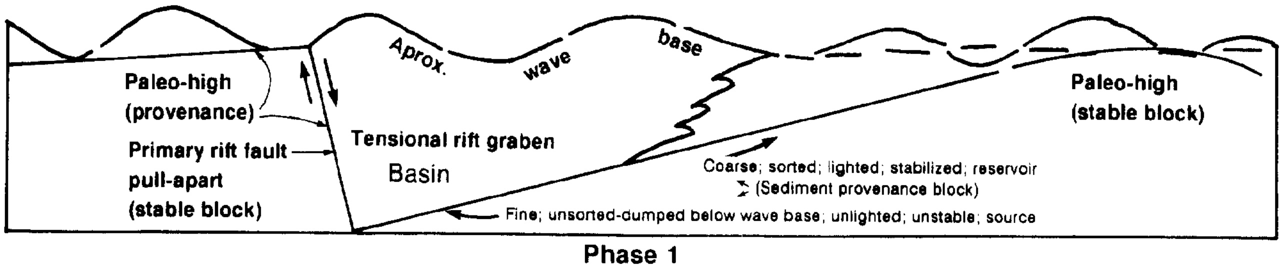

Figure 2.

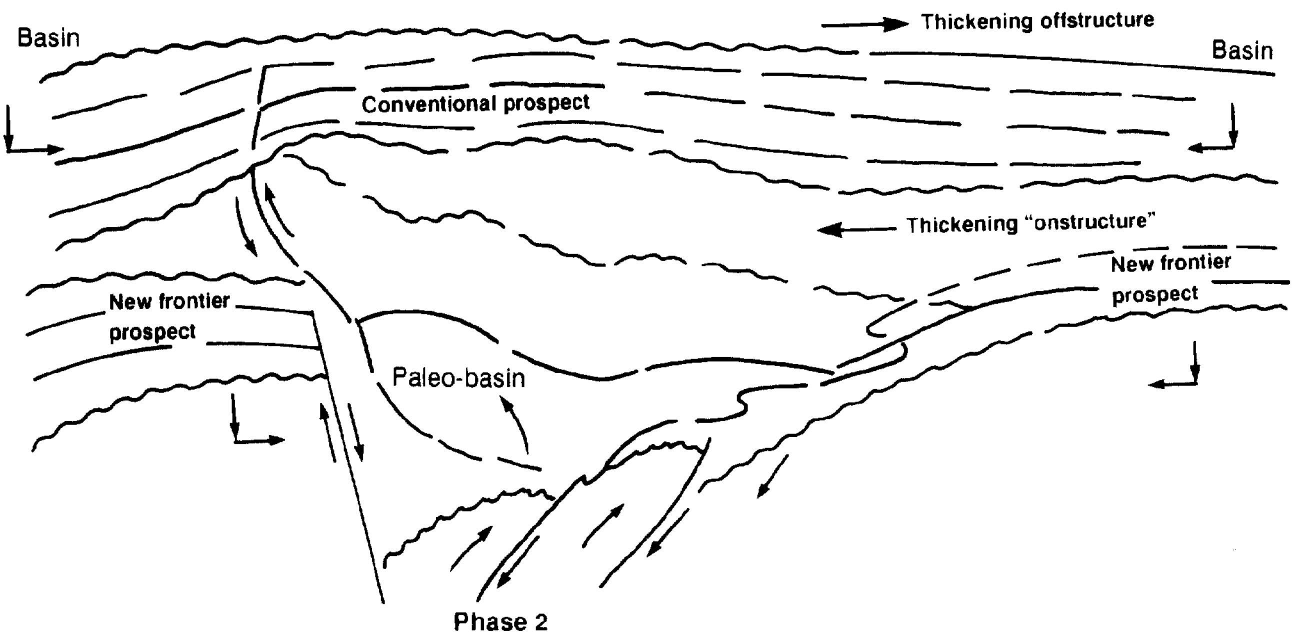

Figure 3.

sediments, in reworked form, back into the sedimentary regime of the upper, or modern, basins. (To the right and left of the "conventional prospect" in Figure 3.)

How does this happen? My explanation is that the deepest lowlands in the seminal phase 1 basin have been uplifted (reversed out of the depositional deep or thick) to become the "new" highlands of the modern, or phase 2 basins—the ones we explore today. During this process, the fine-grained material, originally accumulated in the ancestral lowlands, is redeposited in the new basins. These finer grains (and redeposited paleoforms and geochemical material) are mixed with any sediments which may be arriving from the ancestral highlands left uncovered during infilling of the phase 1 basement depressions. Thus these fine grains are expected to at least partially occlude the coarser grains which may be supplied in the phase 2 sedimentary regime, thereby reducing the reservoir potential of the "modern" basin. What is the final resting place of the phase 2 sediments? They occupy the depressions created by the collapse and inward migration of basement blocks in the ancestral granitic highlands.

This reversal of locations of the basins/bordering highlands is the key mechanical consequence of the movement between phase 1 and phase 2. When the basement blocks which comprise the original (or ancestral) highlands collapse downward and inward (by gravitational force?), they create a "room problem" or basin above themselves. This is a mechanical consequence which results in the offsetting of basinal phenomena in the model's two phases. The basins are said to face opposite directions for the provenance of their sediments, elevation differentials (structure), etc.

To satisfy this "room problem" created in phase 2, in accordance with the law of conservation of matter, the coincidentally uplifting beds of the paleobasin shed their grains into these new depressions defining the "room problem" (i.e., the upper basins). This is a rotational process—that is synchronously, during phase 2 orogeny, the paleolowland sediments of phase 1 are displaced upward by the downward collapse and encroachment of the adjacent paleohighland blocks. In some cases, this involves a subduction process (underthrusting) and, in all, is a geosynclinal-type mechanism.

As a result of the processes described in this article, a complete reversal of highlands and lowlands occurs between the phase

1 and phase 2 ("conventional") tectonics. Therefore the progradation of petroliferous factors is drastically different within the two basinal conditions. Failure to adjust for this reality will be both costly and disappointing to explorationists.

Most models currently being devised for petroleum geology focus on one parameter of the oilfinding formula. This geotectonic model spreads the investigation over all those petroliferous factors which are sensitive to elevation differential or shape.

In summary, this geotectonic model:

- Recognizes geologic structure as being frozen records of the release of forces which originated in the deep interior regions of the planet and which originally express themselves in the observable crust as rift faults and basement block movements, and are fractally similar but downscaled from plate tectonics. (The timing of orogenies in various landmasses and examination of the oldest exposed rocks, in the abyssal plains of the modern oceans, tend to support these conclusions.)
- Is comprised of two distinct tectosedimentary phases which are separated by a transitional cycle of generally shallow water deposits laced by frequently conspicuous angular unconformities. It is the nature of this cycle to generate geologic conditions that resist seismic and other geophysical penetration. These constraints have combined with conceptual deficiencies (with respect to tectonics and other petroliferous projections) to obscure the initial phase of the model.
- This initial phase is revealing a new frontier for the next round of petroleum exploration and promises thick reservoirs as a consequence of moving the play closer to provenance granites both vertically (in the earth log) and laterally (in the basin)
- Depicts that the key mechanical consequence of the model is to cause the new frontier sector of the earth log to face the opposite direction of that in the conventional play that dominates current exploration. This implies that the new frontier play cannot be made by merely deepening the latter, but that the entire play must be redesigned.

This geotectonic model, represented by Figures 2 and 3, differs from conventional exploration paradigms but still mainly consists of recognized geologic processes. It has, in addition, an empirical derivation which can stand alone without theory because the analyzable element has been observed, in many different scales, in basinal areas around the world. And, prior to that confirmation, application of this model led to the discovery of a large new oil field and trend in a previously well explored basin.

The universality of the model was not appreciated at that time but widespread exploration has subsequently been initiated to confirm and refine it. Major, modern oil fields which faithfully reflect the model genetics, as well as the reservoir predictions, are the Tabasco Province trend in lower Mexico (especially Sitio Grande) and the more recent Furrial field in Monagas, eastern Venezuela. LE

W.T. Stilley spent 20 years with Continental Oil Company in various exploration capacities. He was a cofounder of Whitestone International in 1972 and served as its vice-president of exploration and operations for the next 15 years, during which time he and his associates developed the model discussed in this article. Stilley is currently affiliated with Frontier Petroleum Exploration and Rubicon International Corporation.