Monday, December 15, 2003 HGS N. American & International Explorationists

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Social 5:30 p.m., Dinner 6:30 p.m.

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by ***Frank J. Peel,***
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Styles, Mechanisms, and Hydrocarbon Implications of Syndepositional Folds in Deepwater Fold Belts: Examples from Angola and the Gulf of Mexico

This presentation combines recent published material with new ideas to provide a review of how the structural geology of deepwater fold belts influences the distribution of hydrocarbons within them. How do deepwater fold belts differ from orogenic fold belts? What factors control the location of the fold belt? What is the significance of early-formed precursor folds? Why are these factors important in the exploration for hydrocarbons?

> *Compressional fold belts in deepwater settings have been a major focus of recent exploration and appraisal activity*

First, we consider the significant differences between passive-margin and orogenic fold belts, then, the application of Coulomb wedge theory to passive margins (to explain where and why fold belts form), and lastly, explore a critical factor—whose significance has only recently been recognized— namely the influence of early-formed folds on the later-formed large structures, and how hydrocarbons are trapped within them.

Part 1: Comparison of passive margin fold belts with orogenic fold belts

Fold and thrust belts occur primarily in two settings: either linked to an orogenic belt forming due to plate convergence, or in the compressional toe of a system of gravity-driven movement on passive margins. While mixed-mode fold belts also exist, and other scenarios for fold belt formation are also observed, it is instructive to compare and contrast the two end members and consider the implications of the differences for the hydrocarbon systems, which can trap in either setting.

Orogenic fold belts

The ultimate driving mechanism of orogenic fold belts (including accretionary prisms) is relative plate movement. The rate of convergence is effectively fixed, and the main variable affecting the rate of movement in the frontal thrust belt is the partitioning of shortening between the frontal thrust system and contraction within the body of the orogenic belt. Shortening occurs whether or not there is a good décollement. The nature of the décollement does, however, have a strong influence on the structural style. The total shortening in the orogenic fold belt can be 100s of kilometers, and, as a result, most of the thickening of the orogenic wedge occurs by tectonic thickening of the accreted mass.

Passive-margin fold belts

The ultimate driving force of passive-margin fold belts is gravity. This may take the form of gravity sliding, driven by the existing slope of the margin, plus continued tilting (as seen in the outer Kwanza Basin, and the GOM Cretaceous/Paleogene strata), or of gravity spreading of the sediment wedge (like in the Niger Delta, Africa, and Neogene GOM). The rate-limiting factors are the rheology of the wedge, décollement level, and the rate of sediment input to the shelf and upper slope. As a result, passive-margin fold belts are commonly intimately linked to the pattern of depositional systems on the margin.

While most passive-margin fold belts shorten at slower rates than orogenic fold belts, there are no upper boundaries to the possible rates of movement. If the conditions for mechanical failure of the margin are not achieved, no movement will occur; passive-margin fold belts may move continuously, episodically, or not at all. A passive-margin fold belt can develop only where there is a good décollement layer present. This commonly consists of salt or overpressured mud. The total shortening in passive-margin fold belts is limited by the dynamics of the system and is typically 5–50 km, more commonly toward the low end of that range. As a result, the majority of the thickening of the transported wedge occurs by

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deposition on top of the wedge, rather than by structural thickening.

Part 2: Dynamics of "passive" margins—what controls the location of passive-margin fold belts

Simple Coulomb-wedge analysis can be applied to the whole mass of a gravitationally active passive-margin system. This states that the stability of a wedge is defined by 1) the top and bottom slope of the wedge, 2) the internal strength of the wedge, and 3) the resistance to movement of the basal décollement. Active shortening of a wedge occurs where these factors vary in the downdip direction. In passive-margin fold belt settings, the two factors that commonly control wedge stability are the distribution of the décollement horizon and the surface bathymetry. The locus of active shortening in the passive margin wedge, therefore, tends to occur either at the slope toe (the transition from continental rise to continental slope) or at the downdip limit of the décollement lithology. These will be referred to as FATBAST (fold and thrust belt at slope toe) and FATBARDE (fold and thrust belt at regional décollement edge) scenarios. Combination scenarios are possible.

A discussion of likely hydrocarbon systems of orogenic fold belts is found in the literature and will not be repeated here. The systematic differences between orogenic and passive-margin fold belts lead to characteristic differences in the hydrocarbon systems. In a FATBAST scenario, the fold belt develops at the location where the total sediment isopach is at a minimum. Therefore, the maturity level of source rocks also tends to be at a minimum, and such fold belts may therefore have a charge limitation relative to structures in the updip slope. Charge timing is also generally later in the fold belt than in the updip slope for the same reason. In the FATBARDE scenario, the edge is most commonly formed by the limit of a deep salt layer. In such cases, migration from a subsalt source can occur only through synclinal welds in the deep salt or around the frontal limit of the salt. As a result, the frontal fold is exposed to different charge mechanisms from more updip folds. Migration from supra-salt source kitchens is also possible, but owing to the relatively small amount of shortening seen in FATBARDEs, the source kitchens tend to consist of small isolated synclinal areas. This contrasts with the orogenic setting, in which supra-décollement source kitchens may be more extensiveowing to the presence of multiple thrust repeats.

Part 3: Significance of precursor fold structures

This part focuses on a few key aspects of deepwater salt-cored fold belts, using examples from the outer Kwanza Basin of Angola and several different fold belts of the central US Gulf of Mexico margin, including the Cretaceous/Paleogene age Walker Ridge fold belt, Western Atwater fold belt, and a late Mesozoic age fold belt.

Compressional fold belts in deepwater settings have been a major focus of recent exploration and appraisal activity. However, there is relatively little published literature describing the characteristics of deepwater fold belts in passive margins experiencing large-scale gravity spreading or sliding. These fold belts tend to be different from orogenic fold belts in several respects, and these differences influence the structural style, growth, and ultimately the hydrocarbon systems of the fold belts.

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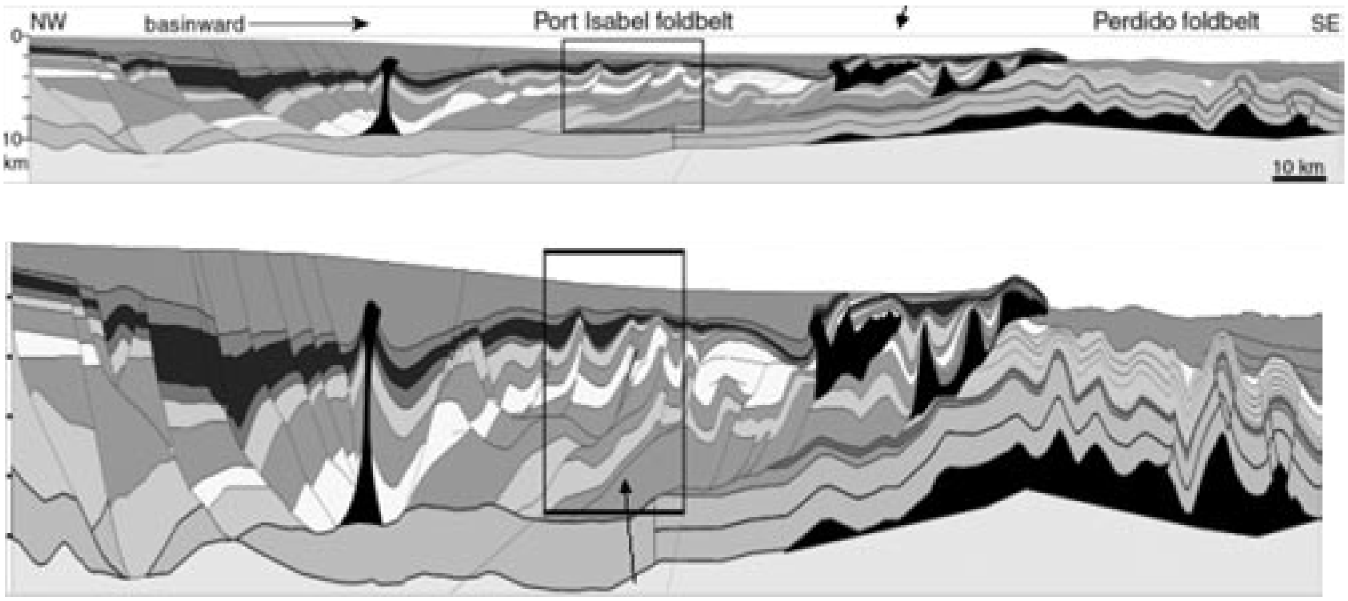
Gulf of Mexico foldbelts



Fold and thrust belt at décollement edge

Fold and thrust belt at slope toe

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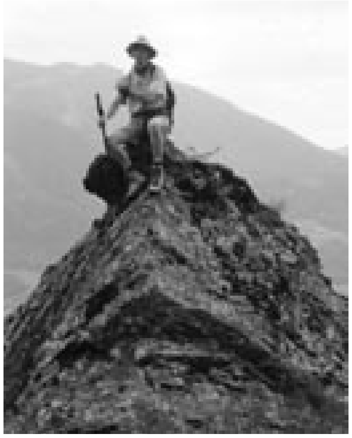
Shortening of the sediment cover sequence in passive-margin fold belts commonly occurs very slowly and continuously compared with the shortening in orogenic fold belts. Cover shortening is usually accompanied by continuing deposition on top of the growing fold. As a result, the sediment sequence is much thinner at the onset of folding than it is at a late stage in fold development. Where there is a long history of fold development, early-formed, short-wavelength folds are deactivated and overprinted by later, longer wavelength folds, commonly tripling in wavelength.

Recognition of the precursory structures is important because these control the structural style of the later folds. Reservoir distribution in the lower part of the structure may be controlled by the distribution of the early folds and not by the later, more obvious structures. The early folds may also have a critical influence on hydrocarbon migration paths. ■

Biographical Sketch

Frank Peel was born and raised near Birmingham, England. He earned a BA and MA with honors from the University of Cambridge. He also was awarded an MSc in structural geology from Imperial College, London, and a DPhil (PhD) from the University of Oxford, UK. His doctoral research involved unravelling the structural history of a metamorphic fold and thrust complex in the French Alps.



Frank began his industry career at BP Exploration during 1985. He worked on the subsurface exploration of structurally complex regions in Iraq, Colombia, and the Gulf of Mexico. The assignments included the opportunity to live in the UK, USA, Mexico, and China. In 1996, he moved to BHP Petroleum to take up the role of principal structural geologist, first in Melbourne, Australia, and currently in Houston. Frank has made numerous presentations at international conferences, some of which are published. His interests include anything to do with fresh air, high mountains, and wild open spaces. His work address is 1360 Post Oak Blvd, Houston, TX 77056; phone: 713-961-8322. His e-mail is frank.j.peel@bhpbilliton.com.