Deepwater Fold-Thrust Belts: Not All the Beasts Are Equal*

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Abstract

Deep-water fold thrust belts (DW-FTBs) are actually several different structural sub-styles considered together. There are at least four sub-styles in active and passive margins with very different driving mechanisms, structural and stratigraphic histories, hydrocarbon system characteristics, and therefore very different hydrocarbon potential. Subduction-driven active margin DW-FTBs were the first to be recognized and are geologically widespread. Active-margin DW-FTBs are accretionary prism created by shearing of sediments of the subducted plate. Though common, absence or dilution of abyssal source rocks, combined with commonly poor reservoir quality caused by volcanogenic sediments have often made them unrewarding exploration targets. On passive margins three types of gravity-driven extensional-compressional linked systems predominate. Among these systems we can further discriminate between salt- and shale-dominated systems. Gravitational collapse of shale-dominated sediment piles (Niger Delta, south Texas, and Amazon fan) produces linked extension-compression "couples," with a DW-FTB as the distal margin. Productivity is strongly dependent upon migration from deeply-buried source kitchens landward of the DW-FTB. Source kitchens are in turn dependent upon depth of burial, a problematic issue at the distal edge of a delta slope. Massive salt gliding DW-FTBs (Gulf of Mexico and South Atlantic salt basins) possess an added complexity in that they grade continuously updip into a salt-tectonic domain. This assemblage is only now being fully-tested, with encouraging results. Last are true gravitational slumps with a DW-FTB at the downdip margin (Equatorial Guinea, South Atlantic salt basins) which differ in that the detachment cuts through stratigraphy. This assemblage is largely untested but with considerable potential

Introduction

The distinction inherent in the term "deep water fold-thrust belt" (DW-FTB) is arbitrary, focusing upon water depth and to a lesser extent basin architecture, rather than tectonic process, as a descriptive term. The most common DW-FTBs – examples of the thrust structural style occurring in or on the margins of deep oceanic basins – are accretionary prisms associated with subduction of oceanic crust. (Figures 1 and 2). However, another large group of DW-FTBs, as the term is most commonly used in hydrocarbon exploration, are passive-margin gravity collapse FTBs (Figures 1, 3, 4, and 5), are component parts of much larger systems that include zones of extensional detachment and downslope translation. These gravity-driven tectonic features are strongly dependent upon (1) the presence of a very deep accommodation basin and (2) rapid sediment input which creates a massive sediment pile with a steep sediment surface slope upon which gravity can act. This combination is achievable only on the margins of the deep oceanic basins. Gravity tectonic assemblages can be further subdivided by tectonic process into regionally extensive systems in which a stratigraphic detachment occurs within evaporites or shales (Figures 3 and 4), and less extensive systems in which the detachment does not clearly follow a stratigraphic detachment (Figure 5).

Active Margin DW-FTBs

FTBs formed by the decoupling and imbrication of sedimentary cover as oceanic crust is subducted at active margins were recognized very early as fundamental features of the plate tectonic model. These active-margin DW-FTBs, normally referred as accretionary prisms, are distinctive and widespread, making-up entire continental margins (Andean South America, much of western North America, the Japanese arc); complicated transpressional margins (southern California, the Sumatran-Burman margin) form additional large segments of the continental margins, though many of the best examples are emergent and not “deep water” (Grant, 2006).

DW-FTBs along active margins have on the whole proven to be only minor producers of hydrocarbons for a variety of reasons. Sediments deposited on oceanic crust are generally not prolific source rocks. Deep-oceanic-basin sediments are typically not high-quality reservoir, and porosity/permeability occlusion is common as the result of volcanogenic debris derived from igneous terrains near the subduction zone.

As always, exceptions occur. The north Borneo margin is a prolific producer, but only because delta/pro-delta sediments comprise the accreted thrust terrain.

Passive Margin DW-FTBs

Passive margin FTBs are simply components of more complex, gravity-driven assemblages along many passive margins. Ironically, in the mid-twentieth century considerable energy was devoted to disproving gravity tectonic models for foreland thrust belts, such as the Appalachians and Canadian Rockies, only to discover that major gravity-driven thrust belts do indeed exist on deepwater passive margins.

DW-FTBs form the distal, downslope ends of gravity detachment systems at several scales. The more common are large regional systems with extensive strata-parallel detachments. The dominant controlling factors are: (1) the presence of a rifted margin which results in a high-standing continental margin separated from low-standing oceanic crust (or thinned continental crust) by a steep slope, (2) initial deposition of salt or massive shales to form an efficient regional detachment, and (3) progradation of a large delta or group of deltas which introduce massive volumes of clastic sediments into the basin. This rapid progradation generates a surface slope sufficient to form a critically tapered wedge, and sufficient shear stress along the detachment/base of sediment pile to initiate thrusting

(Krueger and Gilbert, 2006).

The passive margin DW-FTBs group could be subdivided into three types:

- Salt gliding DW-FTBs, like the Gulf of Mexico (Figure 3)
- Shale detached DW-FTBs, like the Niger delta (Figure 4)
- DW-FTBs (Figure 5), in which the detachment cuts across bedding.

The passive margin DW-FTBs are gravity-driven, and the main difference between the three types is the efficiency of the detachment. Passive margin DW-FTBs are linked systems and are composed of three linked structural domains--the extensional domain, the translational domain, and the compressional domain (Rowan et al., 2004; Billotti and Shaw, 2005).

Regional Salt Decollement DW-FTBs

Salt decollement DW-FTBs occur in the Gulf of Mexico in the Southeastern margin off Brazil and offshore Angola. Salt is an extremely efficient detachment, and as a result these systems tend to have only one detachment level that corresponds to the base of the autochthonous salt layer. Because halite is a viscous material with essentially no strength, these systems tend to have a very long translational domain, and compression tends to be related to the edge of the salt basin and/or a change on the basal slope close to the oceanic-continental boundary (Figure 3). The efficient detachment leads to an early deformation beneath a thin overburden and to the formation of more symmetrical detachment folds (Rowan et al., 2004). Also in these systems shortening can be accommodated by lateral squeezing of the diapirs (Vendeville and Nilsen, 1995; Rowan et al., 2000; Rowan et al., 2004) and salt massifs and by the extrusion of salt nappes (Peel et al., 1995; Trudgill et al., 1999; Rowan et al., 2004). We believe that this process is in part counterbalanced by extension generated by the emplacement of the salt diapirs.

Regional Shale Decollement DW-FTBs

The classic example of shale-detached DW-FTBs is the Niger delta (Damuth, 1994; Sultan et al., 2007), but other examples include the Amazon fan, the Para-Maranhao basin and the Pelotas basin in Brazil. In the presence of high pore fluid pressure shale can be an efficient detachment, but not as efficient as halite. Multiple detachment levels are present always parallel to stratigraphy, forming multiple levels of linked systems, composed of extensional, translational, and compressional domains. The translational domains tend to be shorter than in the salt gliding DW-FTBs, and more internal deformation occurs. These systems tend to prograde basinward and up-section from older to younger. Young systems form in the top of younger systems without cutting it.

Local Non-Discrete Decollement DW-FTBs

These are typically shale decollement DW-FTBs, but the detachment is not efficient and can be discontinuous, causing the system to cross stratigraphic levels. It is the only DW-FTB with a detachment that is not parallel to the stratigraphy (Figure 5). The translational domain is very short, and old systems can cut younger ones. They can occur in the same regions as the shale detached DW-FTBs; a classic example is the Barreirinhas basin in Brazil, where a Cretaceous shale-detached DW-FTB is cut by a Tertiary-age cross-cutting detachment DW-FTB.

Conclusions: Hydrocarbon Prospectivity

Conclusions about the productivity of DW-FTBs are biased by a single, prolific example, the Niger Delta. Exploration of accretionary prisms has been largely disappointing, for reasons already noted. The Niger Delta example biases assumptions about DW-FTBs in general and regional shale detachment DW-FTBs in particular, because most production is actually from relatively isolated thrust or shale cored structures in the translational zone, rather than the FTB component proper. Exploration in the DW-FTB component of salt-detachment systems is in some cases encouraging (Gulf of Mexico) and in others not yet assessed (Brazil). There has as yet been little exploration in the non-discrete decollement DW-FTBs, most numerous on the Brazilian margin.

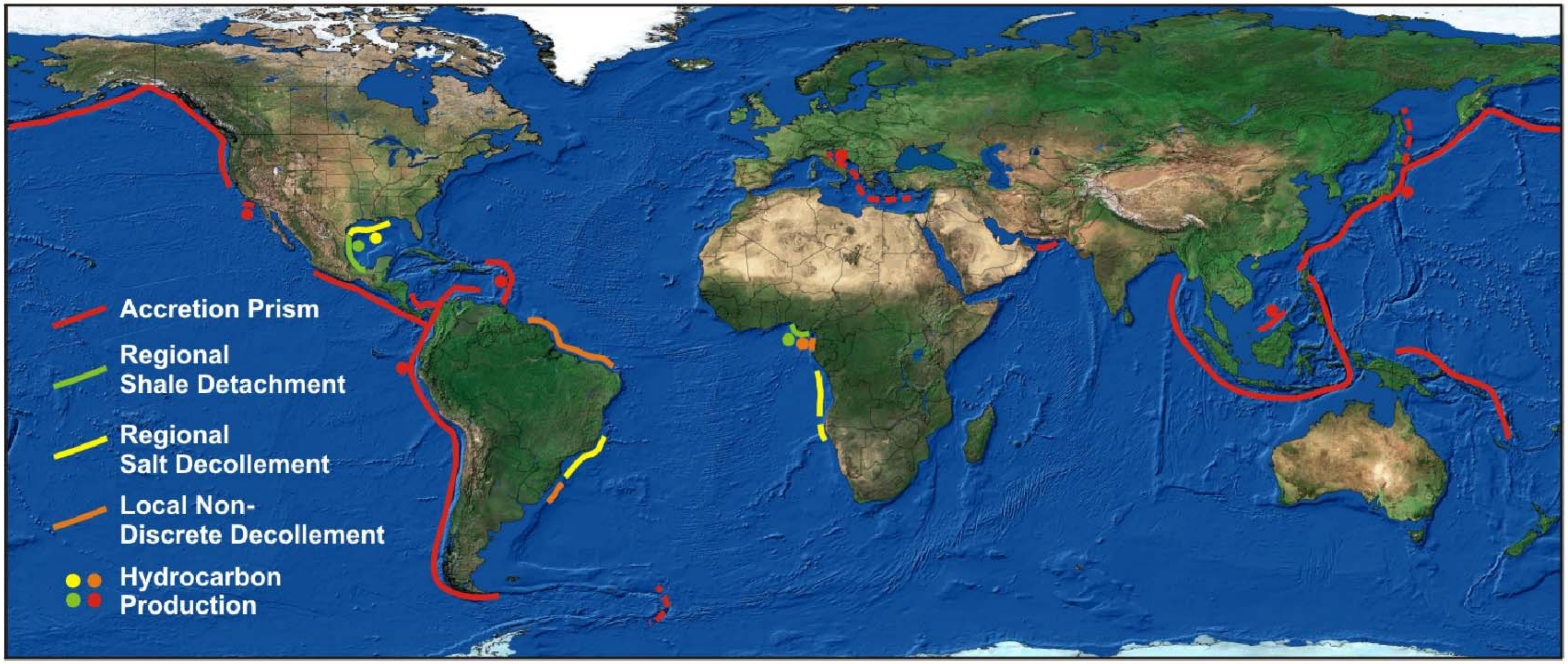

Figure 1. Global distribution of deepwater FTBs.

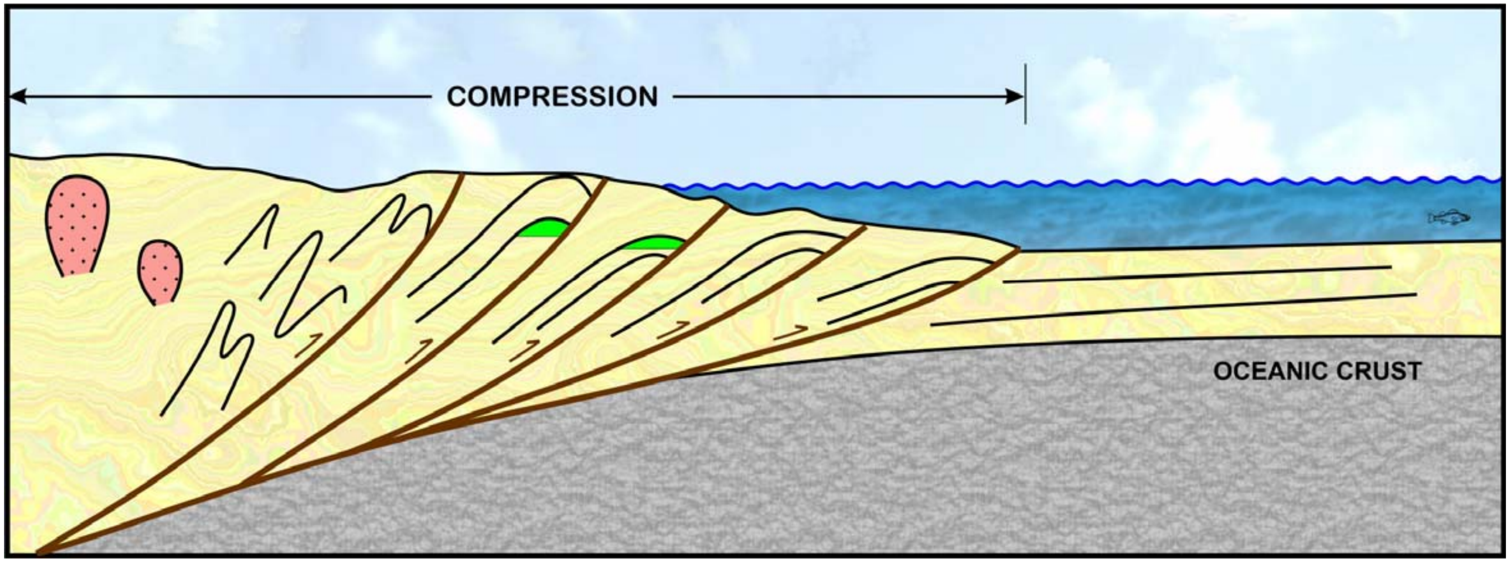

Figure 2. Schematic cross section representing an accretionary prism.

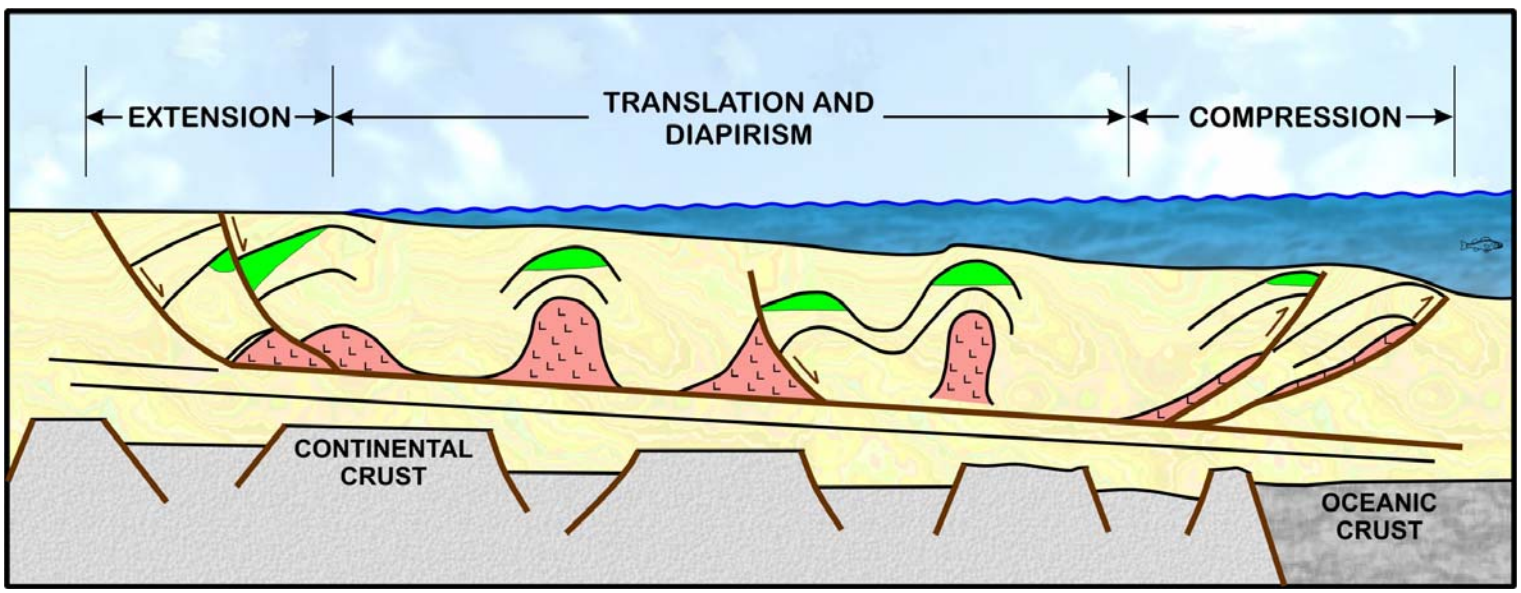

Figure 3. Schematic cross section representing a regional salt decollement FTB.

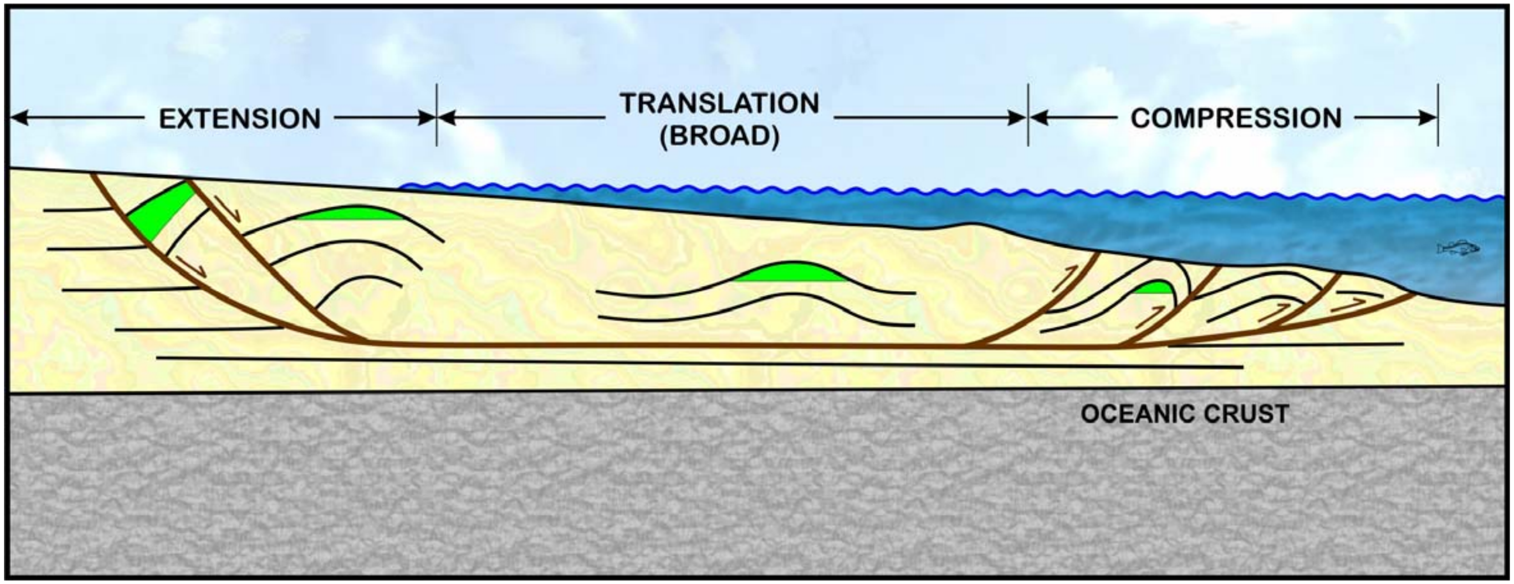

Figure 4. Schematic cross section representing a regional shale decollement FTB.

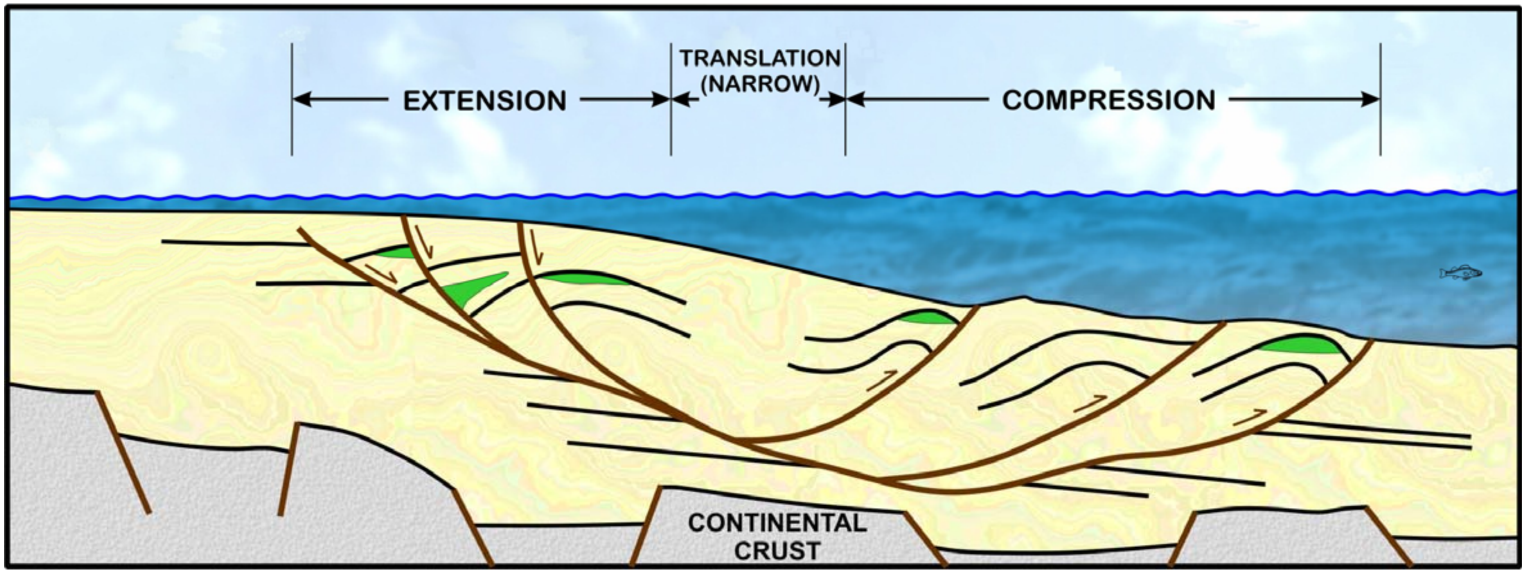

Figure 5. Schematic cross section representing a non-discrete decollement FTB.

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