The Death of Listric Faults and Salt Windows as Hydrocarbon Migration Pathways: A Modern Insight about the *ZIFTT* Role in the Petroleum System Dynamics

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Abstract

Geological and geophysical evidences appear not to support the current axiom for vertical hydrocarbon migration through listric faults and salt windows in the Brazilian Salt Basins. Restrictions imposed on the theory in which such features would act as principal routes for petroleum relies on: 1) dry wells drilled in the specifications of such model; 2) listric faults are closely associated to salt movement, therefore its activity takes place only during a limited period of time, not always coincident with the petroleum expulsion time; 3) the non plasticity of other salt species, but halite, harming the sealing character of the "salt window".

The Transtensional Faulting Incidence Zone (in Portuguese, *ZIFTT*) is proposed as the right model to explain most of the vertical hydrocarbon migration pathways that are present in the Brazilian Salt Basins. The model is associated to localized stress in the continental margin due to the South Atlantic opening which is still active as can be verified by low magnitude earthquakes. Its role encompasses not only hydrocarbon pathways but distribution of dykes and sills in volcanic basins, incised valleys (plataformal environments) and salt diapirism.

Introduction

A model comprising of rift and listric faulting, carrying beds, salt windows and unconformities has been called on to explain the phenomenon of hydrocarbon migration and accumulation in Post-Albian reservoirs from Brazilian salt basins. Although powerful, this model requires a great number of assumptions in which its testability turns out to be unfeasible. Therefore, current discoveries point out several restrictions in the roles played by these features which are still overrated in the authors view. In order to explain the migration from deep rift source rocks to shallower post salt reservoirs and considering the limitations of classic evoked model, an alternative model, based on seismic evidences, was presented and offers an unusual, but consistent, explanation about common geological features such as salt diapirs, canyons, channels, dykes and sills).

The ZIFTT model was born with plenty of seismic data from the Brazilian greater Campos Basin and has been corroborated with geochemical high resolution oil and gas data. Its importance resides on the possibility of submitting once again the areas abandoned by ancient models to an accurate investigation under a new exploration view.

Discussion - Restrictions to Previous Models

Some prospects, as for example the locations of RJS-347, ESS-64 and RJS 481, drilled according to the geological model (which presupposes reservoir pooling due the migration through listric faults and salt windows) have not achieved success. In the Campos Basin, several wells did not even present hydrocarbon shows (*e.g.* RJS 191, RJS 126, RJS 64, RJS 358), what smashes up the consistency of the classic theories based in listric faults.

Simple methodological speculations about the salt nature carry to the conclusion that some salt windows cannot be faced as reliable conduits for hydrocarbons. The evaporitic depositional order, for example, admits that anhydrite always occurs under halite, thus, considering that halokinetics movement occurs only for halite, there won't be a true "Salt Window", but a "Halite Window", and the anhydrite still keeps the salt windows closed. Even though some speculations exist about anhydrites fracturing in anticline tops, it is worth to remind that such features are caused by other tectonic mechanism.

Although, listric faults are associated to anticline structures responsible for part of the oil and gas entrapment in the Campos basin and other basins, its role as a migration pathway is questionable. It is known that listric faulting is heightened by salt movements, thus its activity takes place only during a limited period of time, not always coincident to the petroleum expulsion time. In some part of the basin, like the western Campos, listric faults are Albian-Cenomanian age, not being able to act as conduits for hydrocarbon latterly generated, once it was inactive in that moment. It wouldn't be possible that they could carry petroleum to Upper Cretaceous and Tertiary reservoirs, since it does not affect such sequences. Younger listric faulting equally could not act as petroleum route since its existence is conditioned by salt movements, which means that the salt existing in its base prevent the hydrocarbon penetration.

Results and Discussion - *ZIFTTs* Insight

The "ZIFTT model" appeared preliminarily to explain the existence of petroleum accumulations in the upper sections of the Campos basin (Figure 1). In seismic data, ZIFTTs can be verified as a complex zone of vertical faults with small *dip* fault displacement, deep basement root and representing transcurrent efforts (compressive and distensive efforts at the same time). In a map view, ZIFTTs occur as lineaments with NW-SE direction in South America and NE-SW in Africa. Always displaying negative relief in which channels and canyons are imposed and stacked vertically through time. When ZIFTTs present a wide extension being responsible for structural basin compartmentalization, they are called in the literature as Transfer Zones. The lineaments shown in figure 4, for example extends from the plataformal region of the Santos basin to the continent interior, reaching the Paraná Basin (Guapiara Fault Zone, *e.g.*).

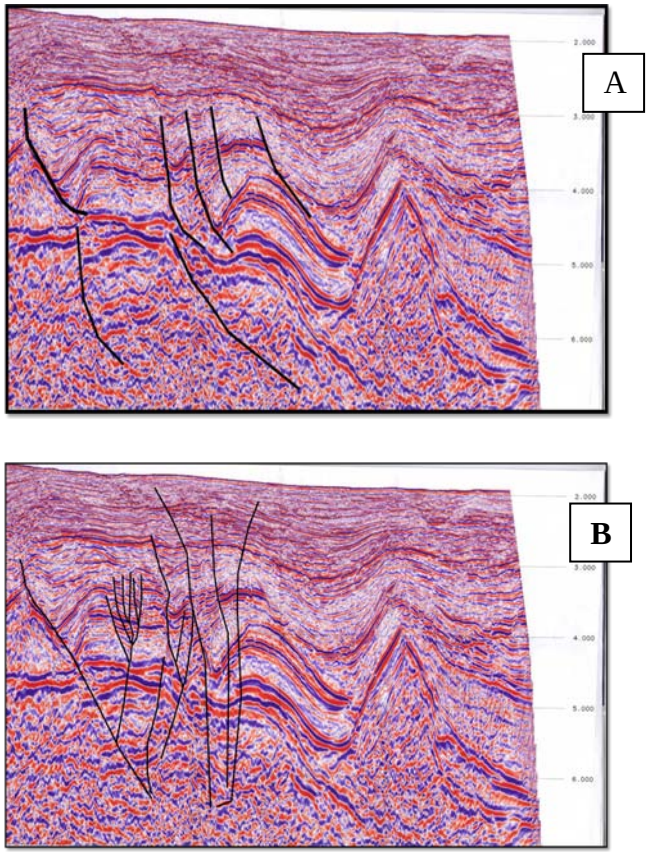

Figure 1. Differences between the classic interpretation based on Listric Faults (A) and the ZIFTTs based interpretation (B) for Roncador Field, Campos Basin.

The ZIFTTs model requires only a few premises: 1) **primary migration**, in which hydrocarbons migrates horizontally and constantly within its own source rock; 2) **primary concentration**, existence of convergence areas within the source section; 3) **secondary vertical migration**, through the **transtensional fault incidence zone (ZIFTT)**; and 4) infilling of the reservoirs directly related to these faulting.

ZIFTT concept, however, comprises more than its role as hydrocarbon pathways, controlling key seismic hydrocarbon exploratory features as:

- Natural oil and gas seepages in the oceanic floor (figure 2). Piston Core Studies generally show a spreading pattern in which the largest anomalies are concentrated in NW-SW trends.
- Canyons in platforms and slopes of marginal basins, responsible for turbidites of large hydrocarbon reserves (figure 3).
- Salt diapirism (figure 4)
- Intrusion network in the Paraná Basin and volcanic tuffs in determined stratigraphic levels of marginal basins.

In all features mentioned above, fluids obey the basic concepts of hydrostatic, going from a bigger to smaller pressure zone using pre-existing tectonic structural patterns..

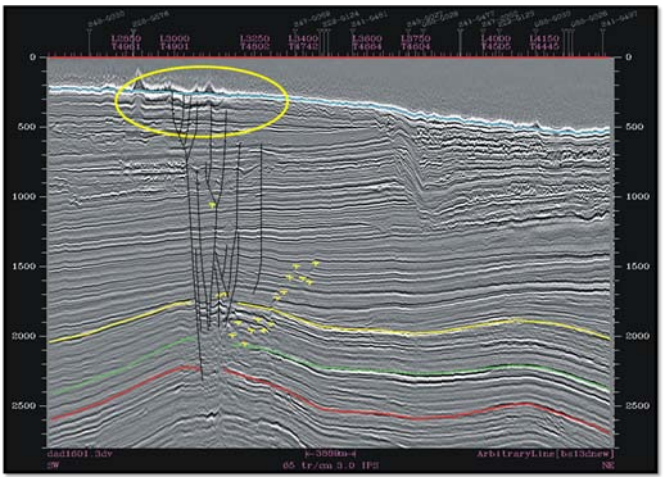

Figure 2. Gas Anomalies in Seismic Line (yellow circle). The gas produced in deeper source rocks migrates vertically thought ZIFTTs to the oceanic floor, presenting a NW-SE regional trend in marginal basins.

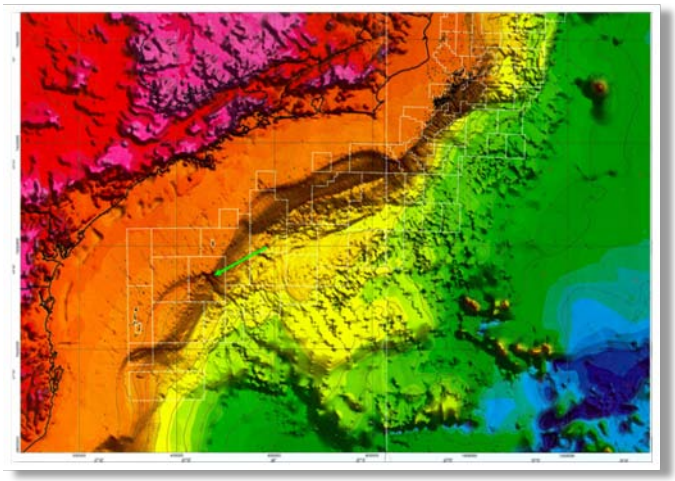

Figure 3. Bathymetric Map of the Santos Basin Area. The NW-SE trending features (ZIFTT related) condition the

turbidite deposition. The green narrow indicates the epicenter of the earthquake that occurred on April, 2008 consequence of the current fault activity.

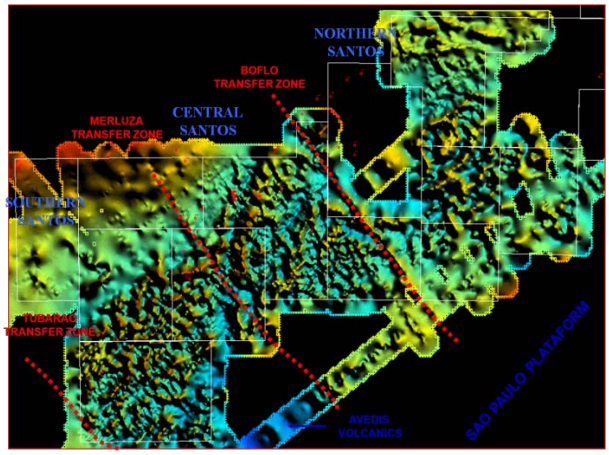

Figure 4. The Influence of NW-SE ZIFTTs in salt tectonics of the Central Santos basin. Such ZIFTTs (transfer zones) cause major segmentations trends in salt diapirs.

Earthquakes monitored within ZIFTT lineaments have indicated that the transtensional faulting is still active. The most recent example is the earthquake which occurred on April, 22nd, 2008 which took place 270km from the coast São Paulo (SP, Brazil). It reached a magnitude of 5.2° in the Richter scale according to the US geological Survey and is located exactly in a major ZIFTT of the Santos Basin (figure 3). Slickenside striations indicating lateral displacement are largely observed in almost all stratigraphic levels in the Paraná basin. But, more striking, such slickenside features also occur in the fault surfaces of Serra Geral Formation and, more rarely, in the sediments above the basalts, indicating the nowadays activity of ZIFTTs.

There is a correspondence between the mentioned features with those that occur in the African basins, where they appear with opposite direction. Such correspondence supports the hypothesis that ZIFTTs generation is a direct consequence from the tectonic plate movements during the opening of the South Atlantic, started in the Jurassic. Figure 5 exemplifies the occurrence of ZIFTTs in the Western African Margin Basins, *e.g.* Namibia. In addition to other petroleum systems elements as ideal geochemical source characteristics, maturation conditions and existence of good reservoirs unities, ZIFTTs offers an increment in the exploratory interest of Namibia and other Western African basins, providing migration pathways and entrapment features.

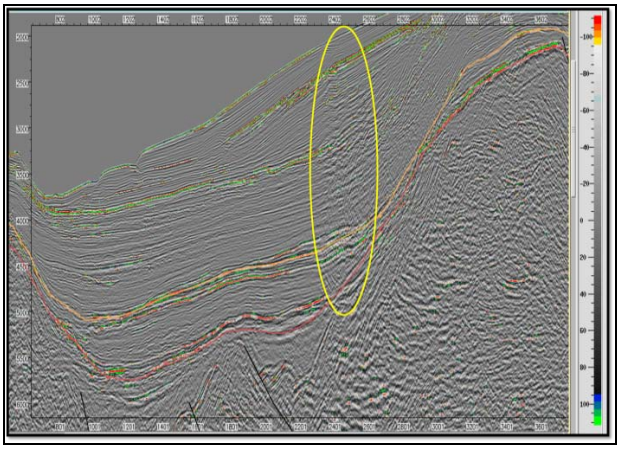

Figure 5. Transtensional faults in the Western African Margin **/** Namibia.

Carefulness must be directed to ZIFTT features not only due to its “useful character” of providing the link between the deep source rocks to upper reservoirs, but due to its capability of carrying hydrocarbons to the surface, being responsible for considerable hydrocarbon volume losses. In the Paraná Basin, for example, in the big lineament areas as Cândido de Abreu and Rio Cantú, thick sections present spread gas shows, being that no accumulation with commercial volumes are confirmed. For that reason, exploration in the Paraná basin in the last few years was directed to areas in which ZIFTTs are less intense. This change in the exploratory point of view had culminated in the discovery of the Barra Bonita Gas Field, the first commercial gas accumulation of the Paraná Basin (figure 6).

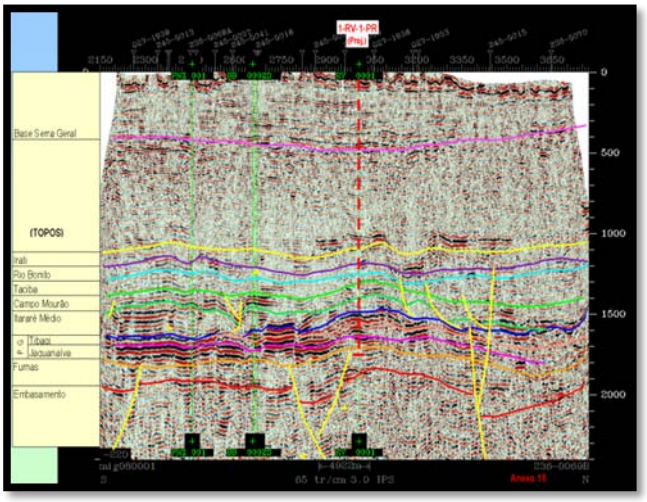

Figure 6. Geological model of the Barra Bonita Field Model over a seismic line. ZIFTTs influence in the generation of underlying incised valleys with present major reservoirs unities. Transtensional faults are also responsible for the pooling of its reservoirs and do not reach the surface and provides hydrocarbon losses, as occurs normally in the Paraná Basin.

Conclusions

Classic hydrocarbon migration models applied to petroleum exploration in the Brazilian Salt Basins do not appear to be able to answer simple geologic questions such as migration pathways from the pre-salt to pos-salt reservoirs. For that reason, a model that fits better with the geologic evidences for the oil and gas migration through the salt sequences in the Brazilian marginal Basins is presented. Such model show the role of transcurrent faults in crucial processes of petroleum systems providing migration pathways, conditioning the canyon and consequently, turbidite reservoir distribution, acting as conduits to magma in volcanic basins and, influencing the halokinetic of evaporitic sequences. Structural, geochemical and geologic evidences have been corroborating the ZIFTT model and have pointed that this faulting system is still active. ZIFTT model must be employed by modern seismic interpreters once it can be decisive in high-grading areas, since the detection of ZIFTTs that reaches the surface can damage the retention capacity of the petroleum system. By the other side, “ZIFTT Model” opens the possibility of submitting once again more areas previously abandoned by explorationist based on ancient models, to an accurate investigation under a new exploration view.

References

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