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Hydrocarbon Exploration Modeling in Thanjavur Sub-Basin of Cauvery Basin: An Alternative

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Summary

Hydrocarbon exploration in Thanjavur sub-basin of Cauvery basin has been hither-to, pursued on a broad horst-graben model, with so-called highs or horsts as major exploration targets. Recent developments in studies on half-graben rift basins, however, demand a re-look into the exploration modeling of these basins worldover. An exercise involving simple review of available (mainly old 2D and some 3D) seismic data and flattening of seismic horizons was pursued using an equally simple exploration model involving half-graben rift structural geometry / depositional set-up with attendant short depositional system. Fan-deltas, typical of short depositional system within fault-controlled hanging wall scarps are envisaged as main exploration targets to unravel the true potential of the basin with its implications on adjacent onland and offshore areas including the deep-waters.

Introduction

Thanjavur sub-basin of Cauvery Basin represents a NW-SE oriented inverse oblique, half-graben rift basin (Fig.1) which is located on the west-central part of Cauvery Basin, an established petroliferous basin of southern India, with a hydrocarbon exploration history spanning over four decades. Barring minor oil and gas accumulations, the absence of major hydrocarbon discoveries in the sub-basin renders the exploration more challenging.

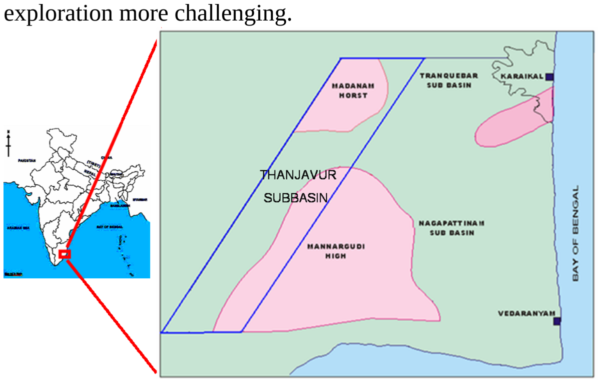

Fig. 1: Location Map of Thnajavur Sub-basin within Cauvery Basin, Southern India.

Cauvery basin has been inferred as a major Mesozoic rift basin with a series of horst-graben features (Vasudevan et al, 1998). Permian to Recent sediment fill with a maximum of 6000m. thickness overlie the Pre-Cambrian granitic basement within this horst-graben set-up. Pre-rift Mesozoic sequence is encountered only as a thin shale unit in a lone well in the northern part of the sub basin and its extent is not clearly documented. It has been generally inferred that *syn- rift* sequences spanning from Albian to Maastrichtian represented by ill-sorted silty to sandy fluvio-lacustrine fan facies. Marine incursions were construed to be locales of deposition of turbidite facies during Turonian toCenomanian. The graben (lows) of Cauvery basin got filled up by finer and coarser clastics during Campanian to Mastrichtian followed by a marked unconformity at the end of Cretaceous. Post Cretaceous *(post-rift?)* sequences are inferred to be deposited within a progradational-deltaic, passive-margin set-up. Generalised stratigraphy of Cauvery basin is given in Fig.2

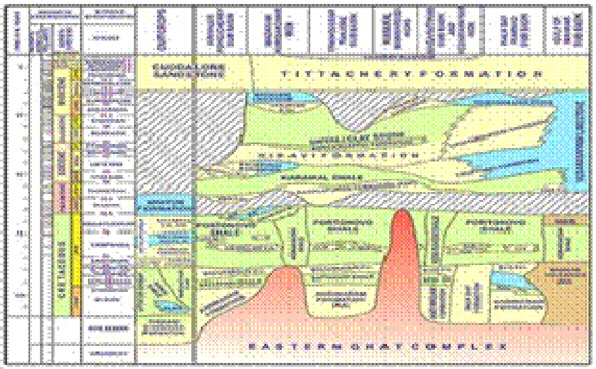

Fig. 2: Generalised Stratigraphy of Cauvery Basin (After Venkatarengan et al, 1993)

Exploration Modeling - Conventional and Alternative:

Hydrocarbon exploration efforts, hither-to, envisaged simple horst graben set-up targeting structural highs as the main sample points around which the total gamut of exploration (depositional-, structural-, reservoir-, source-rock- and entrapment-) models hover, thereby, restricting the exploration wisdom to anticlinal theory. Since these data points are restricted to ‘structural highs’, the construed model fails to address several grey areas concerning the distribution of reservoir, biostratigraphic and source-rock facies especially within structural ‘lows” and their application in understanding structural / depositional set-up and the sequence stratigraphic inferences etc. which have broader implications in basin modeling and in determining petroleum systems.

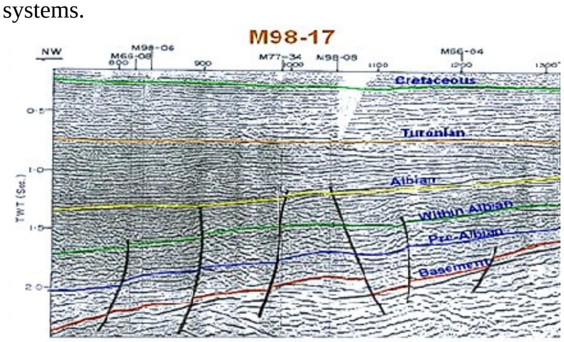

Fig. 3: Horst-graben fetaures hither-to interpreted

Fig. 3 reflects a 2D seismic section from the southern part of Thanjavur sub-basin, inferred to comprise simple horst-graben features, with horsts as main exploration targets which have been pursued with little success.

However, in the light of the recent developments in half-graben rift-basin studies, with a view to reorient the exploration a relook into available 2D and 3D seismic and well data of Thanjavur sub-basin and its vicinities was attempted envisaging a typical half-graben rift-basin geometry. The modeling is a combination of two elements - involving 1) ‘short’ siliciclastic depositional systems with their attendant sequences and 2) their strati-structural significance in hydrocarbon exploration. ***The ‘short’ systems are depositional environments with abbreviated depositional sequences proximal to siliciclastic source lands, typical of tectonically active regimes, e.g. rift-basins.*** The basic depositional element in such an ‘abbreviated’ sequence model is a ***fan delta – an alluvial fan that progrades directly into a standing body of water (lake or sea) from adjacent highland*** – which is ***deposited over the steep depositional slopes with substantial relief, caused by (normal fault-controlled) hanging-wall subsidence and drowning***. These fan deltas are generally ***thickest near the fault scarps, thin rapidly basinward and deposit little subaerial sediment.*** (C.J.Dart *et al*, 1994). Ravnas & Steele (1998) exhaustively discussed geometry of marine half-graben rift basins, highlighting the uniqueness of sequences in each of these half graben. Gawthorpe et al, (2003), while numerically modeling half-graben rift-basins, identified three locales for fan-delta development, viz, fault-tip, hanging-wall dip-slope and foot-wall sourced (fan) deltas (Fig.22). Differential compaction of coarser clastics within these fan deltas (vis-à-vis adjacent finer clastics) may invariably results in subtle structural features.

With this model concept, the available 2D and 3D seismic data of Thanjavur sub-basin were revisited.

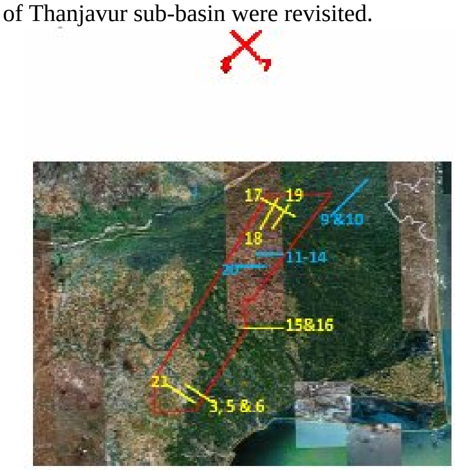

Fig. 4: Approximate location map of seismic sections with corresponding figure numbers

Hither-to interpreted horst-graben features of fig.3 can thus be re-inferred as typical half-graben set-up in the same 2D seismic section (Fig.5). with attendant, normal fault-controlled half-graben with strati-structural anomalies (fan deltas).In addition, recently acquired 3D seismic data also shows this half-graben geometry (Fig. 6)

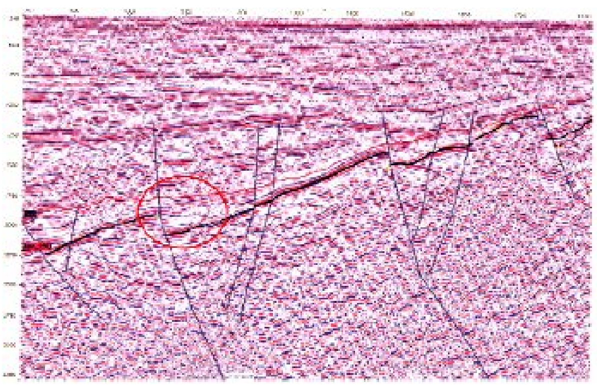

Fig 5: 2D seismic section same as in Fig.3 reflecting half-graben geometry.

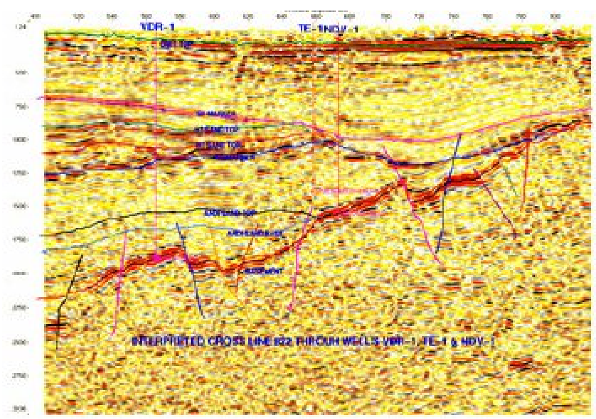

Fig 6: 3D seismic section in the vicinity of 2D seismic sections of Figs. 3 & 5 confirming the half-graben geometry.

A glance at a 2D seismic section (Fig.7) in the area north of Thanjavur sub-basin, within the central part of Cauvery Basin, also depicts three half-graben towards the base of the section and the younger 'passive margin set-up towards the top. Two conspicuous 'shelf-breaks' with attendant onlapping sequences are visible at the top of the section. The so-called syn-rift set-up hither-to-inferred to be restricted by the Cretaceous-Tertiary (KT) boundary, appears to go far beyond post-Cretaceous section, as obvious from the re-activated, basin-building normal faults extending into younger sequences, even controlling the 'passive-margin' onlaps. This suggests that the normal (basin-forming) fault activity is continuous defining the recent 'passive-margin' set-up, thus necessitating a relook into or redefinition of the so-called 'syn-rift' sequences and / or period.

A 2D seismic line (Fig.8) crossing the line of Fig.7 (at the red-arrow) conforms to the half-graben geometry, revealing a drastic facies variation of sedimentary sequences on either side of a 'transverse anticline' with attendant short-distance variations in sequence thickness, typical of a ***short system*** of siliciclastic depositional set-up.

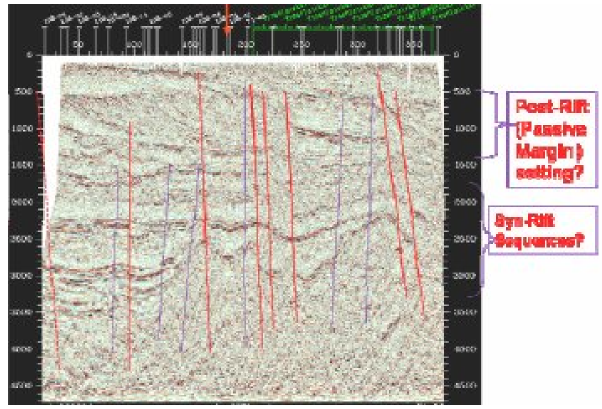

Fig 7: 2D Seismic section showing half-graben geometry and fault extensions into passive-margin set-up.

The foregoing discussion, thus, confirms the half-graben rift-basin set-up for the Thanjavur sub-basin. The next step is to identify locales of fan delta deposition. Hither-to, the interpretation models in vogue generally envisaged 'compressive' models trying to explain all strati-structural 'humps' as compressional anticlines. Fig. 9 representing a 3D seismic section (trace) has been interpreted as a compressional anticline between two 'reverse' faults. However, a closer look at the same reveals the break in amplitudes as well as the variation in thickness of seismic facies within the so-called 'anticline'. An interpretation-alternative for the same seismic section (Fig.10), however,

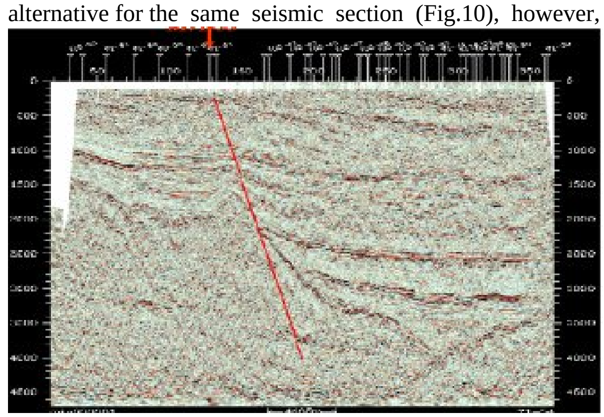

Fig 8: 2Dseimic line perpendicular to that of Fig.7 showing a transverse anticline with conspicuous facies variation on either side reveals a probable normal fault controlled regime, with each fault block comprising unique seismic facies contained within the fault blocks., conforming to extensional tectonic set-up.

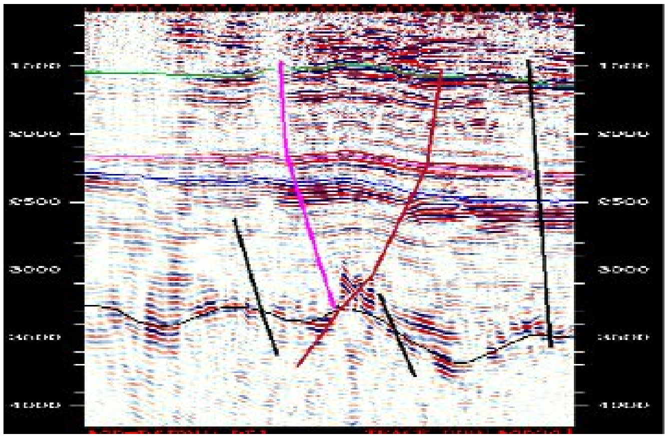

Fig 9: 3D Seismic trace conventionally interpreted to display a compressional anticline.

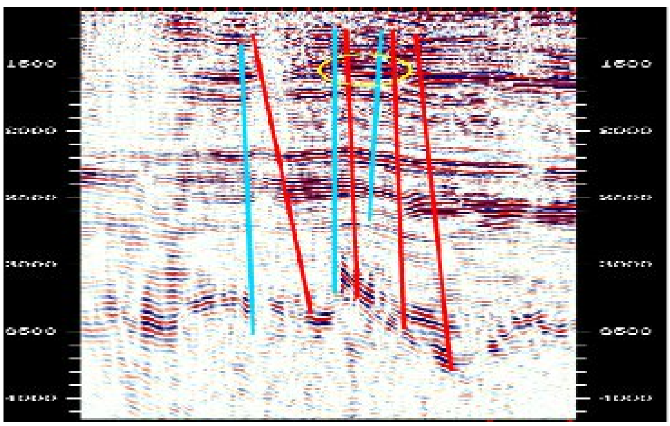

Fig 10: 3D Seismic trace as in Fig.9 showing normal fault controlled regime with attendant facies.

Another example of alternative fault interpretation is depicted in Figs. 11 to 14. Fig. 11 depicts fault interpretation based on the general structural geometry at Cretaceous-Tertiary boundary(K/T) and younger sequences, defining a conspicuous 'low'. However, simple flattening at K/T level (Fig 12) reflects the total obliteration of fault throws. Almost all the envisaged faults show opposite throws/ hades suggestive of reverse faults, especially at the basement level and the so-called syn-rift pre-Tertiary sequences necessitating an alternative fault interpretation. Accordingly, as shown in Fig.13, the fault being reoriented, the same section conforms to the general structural geometry at Basement and 'syn-rift' levels. Flattening at K/T (Fig.14) level brings out a more reasonable fault geometry and attendant breaks in seismic reflections. It is also interesting to note that a fault-controlled depositional anomaly on the right side of the section (Fig.14) is better resolved than is seen in the conventional fault interpretation model (Fig.12), which fails to explain the strati-structural geometries of the pre-Tertiary sequences. interpretation model (Fig.12), which fails to explain the strati-structural geometries of the pre-Tertiary sequences.

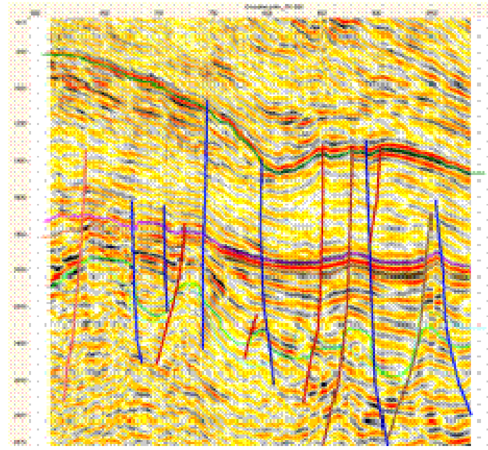

Fig.11: 3D seismic section with conventional fault Interpretation

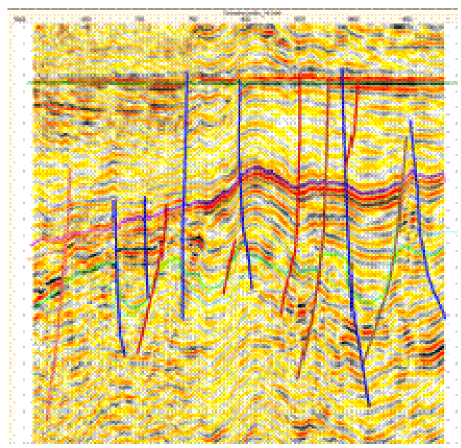

Fig.12: Same section as in Fig.11, flattened at K/T level, with conspicuous alterations in fault hades/dips (red arrows)

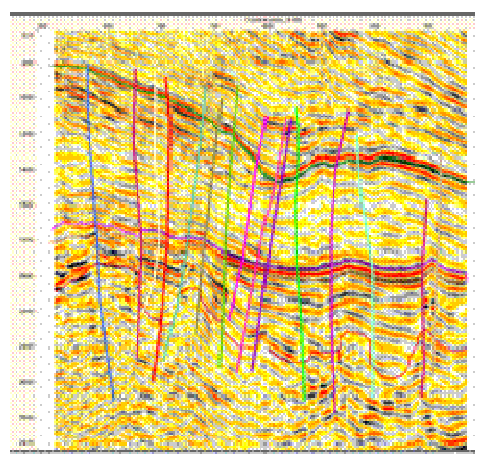

Fig.13: same section as in Fig.11, with an alternative fault interpretation.

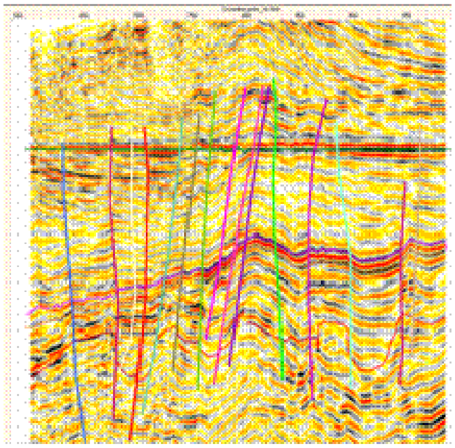

Fig.14: Same section as in Fig.13, flattened at K/T level, with Simple normal-fault geometry and attendant fan-deltas

Implications of Alternative Modeling:

The fore-going discussion, thus, attempts to bring out the alternative structural as well as attendant depositional geometries having a direct impact on hydrocarbon exploration. With this alternative modeling, the old 2D seismic data can thus unravel hither-to missed strati-structural anomalies which are of paramount significance in prospect definition. Accordingly, some of the old 2D seismic sections of Thanjavur sub-basin which were revisited, brought out the presence of such anomalies. Fig.15 to 20 represent old 2D seismic lines depicting typical fan-deltas in the vicinity of drilled wells. A conspicuous strati-structural anomaly from the central Thanjavur sub-basin is obvious in Fig.15. Flattening of the same at K/T level vividly brought out the fault-controlled fan-deltas (Fig.16). An equally interesting and obvious fan-delta is depicted at Nannilam pay level, immediately below K/T boundary, at the crossing of two old 2D seismic sections (Figs.17 & 18) from the northernmost edge of the sub-basin. These fan deltas in the above figures are quite shallow (400-500ms) which may be more advantageous for testing. Another interesting, albeit, small fan delta development is observed in Fig. 19. A well drilled on the 'anticline' apparently missed the structural advantage as well as reservoir facies development vis-à-vis the close-by fan delta separated by simple normal faults as evident from the flattened seismic section (Fig.19, right). Similarly, 3D seismic sections from the northern part of the sub-basin crossing each other (Figs. 20) bring out another fan delta within Andimadam sequence. The drilled well located right side of the said fan delta, narrowly misses this fault-controlled strati-structural anomaly. Fig.21 representing a 3D seismic section reflects an '*ideal'* fan delta within a structural 'low' with all the requisite elements of a petroleum system aptly placed in a half-graben rift set-up. A similar strucvture/fault-controlled set-up can be expected in adjacent sub-basins- onland as well in deep water areas of exploration, where ***FanDeltas*** may form main targets.

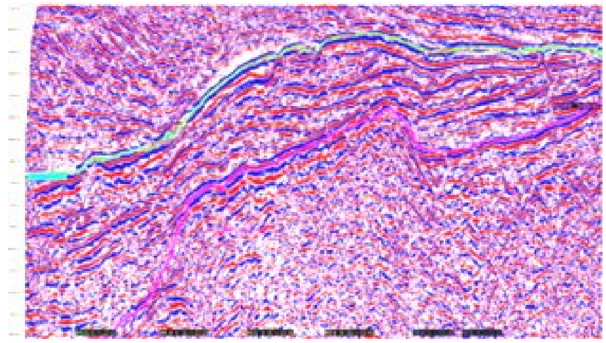

Fig.15: 2D Seismic section showing a Fan Delta

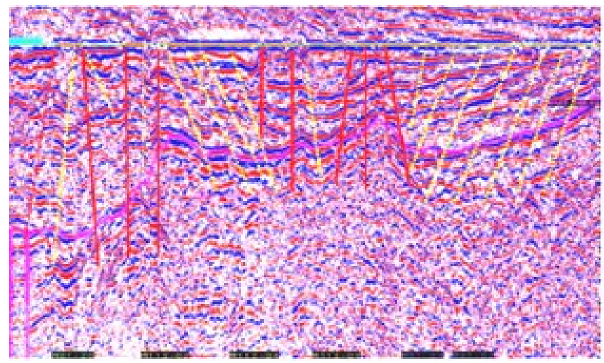

Fig.16: Same section as in Fig.15 flattened at K/T level

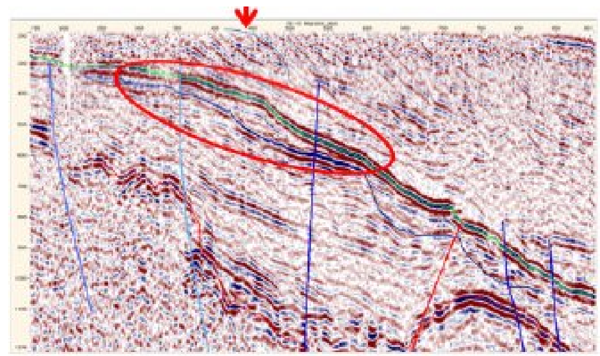

Fig.17: 2D Seismic section showing a Fan Delta

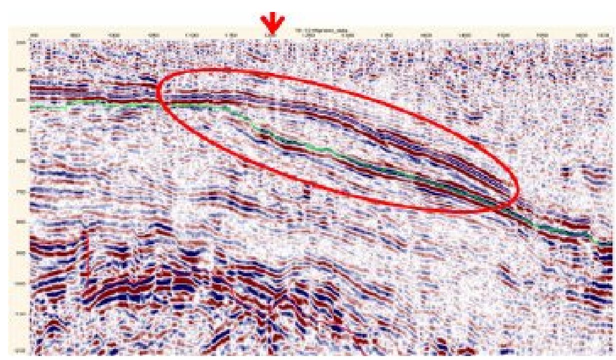

Fig..18: 2Dseismic section perpendicular to that of Fig.17 showing a Fan Delta

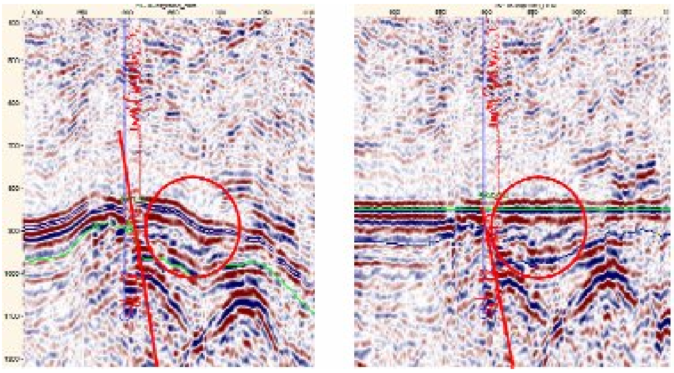

Fig.19 Left.: 2D Seismic section showing a Fan Delta close to a drilled well Right: Flattened at K/T level

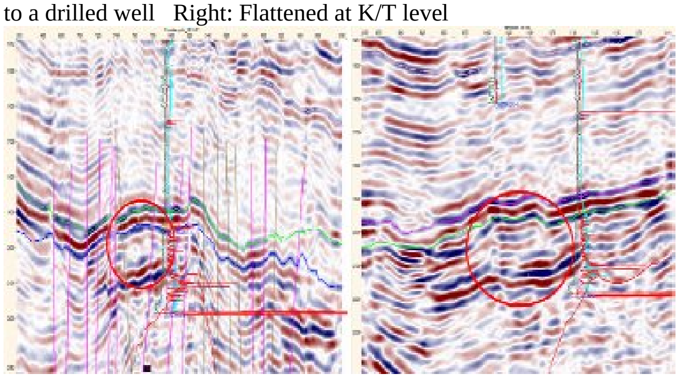

Fig.20 Left.: 3D Seismic section showing a Fan Delta and Right: Cross 3D line reflecting the fan delta which is off a drilled well

Conclusions:

1) Earlier exploration models, principally governed by the sparse sampling over structural ‘highs’ only, rendered reservoir-, source-rock- and entrapment-inferences highly ambiguous

2) A structure-controlled set-up, based on simple seismic interpretation techniques including judicious fault placement, unveil the presence of numerous strati-structural anomalies (***‘Fan deltas’***) suggestive of a need for a reorientation of exploration efforts for a major break-through in the sub-basin, especially in the light of global recognition of Indian eastern margin (including deep-waters) as most promising. (Mann et al , 2006).

3) The tripod of 3***D***s - ***Discovery*** of hydrocarbon pools/fields,and proper ***Delineation*** and ***Development of*** the already discovered pools and fields, can be achieved through 3***A***s - ***Appreciation***, **A*ssimilation*** and ***Application*** of appropriate knowledge and technology for raising the hither-to low-ranked hydrocarbon prospects of Thanjavur sub-basin.

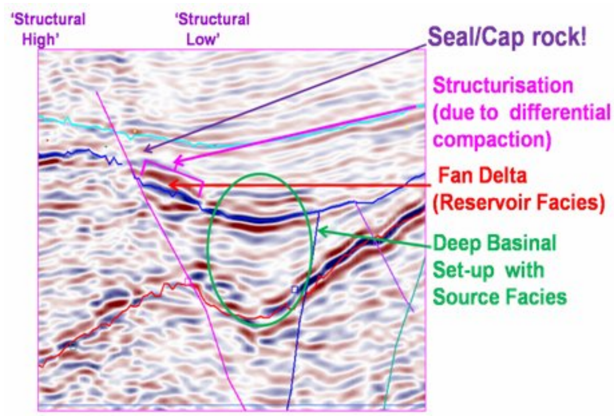

Fig.21: A 3D seismic section form southern part of Thanjavur sub-basin with an idealised petroleum system within a ‘low’ in a Half-graben set-up.

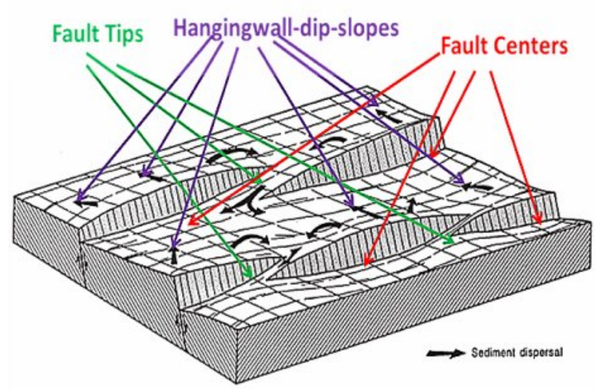

Fig.22: Structural geometry of Half-graben rift Basin (After Ravnas & Steele (1998) showing three locales of fan-delta development as defined by Gawthorpe et al (2003).

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