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Structural Modelling of Inversion Structures: A case study on South Cambay Basin

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Summary

The inversion in South Cambay Basin is attributed to multi-phase tectonic evolutions, which include extension with syn-rift deposits from Late Cretaceous to Lower Early Eocene, thermal sag with subsidence from Lower Early Eocene to Miocene and a Post- Miocene to Recent period of folding, fault reactivation, structural inversion and erosion. The inversion structures as interpreted in the Basin are classified as positive inversion styles

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Two different inversion styles have been modelled by applying trishear-move on-fault algorithm using 2D Move software. Fault reactivated inversions were observed in Narmada Section where the syn-rift beds show minimum reverse separation. The the magnitude of extension as well as orientation of syn-rift faults in response to regional compression during inversion have controlled the geometry of fault reactivated inversion structures. The Broach Section shows cover folded inversion styles, where the normal faults have not reactivated during inversion. Thus the style of inversion might be controlled by deeper faults in the basement which form an anti-formal regional geometry on fault bounded graben.

The quantification of inversion has been carried out using 2D Move software. The degree of fault inversion has been calculated as ratio between reverse slip components during contraction to normal slip components during extension along particular fault. It has been noticed in Narmada Section that all three fault reactivated inversions have <1 inversion ratio and are classified as moderate inversion structures. The horizontal inversion ratio has also been estimated to constrain the relative amount of shortening with respect to extension of structures of the basin. Hence it has been concluded that both fault reactivated inversion and horizontal inversion ratios are influenced by amount of extension.

The study will help to find out: with same amount of shortening, the structures with small amount of extension will have greater inversion ratio than one with large amount of extension.

Introduction

Cambay basin is an aborted rift basin formed during the late Cretaceous time, which is situated in the western part of the Indian shield. The basin is a narrow, elongated, rift basin located between Saurashtra peninsula in the west, Aravalli Hills in the northeast and Deccan craton to the southeast (Fig. 1). The present study area is limited between Mahisagar river in the north and Tapti river in the south covering the Jambusar – Broach Block and the Narmada-Tapti Block of Cambay Basin (Fig. 2). The inversion structures observed in this part of the basin have been attributed to multi-phase tectonic evolution, that include extension with syn-rift deposits from Late Cretaceous to Lower Early Eocene , thermal sag with subsidence from Lower Early Eocene to Miocene and a Post-Miocene to Recent period of folding, fault reactivation, structural inversion and erosion.

Objective of the Study

Based on the interpretation of 2D seismic data, the geometry of inversion has been modelled by applying trishear-move on-fault algorithm using 2D Move software. The quantification of inversion has also been carried out using 2D Move software to know the degree of inversion along the fault. The degree of fault inversion is the ratio between reverse slip component during contraction to normal slip component during extension along a particular fault (Buchanan, 1995).

Methodology

The methodology for estimation of degree of inversion and geometry of inversion styles are given in the flow diagram (Fig. 3A & 3B):

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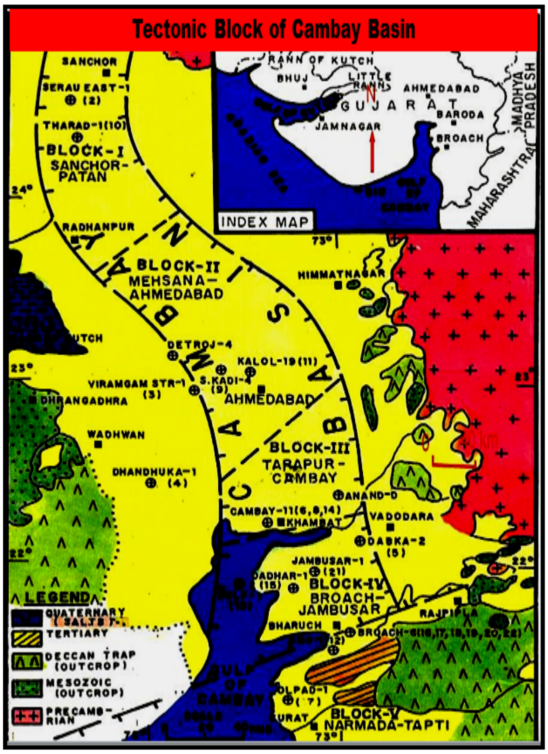


Fig. 1 Tectonic Blocks of Cambay Basin

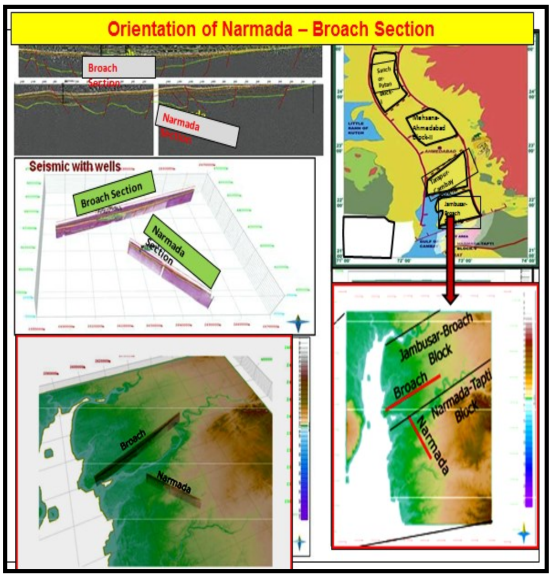


Fig. 2 Orientation of Narmada and Broach Section with respect to Basin

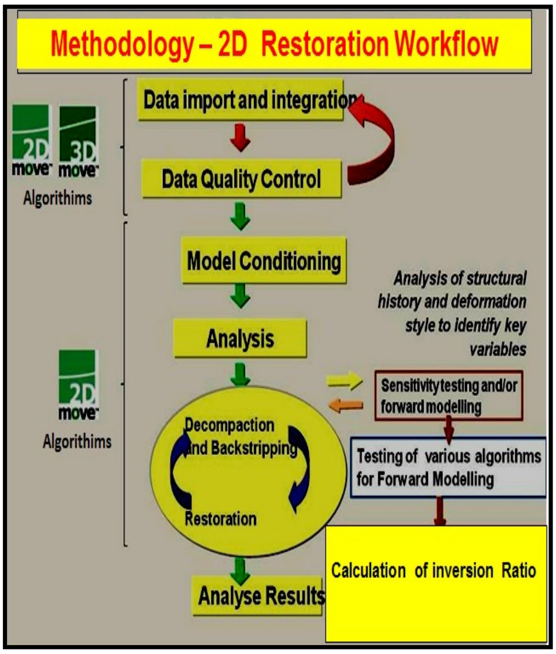
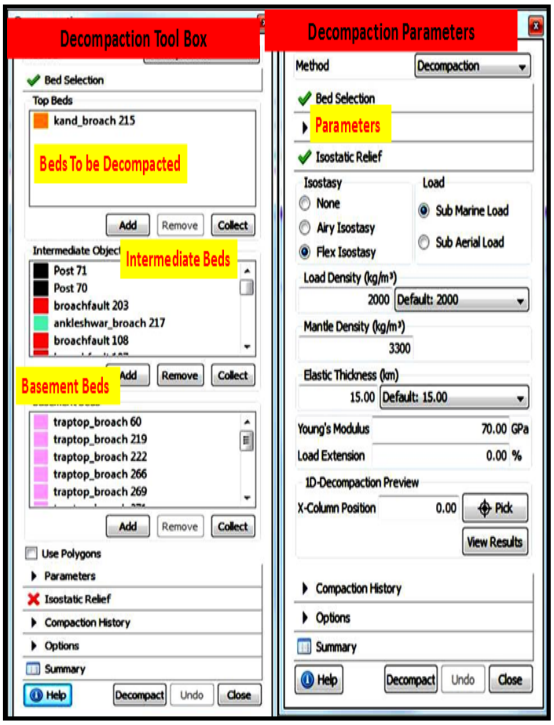
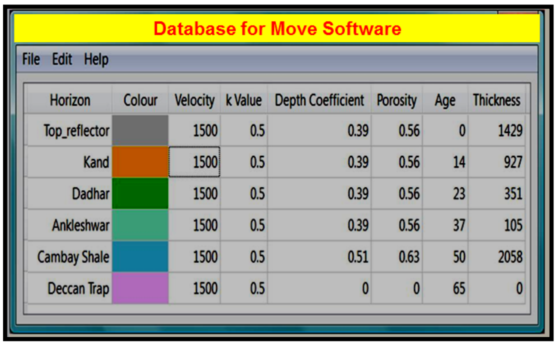


Fig. 3A Flow diagram showing methodology adopted in the study





Database for Move Software

File Edit Help

Horizon	Colour	Velocity	k Value	Depth Coefficient	Porosity	Age	Thickness
Top_reflector		1500	0.5	0.39	0.56	0	1429
Kand		1500	0.5	0.39	0.56	14	927
Dadhar		1500	0.5	0.39	0.56	23	351
Ankleshwar		1500	0.5	0.39	0.56	37	105
Cambay Shale		1500	0.5	0.51	0.63	50	2058
Deccan Trap		1500	0.5	0	0	65	0

Fig. 3B 2D Move data base used in the study

Inversion Styles

The structural styles of inverted basins are dissimilar to each other according to their pre-inversion configuration, lithologic composition of syn-rift sediments, degree of inversion and the orientation of basin axis relative to greatest principal stress which induced inversion (Buchanan, 1995). In the present study area, two different inversion styles have been modelled by applying trishear-move on-fault algorithm using 2D Move software. They are classified as fault reactivated and cover folded inversion styles (Fig. 5A & 5B). The fault reactivated inversions as observed in Narmada Section, in which, the syn-rift beds show minimum reverse separations (Fig. 4). Therefore, the magnitude of extension as well as orientation of syn-rift faults in response to regional compression has controlled the geometry of fault reactivated inversion styles. The Broach Section shows cover folded inversion styles, in which the normal faults have not been reactivated during inversion. Therefore, it has been interpreted that the geometry style of inversion might have been controlled by deeper strike-slip faults in the basement, form an anti-formal regional geometry on fault bounded graben.

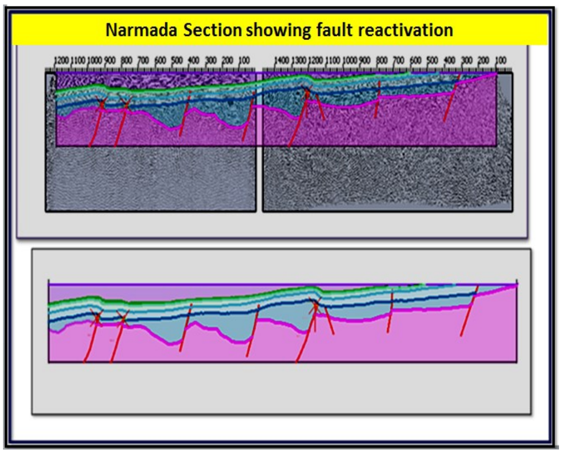


Fig. 4 Narmada Section showing fault reactivated inversion structures

Fault – reactivated inversion ratio

Fault reactivated inversion structure is described as the structure in which reverse slip component formed by compression is accommodated along a pre-existing normal fault. The normal faults developed during rifting might have been dormant or showed little movement during post-rift subsidence. These normal faults have been reactivated as reverse faults when the basin undergoes compression or strike-slip stress regime. Such inverted structures have been observed in south Cambay basin. These inversion structures are formed, where the syn-rift faults are oriented <45° to the orientation of maximum horizontal stress. In present day the south Cambay basin is undergoing in transition phase from extensional stress regime to strike-slip stress regime, where Shmin<Sv<Shmax (Sahoo et al., 2011).

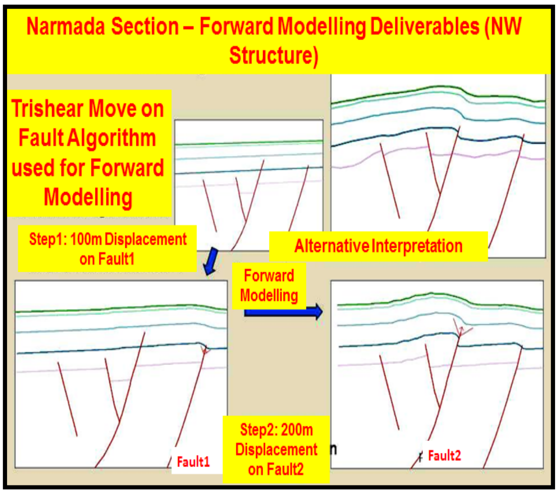


Fig. 5A Forward modelling of inversion structures in Narmada Section

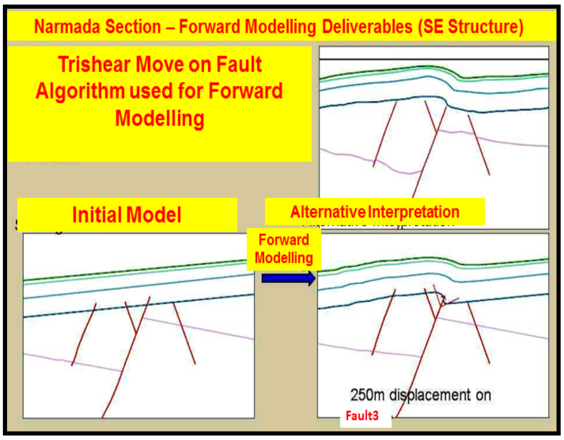


Fig. 5B Forward modelling of inversion structures in Narmada Section

Forward Modelling of Inversion Styles

Forward modelling has been carried out using trishear-move-on fault algorithm in Narmada Section. Different amount of reverse displacements of hanging wall have been measured along the three faults in Narmada Section. Three Fault-related folding inversion structures have been modelled, which are categorized as positive inversion structures. These inversions depict differential shortening, which are accommodated both by reverse slip along the faults and by folding of sequences. The Fault 1 in Narmada Section (Fig. 5A) shows small amount of reverse slip of 100m and has not propagated to shallow levels. Hence folding of horizons accommodate most of the shortening. Fault 2 shows reverse slip of 200m. The folding of the post rift sediments accompanies the reactivation of pre existing fault that controls the half-grabens formed during late cretaceous rifting. The post rift sequences in the hanging wall from Cambay shale to top surface have been uplifted and formed anticlinal structures in response to reactivation of syn-rift normal faults.

The fault in SE part of the Narmada Section shows the hanging wall displacements of 250m which has formed anticlinal geometry on the graben (Fig. 5B)

Cover –folded inversion

Cover folded inversion structures have been observed in Broach Section. The inversion structure has not been affected by syn-rift faulting and also have deformed during inversion. This forms an antiformal geometry at upper levels and synformal geometry at lower levels of syn-rift beds (Fig. 6). The erosion has been reconstructed using flexural isostasy algorithm in 2D Move software. The surface was restored using flexural slip-unfold algorithm. It has been noticed that the inversion is ongoing at present day also. This type of inversion structure is formed by reactivation of basement rooted faults which are involved strike-slip movements during the inversion phase.

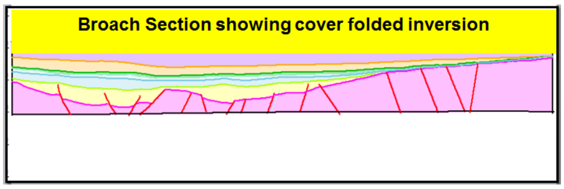


Fig. 6 Broach Section showing cover-folded inversion

Estimation of degree of Inversion

William et al. (1989) analysed the inversion degrees of inverted faults according to the position of null points on the fault planes, assuming that fault reactivation during inversion movements involved only in-plane material displacements. As per them, the inversion ratio is defined as the ratio of contractional to extensional fault displacements: Rfi = dc/dh, where dh is the thickness of syn-rift sequence parallel to the fault and dc is the thickness of sequence above null point parallel to the fault (Fig. 7) . It has been inferred from the above equation that Rfi of a partially inverted fault is less than 1 and that of the Rfi of total inversion is equal to 1 when null point is at the base of syn-rift sediments. In south Cambay basin, the inversion ratios for three faults are less than 1 as summarized in table 1. The table 1 depicts inversion ratios of inversion structures in south Cambay basin and has been calculated by using equations: Rfi=dc/dh and Rhi= ΔC/ΔE.

Rhi Horizontal inversion ratio

ΔC is horizontal compression

ΔE is horizontal extension

Table 1

Inversion ratios in south Cambay basin

Sl.No	Fault	Rfi	Rhi
1	Fault A	0.36	1.28
2	Fault B	0.55	0.85
3	Fault C	0.30	0.45
4	Broach Section	-	0.93

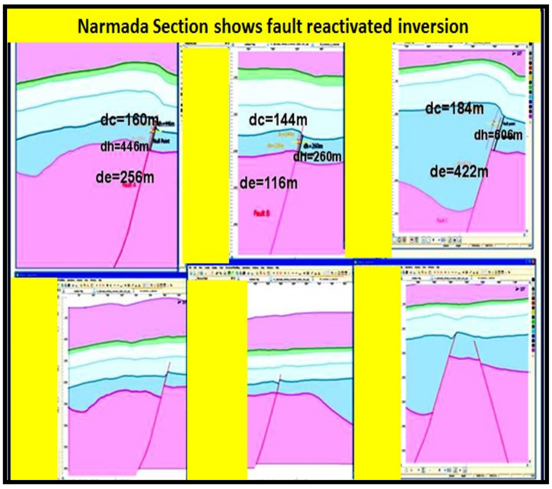


Fig. 7 Narmada Section shows fault reactivated inversion

Horizontal Inversion ratio

Horizontal inversion ratio Rhi is describing the inversion degree of inversion structures without any reactivated fault or with one or more reactivated faults and folding of sedimentary sequences (Fig.8A & 8B). The Rhi is quantified by calculating the horizontal extension during rifting stage and horizontal compression during inversion stage:

Rhi = ΔC/ΔE

ΔC is horizontal compression

ΔE is horizontal extension

In order to calculate the amount of compression and extension in 2D Move software both area and line length balancing have been used.

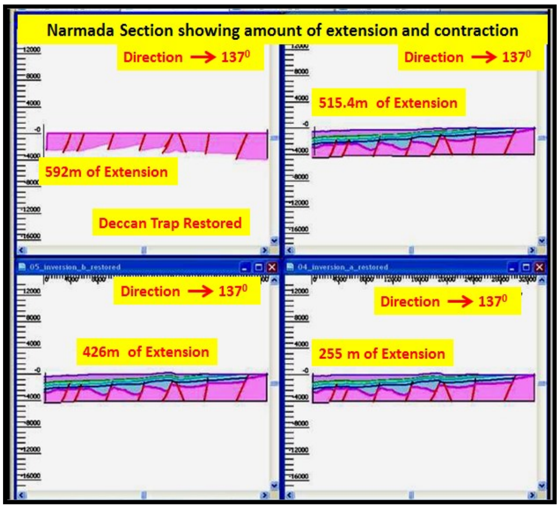


Fig. 8A Narmada Section showing amount of extension and contraction for calculation of Rhi

Discussion of inversion degrees

Both fault inversion and horizontal inversion ratios have been identified in South Cambay basin (Table 1). The magnitudes of extension and thickness changes of syn-rift deposits in the foot wall and hanging wall contribute significantly towards the inversion style and the degree of inversion. Rfi represents the ratio of compressional reverse slip and normal separation by extension along a fault, while Rhi represents the relative contractional versus extensional deformation. Structure with similar amount of extension produced an inversion ratio with Rfi of 0.36 and Rhi of 1.28, where contraction and thickness variation are larger and inversion ratio with Rfi of 0.30 and Rhi of 0.45 where contraction and thickness variations are smaller. Under simillar geological conditions, inversion structures having more shortening during inversion, will show higher horizontal inversion ratio as well as higher fault inversion ratio. The fault accommodates most of the shortening in fault reactivated inversion, where as folding accommodates all the shortening in cover folded inversion. The Sedimentary facies and thickness changes across faults, orientation of structures prior to inversion and their relation to compressive stress field have significant influence on the inversion and inversion degrees.

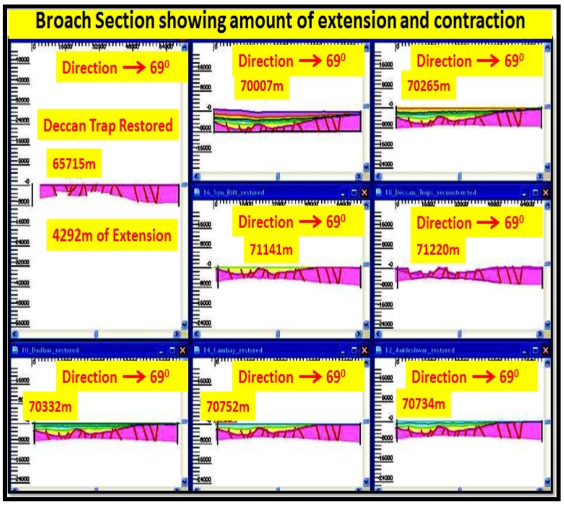


Fig. 8B Broach Section showing amount of extension and contraction for calculation of Rhi.

In fault reactivated inversion with little folding, the two ratios are direct proportional to each other. As observed in cover folded inversion, all the shortening has been accommodated by folding and the reactivated faults contribute little for determining inversion ratio. Hence the horizontal inversion ratio represents the true inversion degree in cover folded inversion.

Conclusion

Two inversion styles, namely fault reactivated and cover-folded inversions have been recognised in South Cambay basin. The cover-folded inversions are observed in Broach Section in which the normal faults are inactive during inversion. Hence the geometry of cover-folded inversion has been controlled by strike slip movement of deep seated faults in the basement. The fault reactivated inversions as observed in Narmada Section, where all shortening is accommodated by reverse dip-slip components along pre-existing normal faults. Hence the geometry of inversion is controlled by amount of contraction. The timing of hydrocarbon migration and reactivation of faults forming inversion structures have a profound effect on prospectivity of the area.

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