Paper ID: 2012807

Evidence of Forced Folds from Purnea Basin, Eastern India – A Possible Hydrocarbon Trap

Kaustav Nag, Rajesh Kumar Srivastava, Nirvikar Pathak, S Durga Prasad, Subir Das, P. Harikumar

Exploration and Development Directorate ,Oil and Natural Gas Corporation Ltd, Dehradun, India
Presenting author Email: *k_nag2006@yahoo.co.in*

Abstract

Forced folds are generally defined as folds in which the final shape and trend are dominated by the shape of some forcing member below. The forced folds have been very well imaged by 3D seismic data in Lower Gondwana sedimentary sequence rocks of Purnea Basin in eastern India and have provided new insights. The forced folds in Karharbari Formation of lower Gondwana sequence seem to have developed over steep normal basement faults as drape or fault propagation folds on cover rocks. High amplitude events also display sill fold relationship which has been documented by well data drilled in the area as igneous intrusive. The forced folds are domal in shape showing 4-way dips. The folding seems to be a combination of continual growth stages of basement faults and also related to mechanical emplacement of the underlying igneous intrusions as sills/dykes. The recognition of these extension related forced folds has important bearing in hydrocarbon exploration as they can act as potential petroleum traps that may subsequently be charged. An improved understanding of the genesis of these folds will lead to reduction of risks associated with hydrocarbon exploration in the area. These structures appear to have formed whererheological contrasts between the basement and stratified cover rocks hinder the propagation of normal faulting into the cover rocks. The timing of formation of these structures has important implications for reservoir development which might be affected due to basin scale processes including sediment remobilisation, hydrothermal fluids and contact metamorphism.

Introduction

Purnea basin located in the north eastern part of Indo- Gangetic plain in the states of Bihar and West Bengal is a polycyclic basin which initially formed as an intra cratonic rift. Measuring approximately57000 sq.km, the basin is bounded in the west by Monghyr Saharsa Ridge and towards the east by Kishanganj fault (Fig.1). The northern and southern extents of the basin are Main Boundary Thrust and Malda High respectively. The basin hosts around 4000m of sediment thickness ranging from Permo- Carboniferous to Recent in age. The Gondwana sediments directly rest over the Pre-Cambrian basement and are overlain by Siwaliks with an intervening hiatus of approximately 180 Ma. The basement is constituted of Pre-Cambrian gneisses and metamorphics for deposition of graben fill Gondwana sequence.

The basin is characterised by typical rift geometry like any other Gondwana basin. The generalised stratigraphy of the basin is represented in Fig 2.

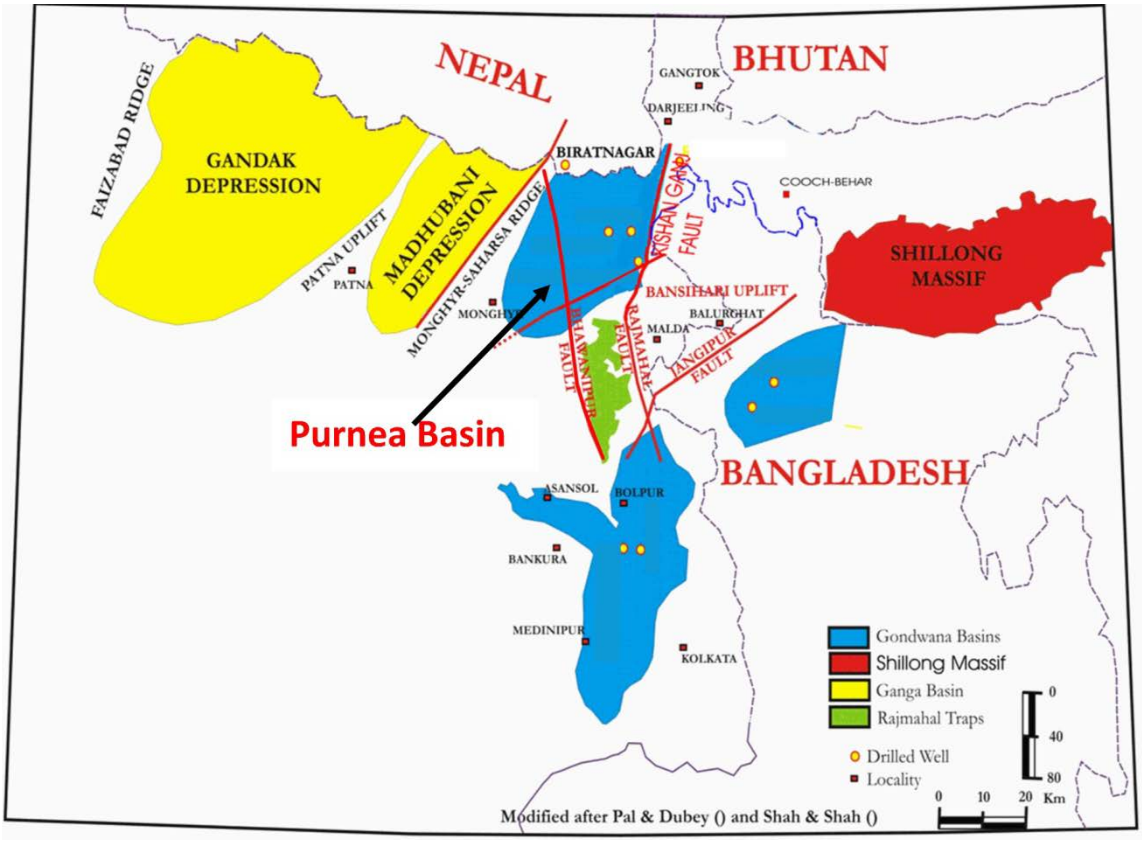

Fig. 1 Location map of Purnea Basin.

Age	Group	Sub-Group/ Formation	Gross Lithology	Thickness (m)	Age (my)
Holocene	Alluvium		Loose Sst, clay & Gravel	400	
Pleistocene	Siwalik		Pebbly Sst, siltstone, Claystone	750	18.5
Pliocene					
Miocene					
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~					
Cretaceous	Upper Gondwana		Sandstone, Claystone, Siltstone	450	208
Jurassic					
Triassic					215
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~					
Up Permian	Lr Gondwana	Raniganj	Sst, siltst, Carb Shale & minor coal	500	245
Lr Permian		Barakar	Sst, siltst, Carb Shale & coal	650	
Up Carboniferous –Lr. Permian		Karharbari	Sst, Carb. Sh & minor coal	250	
		Talcher	Sst,.Sh. & Conglomerate	100	299
~~Unconformity~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~					
Precambrian	Basement		Gneissic rock		4500

Fig. 2Generalized stratigraphy of Purnea Basin.

Methodology

Purnea basin has been an exploration target since mid 1960's. While there was an exploration holiday in the intervening period of about 15 years, the basin has again been in focus for hydrocarbon exploration since 2007. 3D seismic data acquired in the NELP blocks awarded to ONGC was interpreted to understand the subsurface structural and tectonic settings of the basin to identify prospective areas. The events close to top of Basement, Karharbari, Barakar, Raniganj and Upper Gondwana are fairly correlatable and the horizon tops were calibrated with the drilled well data. (Fig.3). The lithocolums of two wells drilled in Purnea basin which encountered intrusive is shown in Fig. 4. The maps prepared at different levels indicate that several longitudinal normal faults dissect the whole basin into different hosts and grabens. The longitudinal normal faults trend mostly NS in the southern part and NNE-SSW in the northern part. The central part of the basin display folding of the strata in Lower Gondwana sequence. It show 4 way dips interpreted as forced folds and also fault bend folds developed on the cover rocks above the basement.Forced folds can control fluid flow and host economically interesting fluid accumulations and is therefore important from hydrocarbon exploration point of view. A proper understanding about their genesis can therefore provide useful insights on this typeof hydrocarbonplay.

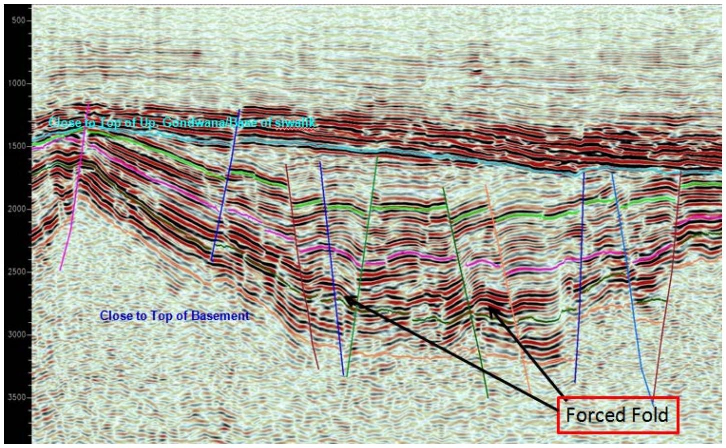

Fig. 3 SW-NE Seismic section of Purnea Basin.

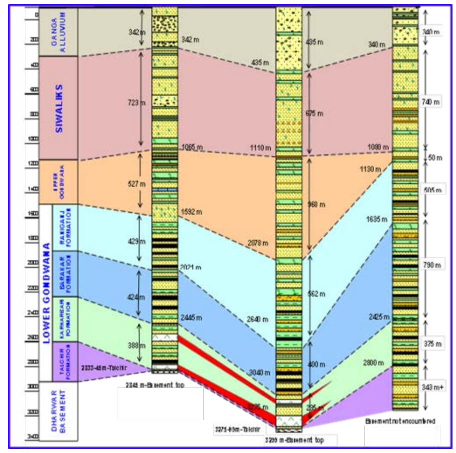

Fig. 4 Lithocolumn of wells drilled showing intrusives encountered in two wells.

Discussion

Stearns (1978) while studying folds in the Rocky Mountain Foreland documented that some folds are characterised by sedimentary bedding that is thinned in the steep forelimbs while in the others the bedding maintains a constant thickness above the basement cover contact. He coined the term Forced folds as “folds in which the final overall shape and trend are dominated by the shape of some forcing member below. Field studies, analogue models (Ameen 1988) and finite element studies have indicated that the profile geometries of forced folds is controlled by the type of movement (normal slip or reverse slip) and the amount of slip on the basement fault. Withjack et al (1990) and Friedman et al (1980) carried out experimental studies using clay and rock and kinematically modelled using standard structural geological geometric constructions. Numerous experimental studies of forced folding have been carried out using clay and rock.

The fault systems that have been identified from the seismic data carried out in Purnea basin are essentially of two types. Anolder basement related longitudinal normal fault typical of extensional settings and another set of normal cross faults trending ENE-WSW with horizontal slip components. The normal faults have resulted into a series of horsts and half graben configuration. The trend of the normal faults is generally NS and NNE-SSW in the northern part. As revealed by the seismic profiles of Purnea basin (Fig. 3& 5) the folds are generally asymmetric overlying curved fault surfaces over the basement cover. The development of folds in basement – cored structures is influenced by the mechanical anisotropy of the sedimentary cover. The lower Gondwana succession comprising sandstone, shale, coal and few intrusives display mechanical anisotropies which are largely known to control fold form in buckling of multilayers. We infer that the forced folds formed in extensional setting as displayed in Purnea basin show no thinning and it is a geometric requirement that decoupling occurs between and basement cover(Fig.5). The genesis of these forced folds also conform to the standard models of development suggested by Narr and Suppe(1998) and Mitra and Mount (1998) (Fig.6).

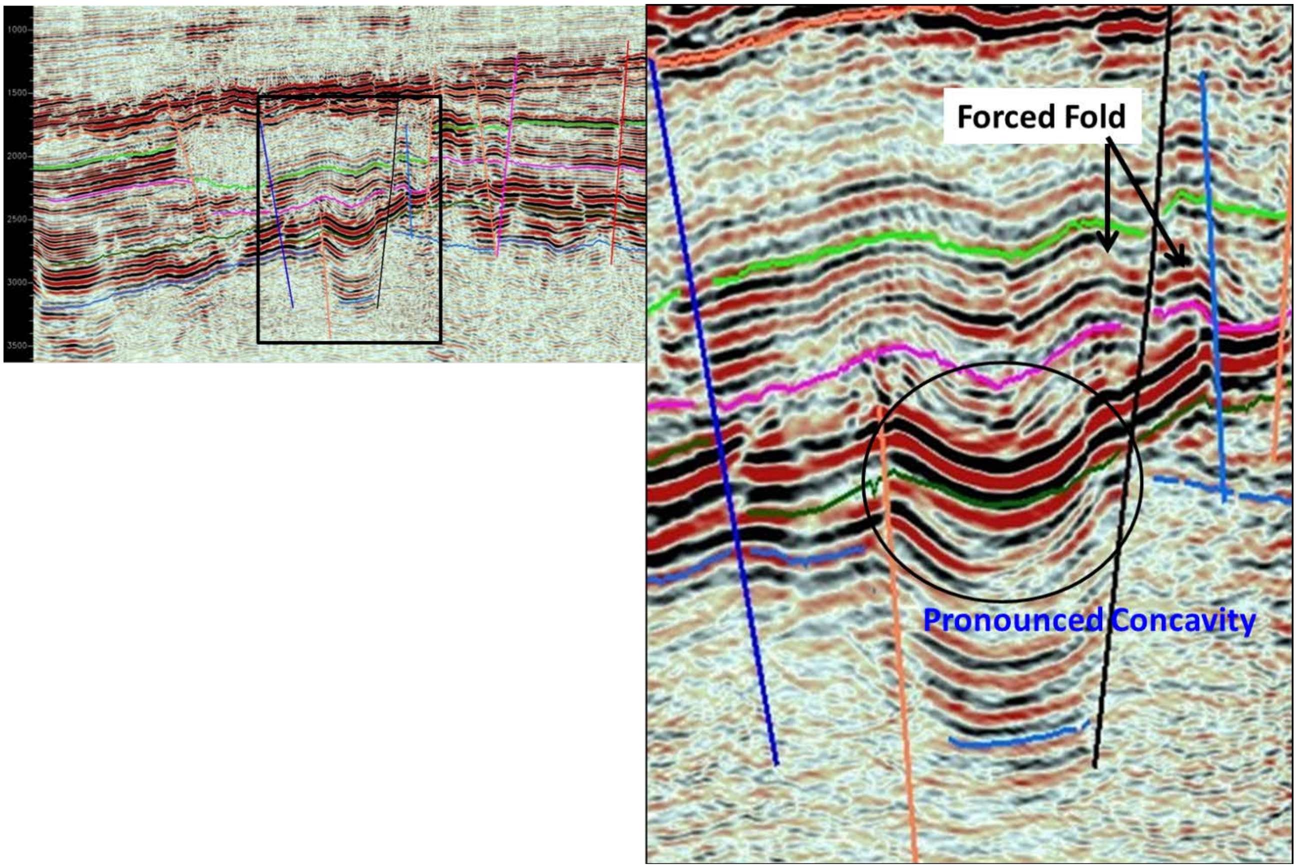

Fig.5 Zoomed Seismic section showing Concavity upward & forced folds above it.

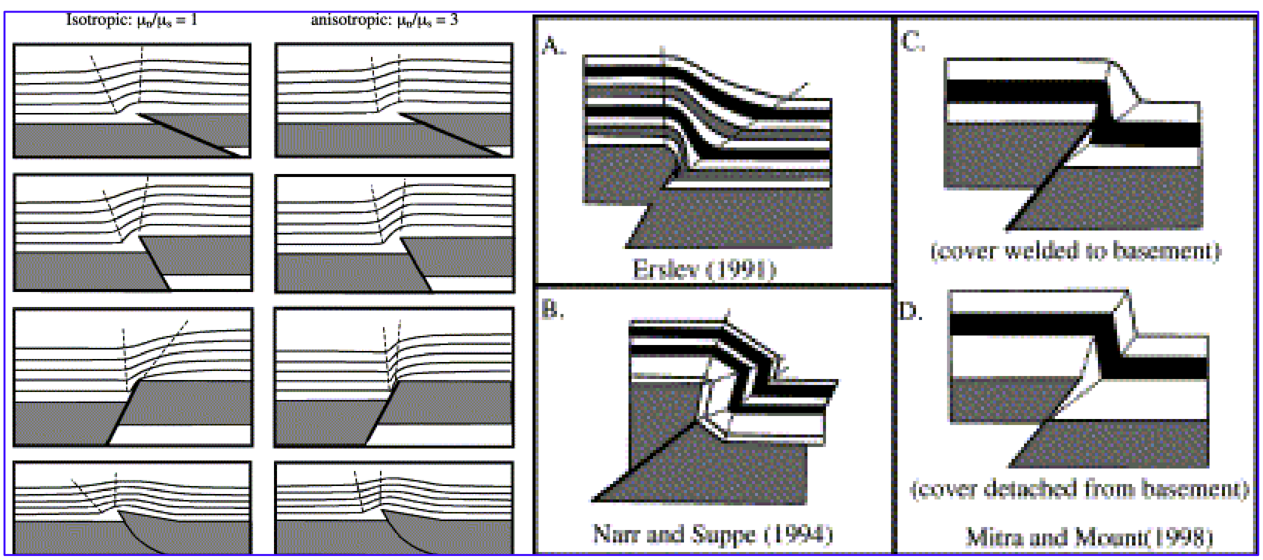

Fig. 6 Forced folds produced with the mechanical model (after Johnson et al, 2002). The fold shape is influenced by the geometry of the fault and the anisotropy of the cover.

In Purnea basin the relationships between faulting and folding is very well brought out through the 3 D seismic profiles. The mechanisms that generated these types of folding have resulted from faulting of cover rocks on to the rigid basement . The faults were originally at a high angle to bedding which is also corroborated by experimental evidences. Besides the folds which show four way dips, fault bend folds are also observed in the seismic sections of Lower Gondwand sequence above the basement. Fault bend folds (Suppe,1983) is a type of forced fold where the folding is not the result of the movement of rigid fault blocks in the basement but rather the result of fault movement within the cover rocks. As pointed out by Suppe, the fault surfaces are not perfectly planar surfaces of slip but have gentle undulations and may display sharp bends or pronounced curvature. The major folds in the sedimentary cover rocks exist within the hanging wall fault blocks as evidenced in our present study also.

Forced folds developed above igneous intrusions causing vertical displacement of cover rocks have been described by Hansen et al (2006). The recognition of intrusion related forced folds on 3D seismic data of NE Atlantic margin has led to an improved understanding about the timing of the underlying intrusion which are rarely encountered in wells to be resolved independent of traditional radiometric dating. A three dimensional understanding of the structural relief on the forced fold and the thickness distribution across the underlying sill can be used to reconstruct the minimum thickness distribution where these are too thin to be fully resolved by seismic data.

Two wells drilled through the Lower Gondwana sequence have encountered around 50 to 60 m of intrusive. These intrusives are essentially dolerites which are present at the top of Talchir(?) and within Karharbari Formation. Petrographic analyses reveal that the groundmass is composed of plagioclase feldspar and pyroxene showing ophitic to sub- ophitic texture. Vesicular fillings of secondary minerals like calcite and kaolinite are also present in the intrusive. Though the exact mechanics of the intrusion could not be deciphered it is suggested that they are offshoots ofRajmahal trap which has locally metamorphosed the adjacent sediments. The lava flows of Rajmahal were extruded in about 2Ma at 117Ma as a result of magma formation in the head of a mantle plume on the Kergulean Plateau. The initial $^{87}Sr/^{86}Sr$ ratios and $^{143}Nd/^{144}Nd$ ratio support the hypothesis that the magmas that formed the Rajmahal basalts originated from the Kergulean Plume at 117 Ma during the initial rifting and subsequent separation of the Indian plate from Antartica in the context of the fragmentation of Gondwana. The elevated initial $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ ratio of some Rajmahal lava indicate that the basalt magmas assimilated basement rocks of Pre-Cambrian age. The basalts of Rajmahal are mainly thoelitic and basaltic andesite with some alkali basalt and conform to the standard model of flood basalt.

The seismic sills are however not clearly discernible on the seismic section as the high amplitude events in the Lower Gondwana section are also shown by sandstone, carbonaceous shale and coal with similar characteristics. The high amplitude events could not be calibrated to the sills either due to lesser thickness than the seismically resolvable limit or due to very little impedance contrasts.

Conclusion

In Purnea basin the relationships between faulting and folding is very well imaged and brought out through the 3 D seismic profiles. The mechanisms that generated these types of folding have resulted from faulting of cover rocks on to the rigid basement. The faults were originally at a high angle to bedding which is also corroborated by experimental evidences. Besides the folds which show four way dips, fault bend folds are also observed in the seismic sections of Lower Gondwana sequence above the basement. Fault bend folds is another type of forced fold where the folding is not the result of the movement of rigid fault blocks in the basement but rather the result of fault movement within the cover rocks.The basement consistsof two rigid blocks separated by a fault. It appears that one block translates relative to the other along a planar fault psurface or gets rotated along a curved fault. The forced folds formed above the concave upward sills as part of the deformation process hold the potential to act as traps. However detailed understanding in their role in petroleum systems need to be understood as part of future work. To what extent the folded strata is altered by hydrothermal fluid alteration and contact metamorphism has significant implications for the quality of reservoir development that may be confined within such structures.

Acknowledgement:

Authors express their sincere thanks to Mr. Anand Sahu, Executive Director and Chief E&D Directorate, ONGC, Dehra Dun for his keen interest, motivation and granting permission to publish this paper. The authors would also like to acknowledge the authors of the interpretation reports generated by Purnea acreage team of MBA basin, Kolkata. The views expressed in the paper are those of the authors only and not of ONGC.

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