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Stress Orientation Analysis in Deep Water Block, Krishna Godavari Basin to identify horizontal stress trends

Abstract

Stress orientation analysis was undertaken in KG-DWN-98/2 North block situated in Krishna Godavari Basin on the East coast of India. KG Basin is a proven petroliferous passive margin pericratonic basin. Promising Oil and Gas indications have been found in the area and the area will be further subdivided into multiple structures for further exploration and future exploitation by ONGC. The study was aimed at identifying the orientation of horizontal stresses by studying Drilling induced tensile fractures and Breakouts on Image logs/ Multi arm Caliper logs and using Stress anisotropy from sonic logs. The data was correlated with world stress map and a reasonable match is seen between the datasets. The dominant S_{Hmax} azimuth established from this study in the block is N178°±15°.

Introduction

Designing an efficient drilling and completion programme is a crucial step towards decreasing costs and maximizing returns. Drilling of any well involves balancing the earth stresses to maximize wellbore stability without damaging the productive zones.

The state of stress in a hydrocarbon reservoir is defined in terms of the vertical stress (S_v) and the two mutually perpendicular horizontal stresses (S_{Hmax} and S_{Hmin}). Inclined wells drilled in the direction of minimum horizontal stress tend to be more stable in a normally faulted basin. They also have the advantage of cutting through the natural fractures as these fractures tend to align themselves with the direction of maximum horizontal stress. Wells drilled in the direction of maximum horizontal stress are likely to be more stable in a strike-slip fault regime or thrust fault regime.

Well stimulation jobs like hydro-fracturing are preferred in the direction of maximum horizontal stress as all the induced fractures eventually tend to align themselves in this direction and fracturing in other directions will unnecessarily increase the tortuosity. Likewise, in unconsolidated sand reservoirs, initiation of sanding starts in the direction of minimum horizontal stress. Production-related problems like sanding can be mitigated by selecting a drilling trajectory that minimises the borehole stress amplification and directional perforations. Thus, knowledge of the orientation of stresses is not only important for well planning, it is equally important for well completion.

The KG-DWN-98/2 block is situated in Krishna Godavari Basin on the East coast of India. The KG Basin is a proven petroliferous passive margin pericratonic basin with onland area of 15000 sq. km and the offshore area of 25,000 sq. km up to 1000m isobath. The basin contains about 5km thick sediments with several cycles of deposition, ranging in age from Permo-Triassic to Pleistocene. The basin came into existence following rifting along eastern continental margin of Indian Craton in early Mesozoic. The basin is characterized by series of horst and grabens cascading down towards the ocean aligned NE-SW along Precambrian Eastern Ghat trend.

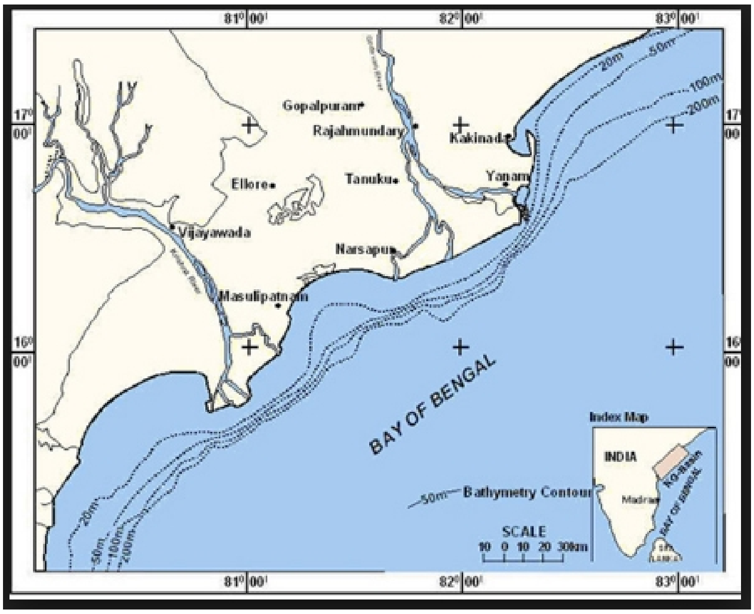


Figure 1: KG Basin Location
(Image credit: NDR-DGH website)

Krishna Godavari Basin is an extensive deltaic plain formed by two large East Coast Rivers, Krishna and Godavari in the state of Andhra Pradesh and the adjoining areas of Bay of Bengal in which these rivers discharge their water is known as Krishna Godavari Basin

Objective & Theory

Figure 2: Study area (Image credit: Google Earth)

Current study utilized data from 10 vertical exploratory wells drilled during ONGC's Deep water exploratory drilling campaign in the area (Figure 2). Lithology encountered during drilling comprised of Sandstone intercalations within Clay with stratigraphic age ranging from Paleocene to Recent. Water depth in the study area ranges from 500m to 1000m. Promising Oil and Gas indications have been found in the area and the area may be further subdivided into multiple structures for further exploration and future exploitation by ONGC

Orientation of horizontal stresses is important for planning horizontal & inclined well bores. Inclined wells drilled in the direction of minimum horizontal stress tend to be more stable in normal faulted basin with an added advantage of cutting through the natural fractures as these fractures tend to align themselves with the direction of maximum horizontal stress. Also planning of well stimulation jobs like hydro- fracturing and controlling sanding in unconsolidated sand reservoirs requires knowledge of stress orientation. The study was aimed at identifying the orientation of horizontal stresses by studying Drilling induced tensile fractures and Breakouts on Image logs/ Multi arm Caliper logs and using Stress anisotropy from sonic logs.

Stress-induced well-bore breakouts indicate the orientation of the principal Minimum horizontal stresses (S_{Hmin}) in the uppermost crust. When the vertical stress (S_v) is nearly parallel to the axis of a vertical well, breakouts form in the direction of the minimum horizontal stress, S_{Hmin}, where stress concentrations at the borehole wall exceed the rock strength. Further, in a vertical well Drilling Induced Tensile Fractures (DITF) form in the direction of maximum horizontal stress (S_{Hmax}) (Zoback et al., 1985; Bell, 1990).

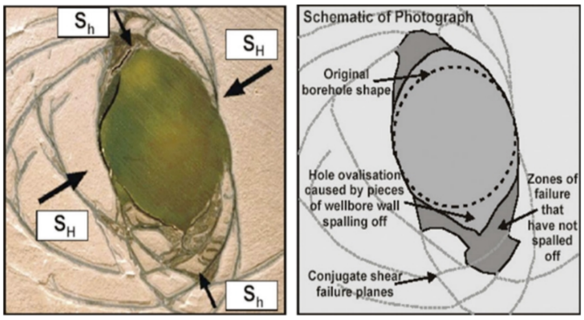
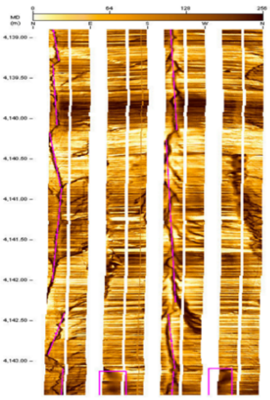
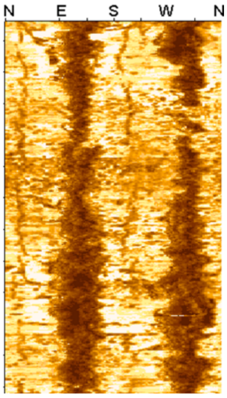


Figure 3: Schematic of wellbore breakout and its relation to horizontal stresses. Type of failure is dependent on rock strength, pore pressure, and stresses; as well as mud weight used while drilling. S_H and S_h refer to the orientations of maximum and minimum horizontal stress respectively (From the World Stress Map, Heidbach et al; 2008)

Analysis of electrical image logs has been found to be best suited for visual observation of these type of failure within the borehole (Figure 3). Four arm Caliper log data also helps in indirect identification breakouts through study of wellbore failures as the tool stops rotating in break out zones with one pair stuck in enlargement direction (Plumb and Hickman, 1985, Zajac and Stock, 1997).





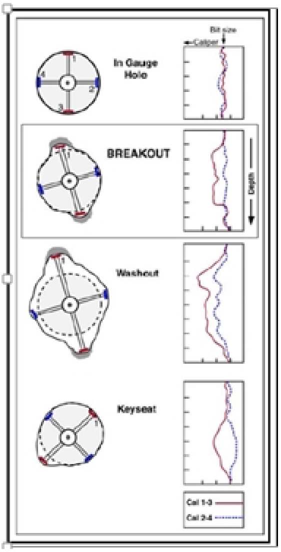


Figure 5: Common types of enlarged borehole and their Caliper log response (adapted from Plumb and Hickman, 1985).

Drilling Induced Tensile Fractures Breakouts

Figure 4: Indicative examples of Drilling induced tensile fractures and breakouts on image logs

The data was correlated with stress anisotropy data using sonic scanner (Schlumberger tool) whenever available for each well for additional corroboration (Figure 6).

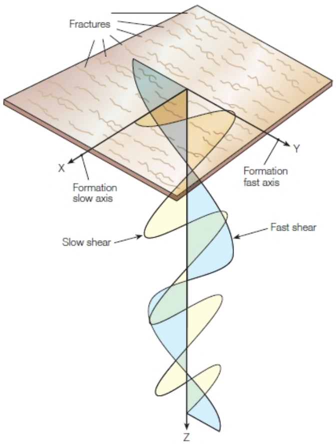


Figure 6: Shear wave splitting: Shear waves travel in an anisotropic formation with different speeds along the directions of formation anisotropy, i.e. if one direction is stiffer, shear wave polarization aligned in stiff direction will travel faster. In this example anisotropy is caused by the vertical fractures (or micro-cracks) with a strike direction along the formation Y-axis, and the fastest shear wave (with the longer wave component) will be polarized along the fracture strike direction as it propagates along the bore hole (Z-axis). When shear-wave splitting is the result of stress anisotropy the Y axis corresponds to the direction of maximum stress and the X axis corresponds to the direction of minimum stress (Brie, Alain et.al., 1998)

Methodology & Results

After data analysis breakouts were identified in two wells from Multi arm Caliper logs (Figure 7). Image logs in three wells showed DITF's & Breakouts (Figure 8).

Figure 7: Four Arm Caliper data analysis

Well 1 Well 4

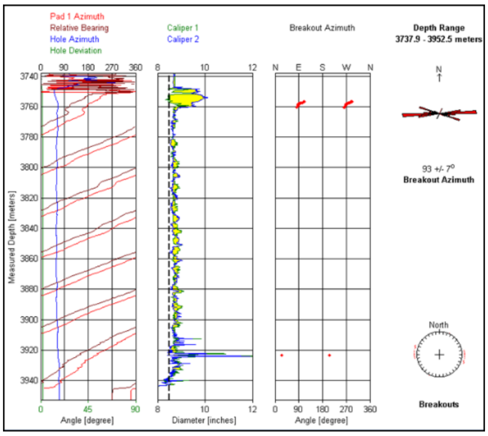


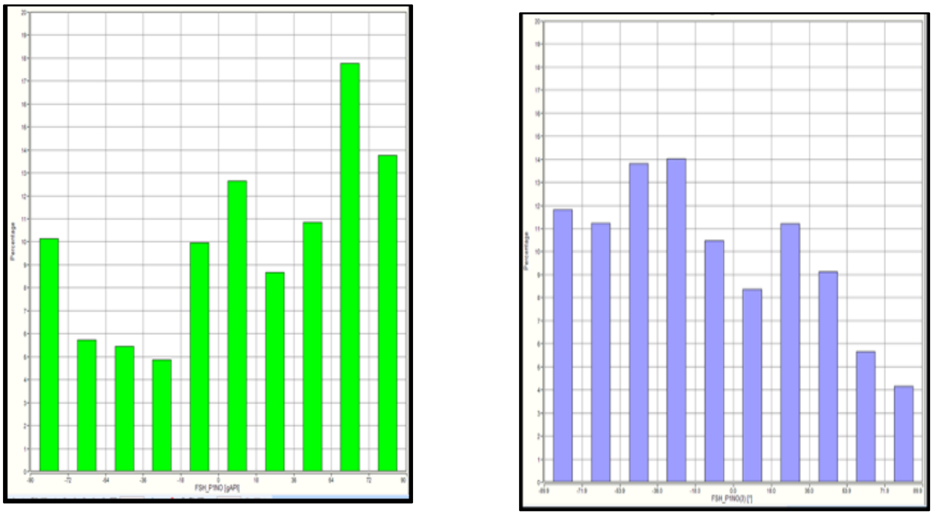
Figure 8: Image log Data

Well 3: OBMI Well 8: FMI Well 9: Azimuthal Density Image

Dipole shear wave anisotropy data was available for five wells and was analysed to identify S_{Hmax} direction through distribution patterns (Figure 9). Fast shear azimuth direction could be determined from three wells, however two wells did not show any clear trend. The data could not be corroborated with other methods in the same well bore but shows good correlation with wells in the area.

Figure 9: Anisotropy data distribution

Well 2 Well 6 Well 7



Well 8 Well 9

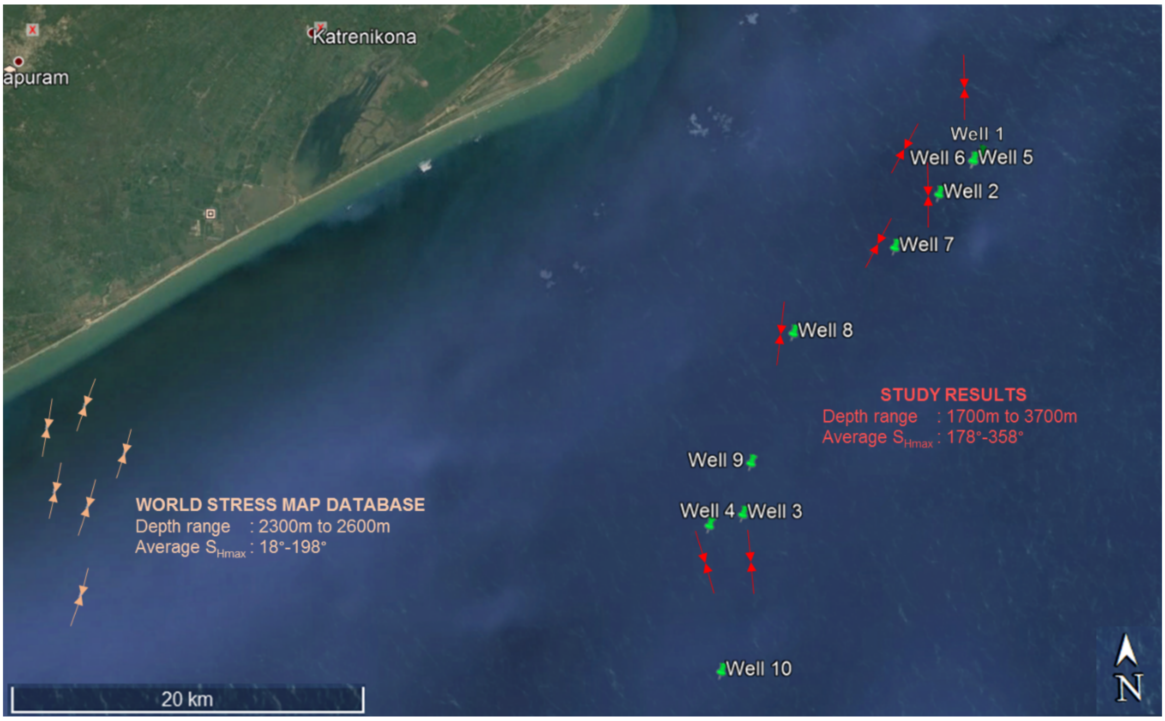
In addition to unbalanced tectonic stresses, shear wave splitting can occur due to fractures, faults or bedding planes intersecting the wellbore. Further, the measurements depend on wellbore conditions thus as factors other than stress may be influencing the anisotropy, hence the interpretation from anisotropy data is of low confidence.

Controlled drilling, real time monitoring, usage of synthetic Oil Based mud all aimed at reducing wellbore failures and smooth well operations are a norm in deep water drilling. However, this significantly reduced the data quantity/quality available in each well. Inferences from each method are presented in Table-1.

Table 1: Inferences from data analysis for Stress Orientation

Well	Depth Range (m)	Caliper Breakout direction	Image logs		Fast shear Azimuth direction	S_{Hmin} Direction	S_{Hmax} direction
			Breakout	DITF			
1	3750-3760	93°	-		-	93°±7°	183°±7°
2	2900-3100	-	-		342°-18°	90°±36°	180°±36°
3	1700-1730	-	NA	170°±15°	-	80°±15°	170°±15°
4	1650	70°±11°	-		-	70°±11°	160°±11°
5	-	-	Not visible		-	No results	
6	1300-2350	-	-		18°-54°	126°±18°	36°±18°
7	1500-2600	Not visible	-		306°-342°	126°±18°	36°±18°
8	2300,2600	-	-	17°±18°	No clear trend	107°±18°	197°±18°
9	2540-2550	-	50°-110°	No	No clear trend	-	-
10	-	-	Not visible		-	No results	

Figure 10: S_{Hmax} orientations inferred from data analysis in conjunction with World Stress map (2016)
Image: Google Earth & Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences



It may be noted that world stress map orientations are very sparse and solely from shallow water wells

Conclusions

10 wells were studied, out of which 7 wells give clear trends. Five wells give the dominant trend of S_{Hmax} azimuth as N178°±15°. Two wells show S_{Hmax} orientation in N36°±18° on the basis of anisotropy data. This may indicate factors other than stress influencing anisotropy. The results match reasonably with world stress map database orientations.

The study will be useful in devising future strategies regarding well trajectories, optimal mud planning, production planning etc. and provide valuable input for generation of 1D & 3D models in prospective areas. It also identifies data gaps for further improvement in data quality and improving the focus of exploration programme.

Acknowledgment

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