Detection of Structural Elements Using Borehole Imagery Techniques, A Case Study From Krishna-Godavari Basin, India

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ABSTRACT: Fullbore Formation MicroImager tool is part of new generation borehole imaging devices provided by the MAXIS 500 system. It is an extension of traditional dipmeter technology and overcomes the inadequacies of conventional dip data. The Fullbore Formation MicroImager tool has eight pads, including four flaps consisting 192 array electrodes with a vertical and lateral sidewall image resolution of 5mm and image coverage up to 80 percent in 8.5 inch (21.59cm) diameter borehole. The tool offers enhanced vertical resolution, lateral exploration capabilities, high volume of data acquisition with real time processing and image display. A detailed image interpretation and dip evaluation has been carried out in Krishna Godavari Basin. The analysis aimed primarily to recognise structural elements and associated features. In the present study, structural elements like unconformities, fractures, faults, slump deformation structures and foliations were detected and defined. Infact, some faults were recognised even in the absence of distortion. Complex structural features like growth faults and associated antithetic faults were clearly visualized on the images. As exploration and production become critical and geological problems encountered become increasingly complex, the use of borehole imagery techniques will help the geologist, log analyst and production engineer for enhancing the future exploration and exploitation programmes.

INTRODUCTION

The Fullbore Formation MicroImager (FMI) tool is the latest generation electrical imaging device and belongs to the family of imaging services provided by the MAXIS 500 system with its digital telemetry capability. It is a revolutionary logging technology which was introduced in oil industry by M/s Schlumberger with wide range of applications. The tool consists of 4 arms and each arm supported by one pad and one flap. A total of 192 scanning electrodes distributed equally in two rows on four pads and four flaps to provide high spatial sampling of formation microresistivity in both the vertical and azimuthal directions on the borehole surface.

During logging, each microelectrode emits a focused current into the formation. The button current intensity measurements, which reflect micro resistivity variations, are converted to variable intensity colour images with identical horizontal and vertical scale. The images produce ‘core like’ borehole wall picture, which allows detection of fine scale geological features with excellent vertical resolution. For the first time in the Krishna-Godavari basin, FMI has been recorded in two wells viz. E#A and P#A of East Godavari Sub-basin representing different geological setup. The acquired field data was processed using ‘Geo-frame’ software on Sun workstation (UNIX based). The images allow continuous observation of detailed vertical and lateral variations in formation properties.

The objective of the study is to detect and define structural elements, by evaluating responses of FMI tool which is an indispensable electrical imaging device in visualising and solving complex geological and exploration problems.

GEOLOGICAL SETTING

Geological setup

On the East coast of India, Krishna-Godavari Basin is a fairly large sedimentary basin covering an area of 20,000 Sq.km onland and extends offshore into the Bay of Bengal, measuring about 21000 sq.km up to 200m isobath. The basinal extension into deeper waters up to 2000m isobath involves an additional area of about 18,000 sq.km. The basin is divided in the subsurface into several sub-basins (grabens) and ridges (horsts) running in SW-NE direction along Pre-Cambrian Eastern Ghat trend. The different sub-basins from SW to NE are Krishna sub-basin, Bapatla horst, Gudivada graben, Kaza-Kaikaluru horst, Bantumilli graben and Tanuku-Bhimavaram horst (Fig. 1). The area covered by Gudivada graben, Kaza-Kaikaluru horst, Bantumilli graben and Tanuku-Bhimavaram
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horst constitute West Godavari sub-basin. The area towards southern part of Tanuku-Bhimavaram horst falls under East Godavari sub-basin, which extends into offshore. The present study is confined to the wells E#A and P#A of East Godavari sub-basin.

In this sub-basin, the oil and gas accumulations have been found mainly in Mandapeta (Chintalapudi), Gollapalli, Pasarlapudi, Mastyapuri and Ravva Formations. A few sporadic occurrences of hydrocarbons are met within the sands of Raghavapuram shale and weathered trap in the northern part of MTP-PLK fault. Apart from this, hydrocarbon indications are also noticed in the sands within Palakollu and Vadaparru shales along the coastal tract and offshore area.

INTERPRETATION AND RESULTS

The aim of image interpretation is to characterise formation properties for detecting and defining various geological features. The study has been carried out to interpret the structural elements and associated features by using FMI log responses. Some of the features are interpreted easily because of their clear shape, length, pattern and variations in resistivity on the normalised images. However, in case of irregular, noisy and localised features, the data from other wire line logs and cutting samples have been integrated and analysed for better interpretation.

DETECTION OF STRUCTURAL ELEMENTS

Unconformities

Fig. 2 representing unprocessed FMI field log of E#A displays an abrupt change in resistivity at 1855.75m, indicating sudden change in formation characters. The different colour patterns observed in the beds above and below this feature are the manifestation of textural variations in terms of resistivity. The bounding surface of these two litho units suggests a major unconformity at this level between Gollapalli and Raghavapuram Formations. The upper part of Gollapalli sands (1857.20 – 1855.75m) appears to be clean, well sorted, having good porosity and permeability. The variation in reservoir properties above and below 1857.20m in E#A can be seen clearly on the FMI field log. Fig. 3 illustrates an irregular surface at the top of basement which is identified at 1956.50m in E#A. The example does not exhibit a clear unconformity on the images. However, the presence of unconformity is readily recognized by the sudden change in dip amount and direction at 1956.50m. Below the unconformity, the images covering the...
basement complex, which shows resistive character due to lack of porosity. The conductive features observed in the images are the result of alternation of mafic and felsic minerals in the basement. However, the type and nature of rock cannot be defined with the downhole imaging system alone as the images are electrical measurements and do not represent the mineral composition of the rock (Bhavana and Rao).

**Fractures**

Imaging logs offer unique advantage in identifying fractures. Fig. 4 is an example from the metamorphic basement of E#A which reveals, two high conductive (dark) linear features intersect on the right side of the dynamic image with an angle of 145° at 1976.90m. They form an angle of 15° with the vertical to the bedding. These observations indicate that they correspond to conjugate shear fractures. The strike of the fracture plane is about 165°, which is also the direction of the mean principal stress axis. The dips of the fracture planes are 40° N35°E and 80° N330°. These sets of fractures are very common in igneous and metamorphic rocks.

**Growth fault**

A distinct, high angled conductive feature is observed on the images at 2205.80m of P#A (Fig. 5). The beds above and below are deformed and show abrupt change in dip magnitude and azimuth. This phenomenon indicates the presence of a major growth fault crossing the well bore at 2205.80m, which dips to SSE at 35 degrees. The fault is truncating the resistive sands below and conductive shales above the fault. The sands below the fault are clean and resistive in nature, which can be seen on the static image. The rollover zone appears on the images, which begins at 2205m and extends up to the fault plane. The SSE dipping growth fault is up thrown to the SSE, down to the NNW and striking in NE-SW direction.
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A continuous change in dip angle is noticed between 1985.50m and 1984.50m which reveal the presence of overturned features and also associated micro fractures. These features may correspond to slump deformation structures. A very high angled conductive event which looks like an ‘eye’ has been recognised and a sudden change in dip motifs is also observed at 1985.80m on imaging logs suggesting “bulls eye’ structure which indicates slump structures within the basement. Presence of a minor fault dipping 50° towards west at 1985.80m may not be ruled out (Fig. 7).

Foliations

Fig. 8 depicts the presence of numerous conductive layers, showing planar dip at high angles around 25-65 degrees in the interval of 1975.50-1973.50m of E#A. The interval generates several diagnostic dip patterns characterised by decreasing dip with depth and indicating consistency in orientation, which is in NE direction. Often these features

**Antithetic fault**

The interval 2204.50-2202.50m of P#A (Fig. 6) shows a small antithetic fault crossing the wellbore at 2203.50m, which dips at 50 degrees NNW. This fault is down thrown towards the large growth fault, which was observed at 2205.80m. The static image exhibits a relatively conductive shale formation with presence of calcite lenses observed in the bottom of the section as irregular resistive streaks. However, the bed displacement has been noticed across the antithetic fault on the dynamic image.

**Slump deformation and bulls eye structure**

Basement characters and associated features can be interpreted with confidence from the responses of static and dynamic images. The interval 1986-1984m of E#A indicates compressed, folded and swirling features around 1984.50 m.
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Figure 7. FMI images showing slump deformation & bulls eye structure in E#A

appear streaked with conductive laminations and are interpreted as foliations, showing unimodal dip distribution. The conductive nature of these foliations is due to the presence of mafic minerals, however alteration of felsic minerals to clays may not be ruled out.

CONCLUSION

FMI logs though do not represent core in true sense, it provides a virtual model based on electrical responses where in structural elements of a formation can be analysed. A detailed image interpretation and dip evaluation was carried out in E#A and P#A of East Godavari sub basin. Structural elements like unconformities, fractures, faults, slump deformation structures and foliations were detected and are well defined. Faults were recognised even in the absence of distortion. Complex structural features like growth faults and associated antithetic faults were identified and visualised clearly. However, type and nature of rock cannot be defined with downhole imaging techniques.

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