Structural Interpretation of Dipmeter Log – A Case Study from Baramura Field of Tripura

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Summary

Dipmeter logging tool has gained acceptance in petroleum industry as a means to define subsurface sedimentary structures and to detect geologic signatures of tectonic events. The advantage of dipmeter, over seismic is that it provides accurate informations near the well bore and detects structural features beyond seismic resolution. Identification of these structural features and detection of their orientations are done on the basis of structural dip trend analysis which compares characteristic dip patterns of various geological structures with observed dip patterns on computed dip plot. A detailed examination of raw dipmeter curves and correlation logs and proper selection of dip processing parameters are significant in this respect. These facts have been explained with the help of dipmeter log data of a well in Baramura field processed with in-house software. In this well, a minor normal drag fault has been identified and its orientation has been determined. Various conditions necessary for reliable and meaningful structural dip trend analysis have also been discussed.

Introduction

Used initially in exploration, the dipmeter tool helped to locate and identify the major features of geologic structures that serve as oil traps. With improved techniques in data acquisition and computation, the application of this tool has expanded until it has become the principle logging measurement for describing internal lithologic features as well as revealing the sedimentological process responsible for them. As a result, the dip information now a days is used to identify both structural features such as faults and folds and stratigraphic features such as paleocurrent direction, sand or shale thickening direction and sand body orientation.

The primary function of the dipmeter tool is to measure the magnitude and direction of the slope (known as dips) of sedimentary features such as bedding planes. Most sediments were essentially deposited nearly flat, and subsequently subjected to post depositional structural uplifting or down wrapping. This post depositional tilt is what is referred to as structural dip. A computed dip arrow plot (called Tadpole plot) presents individual dip measurements computed from micro-resistivity data recorded at measured depths. Certain dip trends or dip patterns can be expected to occur with different geological features including folding, faulting and unconformities.

Modern 3D seismic techniques provide both high resolution and dense coverage for interpretation of subsurface structures and are a great improvement on older 2D methods. However, features at the lower limit of seismic resolution (less than 20 meters thick) or with low acoustic impedance contrast are often not resolved and interpretation can become ambiguous. Structures at this scale, in particular small scale faults are important to reservoir production as they may form permeability barriers. Identification of such features are critical for optimum placement of production wells and enhanced field development. Integration of structural analysis derived from borehole dipmeter data with 3D seismic data allows better structural control in complex structural settings.

Structural interpretation of Dip Data

Successful structural dip interpretation is based on the good knowledge of geometrical and geological character of the structural features and their characteristic patterns on computed dip arrow plot. Structural features, such as faults and folds, generally result from laterally directed forces which are either to compress or pull apart the rock strata of the earth's crust.

Folds are undulations in the rock strata. They are displayed at their best in well stratified formations. Many structural reservoir traps are the result of folding. A clear indication of a fold on a dip arrow plot requires the borehole to cut across the axial plane. The plot will then show changes in dip from one side of the plane to the other. Because of this reason, in case of symmetrical fold where the axial plane is vertical, the computed dips of a vertical borehole will register no change in dip trend. However, within an asymmetrical fold, the dipmeter log will register a change in direction from one flank of the fold to the other where the borehole crosses the axial plane. In case of overturned folds, we can expect dramatic changes in dip trend. For example, in case of overturned anticline, both flanks may dip in the same direction but lower flank dips at a steeper angle than the upper flank. An overturned syncline would do the opposite. Between the flanks, the dip sweeps from 0 to 90°. In a recumbent fold, the upper and lower flanks dip in opposite directions. In this case, the dip trend will increase to 90° between the two planks and an inverse repetition of the folded beds (mirror image) is usually recognizable on the log correlation curves. Flexures usually appear on the arrow plot as alternately increasing and decreasing dip angles with nearly constant azimuth.

A fault is a natural fracture marking displacement – vertical, lateral and/or rotational of geological strata in the earth's crust. Faults are classified according to the kind of movement exhibited by the upper and lower blocks, the rocks on either side of the fault plane (or zone). Normal faults or gravity faults are those in which upper block has moved downward. If the upper block has moved upward, a reverse fault is resulted. Low angle (low dip fault plane) reverse faults are commonly referred to as thrust faults. Faulting with progressive distortion on one or both sides of the fault creates the best conditions for detection by dip analysis. This distortion is akin to folding and gives rise to characteristic dip patterns. Folding of this sort, called drag, is produced by the friction between the fault blocks as they move past one another. Drags usually create concave folds in the downthrown block and convex folds in the upthrown block (Fig.1). However, when faulting occurs during sedimentation, bedding dips into the fault rather than away from it. This is rollover or growth fault.

A normal drag fault is characterized by drag in both the upper and lower blocks. The dip results usually reflect this distortion with a red dip pattern (a set of successive dips with constant azimuth and increasing magnitudes with depth) in the down thrown block, the dips pointing in the direction of movement. The blue dip pattern (a set of successive dips with constant azimuth and magnitudes decreasing with depth) is the result of drag in the upthrown block. Ideal characteristic dip pattern of a normal drag fault is shown in Fig.1. Strike of the fault is generally perpendicular to the average direction of the red dip pattern. Dip magnitude of the fault plane is picked near the point of intersection or the two coloured

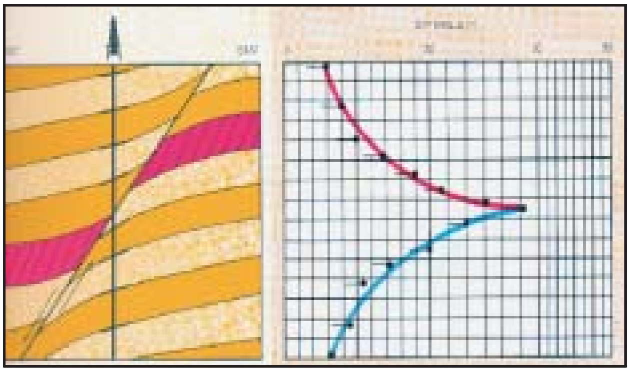

Fig.1: Ideal dip characteristic pattern for normal drag fault

patterns on dip plot. In case of normal growth fault, the red and blue patterns will be in opposite direction. The drag in a reverse fault occurs frequently on both sides of the fault, although distortion is usually greater in the overthrust block, due to faulting mechanism. The characteristic dip pattern of a reverse drag fault is similar to that of normal drag fault. However, dip of the fault plane in case of reverse fault is opposite to the drag or overthrust direction and normal to the strike of the fault. On well logs, the presence of faults often shows up in the form of missing (normal faults) or repeated (reverse faults) sections. The thickness of the missing or repeated section, measured on a well log, is equal to the vertical separation (throw) produced by the fault, if the well is vertical. Sometimes, the faulting process forms a broken up zone of shatter rock or breccias near the fault surface. This region has no bedding and thus appears on the dipmeter arrow plot as a gap (if no correlations are found) or a series of random, usually low quality dips.

In this section we have discussed about some common geological structures in terms of their geometrical features and their characteristic signatures on computed dip arrow plot in the form of various dip patterns. In the next section, we will show a field example of processed dipmeter data and attempt to identify specific structural deformations based on pattern recognition from arrow-plot results.

A case study

Tripura area is located in the North Eastern part of India and forms a part of Assam-Arakan frontal belt, characterized by a number of N-S trending long narrow elongated anticlines and broad flat intervening synclines, occurring in an en-echelon fashion. Located in this area, Baramura field is an asymmetric doubly plunging anticline trending roughly NNE-SSW. Tectonically Baramura falls in the frontal folded belt of Tripura, which is the western continuation of the Surma Valley folded belt. The eastern flank of Baramura structure has been affected by a thrust dipping westward. Located on this flank, the well Baramura-A was drilled to the depth of X185 m to explore hydrocarbon potentiality in Bokabil and Upper Bhuban formations of Miocene age.

In this well, dipmeter log was recorded using four electrode dipmeter (FED) tool of Gearhart Inc. (presently Halliburton). The dipmeter raw data has been processed with in-house software DAISY. The algorithm is based on pattern recognition and feature extraction methods similar to Schlumberger's GEODIP processing. In this program, different features called elements such as peaks, troughs, spikes and steps are identified in each micro-resistivity curve and accordingly each curve, to be correlated, is mathematically decomposed into a depth ordered sequence of ranked elements. The program then correlates the elements on each curve (and not the actual resistivity curves) and relates them to the same geological event. As a result, the density of the output data (dips) depends on the density of geological events. This makes DAISY processing particularly successful in fine structured sedimentary

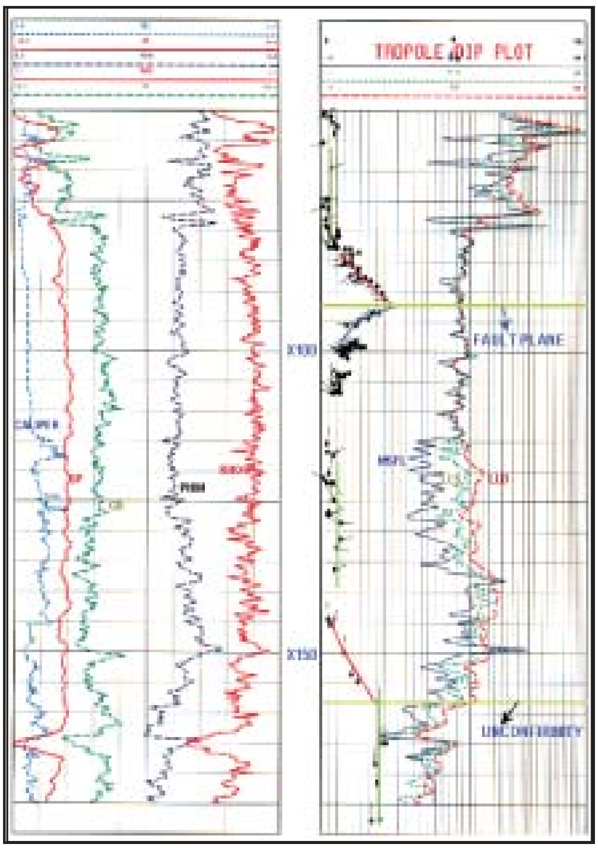

Fig.2: Dip arrow plot along with correlation logs in the interval X060-X180m of well Baramura-A

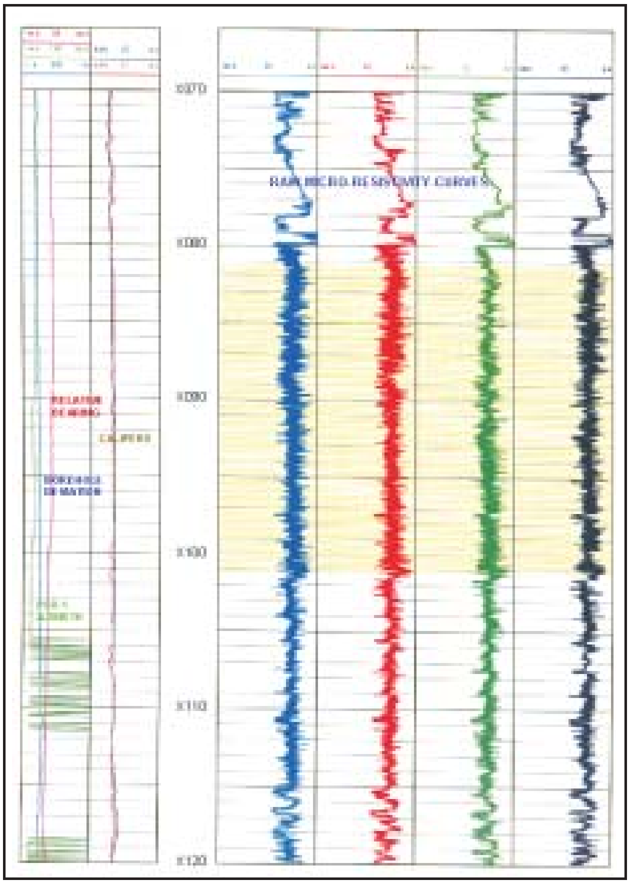

Fig.3: Raw microresistivity and auxiliary curves of dipmeter log of Baramura-A. Deformed zone is indicated by shaded portion.

sections. For structural interpretation of dipmeter data, the selection of processing parameters are crucial so that we can obtain high dip angle and large scale dip pattern (without finer details). Because of this we have taken search angle as 45^o and t_{min} (minimum bed thickness) as 0.2 meter. Dips corresponding to different filters (1 to 20) were generated and optimum filter was selected for structural analysis. Here, higher filter means more averaging and screening.

A section of the computed dip-arrow plot is presented in Fig.2 in the depth interval X060-X180 m in 1:500 depth scale. A close inspection reveals that a structural deformation of small scale is prominent in the interval X081-X101 m represented in the form of a red pattern underlain by a blue pattern. To know the lithology, conventional logs (Resistivity, GR, RHOB, PHIN, SP and Caliper) are also plotted alongwith computed dips. They indicate that the event occurred in shale section. Above and below this section, the structural dip is very gentle (2-4^o pointing towards East). Once a structural deformation has been identified using dip trend analysis, it is essential to examine the raw dipmeter data for confirmation of arrow plot interpretation. The micro-resistivity (four in number) and auxiliary (calipers, Pad-1 azimuth, relative bearing and borehole deviation) curves covering this interval is presented in Fig.3 in 1:200 scale. The visual inspection of these curves shows that deformed zone is marked by conductivity anomalies (shaded in the figure), very less tool rotation and vertical and gauged hole. Reliable interpretation of the raw data requires that effects such as excessive tool rotation or borehole rugosity are not responsible for producing such conductivity anomalies.

Analysis and discussion

If we examine the dipmeter response of the deformed zone in Fig.2, the possibility of occurrence of any kind of fold system can be excluded. This is because except recumbent fold, no fold system has a dip response of a red pattern in the upper flank and a blue pattern in the lower flank. We also observe no sweep of dips from 0 to 90^o between the flanks. In case of recumbent fold, upper and lower flanks dip in the opposite directions. In our case, both red and blue patterns have the same azimuth. Moreover, a mirror image of geological section is not noticed on the log correlation curves.

When we consider the presence of possible fault system, this sort of dip response is possible only in case of normal and reverse (or thrust) drag faults. However, when a borehole cuts a reverse fault, it re-enters the same interval of the geological section that it had just passed through and the correlation logs show this section as repeated. No such repeat section is observed in our case. Hence, the possibility of the presence of a minor normal drag fault in the interval X081-X101 m is the logical conclusion.

Once a specific fault system has been identified, its orientation can be determined by a careful inspection of the dip arrow plot. As mentioned earlier, the position of fault plane can be located as the point of intersection of red and blue pattern. Thus the fault plane is located at X092 m in this well. The fault plane is dipping at an angle of 18^o. Azimuth of fault plane should be same as that of red pattern of hanging wall block. Hence the fault is downthrown to west. The strike of the fault is N-S. The fault is slowing a blank expression (no dips) in the interval X091.5-X093.5 m on dip plot. This might be due to intensive brecciation of the rocks producing high dip scatter which has been subsequently removed by high filter dip processing.

Another geological event is observed in the interval X145-X158 m of Baramura-A (Fig.2) in the form of a red pattern. This is correlated with an angular unconformity at the depth of X158 m. Unconformities are breaks in the otherwise regular stratigraphic sequence marked by a surface of erosion or non deposition separating the younger strata from the older rocks. Although unconformities are considered to be stratigraphic events, their characteristic dip patterns resemble those found associated with folds and faults. Angular unconformities will show a change in dipmeter pattern due to differences in dip and azimuth of the strata above and below the unconformity. The older rocks usually dip at a much steeper angle since they are more likely to have been tilted tectonically prior to the deposition of upper strata. Also the beds overlying an unconformity tend to be laid parallel to the surface of unconformity. This differentiates between the characteristic dip patterns of unconformity and fault. Moreover, unconformities usually occur at lithology boundaries but faults are not so selective. The conventional logs plotted in Fig.2 indicate the change of lithology at the unconformity surface. The lower beds below the unconformity are dipping towards North at an angle of 15^o whereas upper beds have very gentle structural dip of 3-4^o pointing towards East. Occurrence of a red dip pattern just above the level of unconformity in Fig.2 may be because of the following reason. The erosion linked to unconformity had created topographic relief whose hollows were first filled when deposition resumed and later these filled sediments were differentially compacted by subsequent overburden layers of strata. This is reflected on the arrow plot by an increase of dip with depth down to the level of unconformity.

Conclusions

Resolution of seismic under optimal conditions is about 20 meters. This represents a considerable uncertainty regarding interpretation and mapping of small scale structural features. The importance of dipmeter tool is that it provides more accurate information at the well location and detects structural features either beyond seismic resolution or with low acoustic impedance. These informations are important for optimum well positioning to maximize hydrocarbon recovery. Identification of these structural features and detection of their orientations are done on the basis of structural dip trend analysis which compares characteristic dip patterns of various geological structures with observed dip patterns on computed dip plot. This technique has been applied to a field example where a minor normal drag fault has been identified and its orientation has been determined on the basis of structural dip trend analysis.

Identification of structural features from dipmeter data is limited to those which display clear bedding deformation or which allow orientation. When these are not present, or when chaotic dips result from shattering or poor borehole conditions, it is not possible to characterize structural deformations fully from dip data alone. Moreover, steeply dipping events such as faults are not picked up by computed dips due to the different response of the tool on the opposite sides of the borehole. This necessitates the critical examination of raw dipmeter curves and other log curves along with computed dip data. A visual inspection of formation microresistivity image log will be of great help in these situations.

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References

Adams, J. T., Ayodele, J. K., Bedford, J., Kaars-Sijpesteijn, C. H. and Watts, N. L., 1992, Application of dipmeter data in structural interpretation, Niger Delta; Geological Society Special Publication, UK, No.65, 247-264.

Atlas Wireline Services, 1987, Fundamentals of Diplog Analysis; Atlas International Inc., Houston, Texas. USA.

Deilliers, M.C. and Werner, P., 1990, Example of fault identification using dipmeter data; Geological Society Special Publication, UK, No.48, 287-295.

Schlumberger, 1986, Dipmeter Interpretation-Fundamentals; Schlumberger, New York, USA.