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Dip Meter Logs Applications on Structural and Sedimentary Studies

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Abstract

Dip Meter logs represents an important tool for structural and sedimentary formations features characterization. Dip meter data may be grouped in distinct representative models and consider them an as geophysical response to layers positioning and can emphasize important events as faults, unconformities of structure geological evolution. Also second order models, with smaller extension are the effect of sedimentary structures in the larger layers units. In the worked example is presented, on a real data set the clarify of the structural model of a productive oil structure by emphasize and interpreting of these patterns, interpretation which changes in a benefic manner the geological model of the reservoir.

Key words: *dip meter, plots, pattern (model), structural, sedimentary, geological interpretation.*

Dip Meter Logs Data Representation

Dip meter logs data can be represented both as primary (raw) data or in any other refined modes[1,7,8,] in order to emphasis some of the formations properties.

The usual representations are:

- Raw data:
  - Arrow plot,
  - SODA (separation of dip and azimuth) plot;
- Statistic representations:
  - Azimuths' frequency plot,
  - Polar (Modified Schmidt) plot;
- Complexes representations:
  - FAST (Formation Anormality Simulation Trace), cylindrical plot,
  - Stick plot,
  - Geodip plot,
  - Dualdip plot.

The name of the representations may differ from a company to another (Schlumberger, Weatherford, etc.) but their aspects are similar.

Geological Interpretation

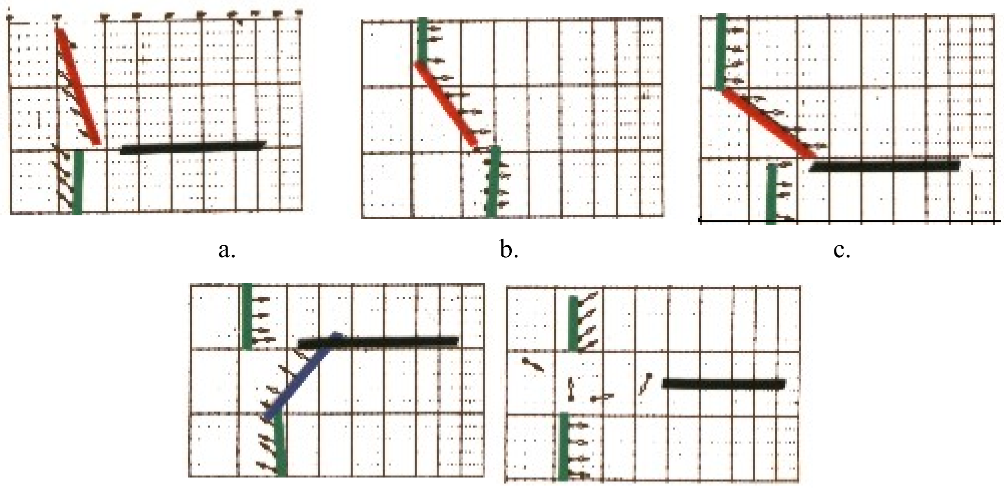
Dip logs data, processed and displayed in the different ways presented before provides a multitude of information with geological significance.

The geological interpretation procedures mainly consist of recognizing of some characteristic models and their geological meaning. So in order to facilitate the interpretation of such a huge number of measured points (presented for instance on Arrow Plot) they were grouped by the data arrangement in more models (patterns) which, for an easier geological interpretation are symbolized with different colors [3,4,5] as:

- *Green Model(G):* Points have relative constant dip and azimuth on an interval; these values reflect the normal dip and azimuth of the formations;
- *Red Model(R):* Azimuth values of the observed points remain mainly the same but dipping values increase with depth; this model is characteristic for faults, sedimentation above unconformities, sands banks, buried channels and reefs;
- *Blue model (B):* Azimuth values of the observed points remain mainly the same while the dipping values decrease with depth; this situation is characteristic for faults, unconformities, delta sediments systems and current deposits (with high water energy).
- *Black model (Bk):* abrupt changes or breaks in dip and/or direction, representing unconformities, or erosional boundaries between stratigraphic units.
- *Yellow (Random) model(Y)*: caused by poor hole condition or random stratigraphic events, such as pre-depositional burrows and cracks.

The color assignments, namely green, red, blue, black, and yellow, are purely arbitrary but have become an industry standard [2,3] by common usage. Appropriately colored pencils or ink markers are used to join dip arrows to emphasize the patterns.

In the figure below are presented the main combinations of these patterns.



a. b. c.

d. e.

Fig. 1. Grouping models for dip meter data (from top to the bottom of pictures):
a. R – Bk – G same azimuth; b. G – R – G, same azimuth; c. G – R – Bk – G, same azimuth;
d. R – Bk – B – G, azimuth change; e. G – k – G, azimuth change

The statistic representations may emphasis, also many specific models with distinct geological signification. So by the points grouping mode on the Polar Plot can be distinguished a difference between the structural and depositional dipping size and orientation.

So after marking the points' positions on the diagram we unify the equal value points' concentrations obtaining contour isolines.

By the shape of these contours can be depicted the depositional dip (triangular shape isolines with the peak, top, oriented towards graphic center) from the structural ones characterized by isolines following the graph contour.

Making the vectorial difference between these values, depositional dipping minus structural dipping, we obtain a more realistic reconstruction of the initial depositional dipping. The obtained results can be successfully used in sedimentary history studies.For the azimuths' frequency plots their unimodal, bimodal or polimodal distribution combined with the model from the arrow plot (green, red, blue) will provide information regarding the depositional type and the sedimentary basin.

Complexes plots as GEODIP may emphasis, by resistivity curves correlation, the succession of depositional sequences and their content, being extremely useful for the sedimentary studies of deep positioned formations. The modern techniques as FMI or similar tools supplies SHDT, tools data and may provide an accuracy of less than 2 inches in data interpretation so they will provide a lot of useful informations.

With the increased number of dip determinations, it is possible to relate small scale patterns of dip variations with detailed internal structures of sedimentary bodies. In many cases, stratigraphic analysis can still be done on older HDT data, but the processing and resolution will not provide the same quality of results as more modern techniques.

Also the complex representation including resistivity curves provide a comparative term in order to separate the different lithological units and thus eliminate an error which may occur. It is not possible that a pattern, dip model to overpass important lithological changes so we must shift the dip patterns (models) to lithological units.

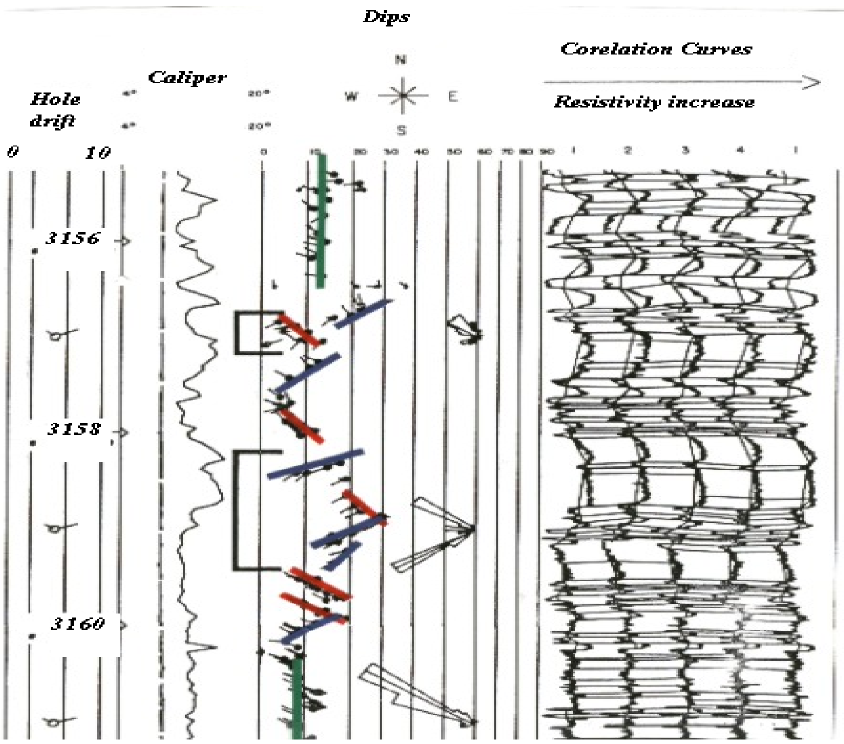


Fig. 2. SHDT data correlating (after Crane, 2010)

The image presented above illustrates how GEODIP arrow plot emphasis with high precision even in relative thin layers changes of dips in can be detected. The two bracketed intervals of lengths 0.6 and 1.5 m have a southwest dip, roughly separated from the west northwest structural dip of the studied interval. The southwest dip is assumed to represent current direction for those two units.

Rapid changes of sequences disposal, must be analyzed and interpreted together with all the available information regarding lithology, sequences depositional model and facies. Because coarser deposits reflect usually instability of sedimentary regime the best way to have a good interpretation is to focus on shale deposits. These beds, formed in a “quiet” zone of the depositional system are maintaining a monotone dip. Scattering values of dip magnitude, significant azimuth changes, manifesting in a regional trend of preferential direction emphasize layers cross-bedding. These features may indicate a rapid intermittent deposition or a continuous one with variable sedimentation rate. Displaying lithological curves as SP, GR, or if is available PE together with dip meter data allows the interpreter to relate sedimentary dip with lithologic changes and correlate them with resistivity curves from dip meter.

In the log illustrated above we may see that between 3156.5 respective 3160.5 m is a rapid succession of more red – blue models suggesting in high instability of depositional features of the system on this interval. Looking on the lithological curves (resistivity) displayed on the left trace we may see that the sediments from this interval have higher values suggesting the existence of a coarser lithology also specific for high energy transporting system and/or relative highstand tracts regime.

Also regarding the existence, below and above the mentioned zone of two green models, well developed, the turbulent middle zone may be also linked with a “solid flow” as turbiditic, deep sea fan, piedmont deposits.

Interpretation Phases

In order to achieve a correct stratigraphic analysis it’s important to begin with a review of well data as: lithological column from cuttings, core data, if there are present age markers and their position in the column and also if they are in situ or reworked. Also is essential to correlate all the log curves, mark the stratigraphical limits and separate the superior degree sedimentary sequences.

As long as regards the dip meter data mainly from statistical representations can be obtained the regional dipping data as structural and depositional dip. On the arrow plot may be marked the main models presented in the previous section.

The analysis will begin usual from the top of the log or above (at least 100 – 200 m.) the focused interest interval. The longer the interval, the better interpretation will be.

On the studied interval are marked the principal models (patterns) respectively Green, Red, Blue and Black in the presented order, from obvious, simple models to more subtle or smaller ones. For an appropriate models limit must be considered and correlated the lithology clues respective to compare them with SP, GR, and resistivity curves. There is a minor problem regarding the depth scale. Excepting resistivity (usual MLL curve) which is recorded by the dip meter log, the others are recorded to a smaller scale but it can be overstep. This correlation able the interpreter to separate “real” boundaries. Stratigraphic units seldom cross obvious boundaries [4,5] , but this rule may be broken.

Usual red and blue patterns complete each other (beginning of the one is the end of the other) and as a rule at the end with the higher dip appear a break (black pattern). Sometime these models cannot include all the measured values because of random distribution or investigation noise.

There is an important difference between structural and stratigraphic units. While structural assemblies may yield hundred of meters thick intervals the stratigraphic units may be superimposed [2,11] on the structural patterns and may have from a few meters to more than

100 m., but more thinner than structural units. Some of them as over drape sedimentary units may be even thicker. For example a draping unit above on a paleoshape or a reef may retain its dip on a significant interval or decrease very slow.

Red patterns emphasizing faults and unconformities have a rapid dip variance and are usual short intervals. Blue patterns linked with sedimentary structures are short and unconformities and fault reported ones are much longer.

Representative Patterns Arrangement

Regional, structural dip. On an apparent random distribution we may emphasize Green models corresponding mainly to shale deposits from the lithological column. Relative constant values (dip an azimuth) of these shales represent the regional structural orientation.

Anticlines structures. The models combination is depending both of flanks dip and well position on the structure. When the well is placed nearby the anticline axis and this one is vertical layers look close to horizontal and the pattern will be a green one. If is a dipping axis and the well is crossing it the dip values will have a green / blue / red / green pattern with a 180°azymuth change. The dip values are related with axis position and characteristic is the azimuth change (opposite). If the axis position is horizontal the layers distribution on lithologic logs (SP, GR) will be symmetric from axis.

Faults. When the well is crossing a fault we may encounter a wide variety of arrangements so the patterns are also variable.

Unconformities. They may have different models bur the most important feature is the obvious change in dip and azimuth between the layers above and below the unconformity. Usual above the unconformity occur a red model and below a green one.

Case Study

The studied case is referring to an old oil productive structure from the so called Getic Depression from Romania. From stratigraphic point of view this structure consists of Miocene and Pliocene formations [2, 11] from upper Burdigalian to Romanian deposits. They are developed in a detritic facies forming an alternation of pellitic (shales, marls) and arenitic (sands, sandstones) deposits.As is shown in the figure below its structural arrangement is an anticline oriented West- East formed by sarmatian to upper Pliocene deposits overlying an unconformity situated on the top of middle miocene deposits (Badenian – Upper Burdigalian). These deposits are regionally called, in the oilfield, “Helvetian” formation.Initially the position of “helvetian” deposits was assumed to be also an anticline having mainly the same orientation.

Initially the position of “helvetian” deposits was assumed to be also an anticline having mainly the same orientation as the Pliocene one. The reservoirs encountered below the unconformity had a random behavior not correlating both as production data and as water flood response.

For this reason the new drilled well marched on the section as *DIP,* Was completely investigated the logs menu containing also a dip meter type investigation (CMI – Compact Micro Imager).

For geological interpretation of dip meter data we separated on the arrow plot more zones having different patterns as is shown in the fig. 5.

So until the 1562 m depth a green model is present (in the figure are only a few meters but this model is obvious for the entire sedimentary column of upper Miocene (Sarmatian, Meotian) and Pliocene formations representing the regional dip about 5 – 10 degrees towards North.

The interval 1562 – 1582 representing basal sarmatian deposits emphasize for the first meters 1562 – 1572 a red model corresponding to the layered strata sedimentated on the unconformity zone[9,10, 6], with decreasing upward dipping and the 1572 – 1582 m represents the initial transgreding coarse and mixed sequence, with a random distribution (yellow pattern), from the beginning of sedimentary process above the discordance.

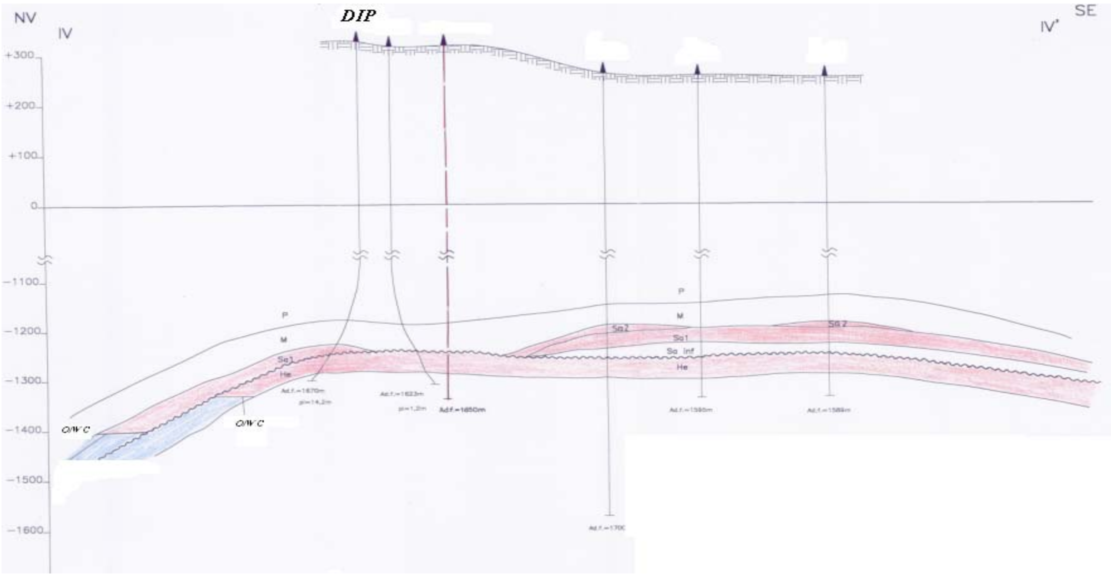


Fig. 3. Initial image of structural arrangement

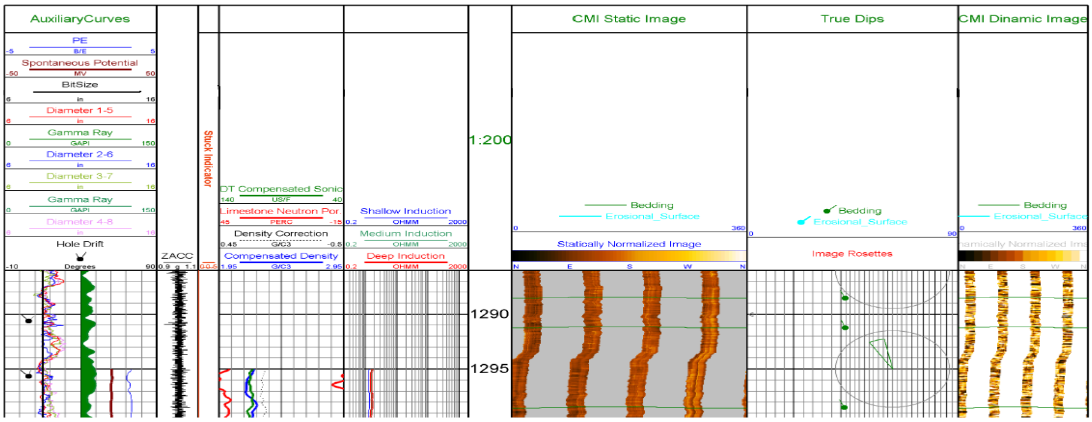


Fig. 4. Main curves recorded in the well

Below the yellow model is present an important brake to a second green model, with the same azimuth but with a dip about 45 – 50 degrees representing the “Helvetian” monocline. This is confirmed also by the water flood processes results when an injection done in the nearby well had no effect to the others because they were perforated in different reservoirs even if they are at the same isobathic level.

In the main green pattern of the “helvetian” deposits we encountered also second order alternating red / blue patterns related with the rhythmic supply of sediments and the existence of some braided channels. Also the lithological curves suggest that these intervals have a higher porosity (sand/sandstone deposits).

The new image of the structure (fig. 6.) permitted to explain the reservoirs behavior and improve water flood processes bz detecting the real fluids paths.

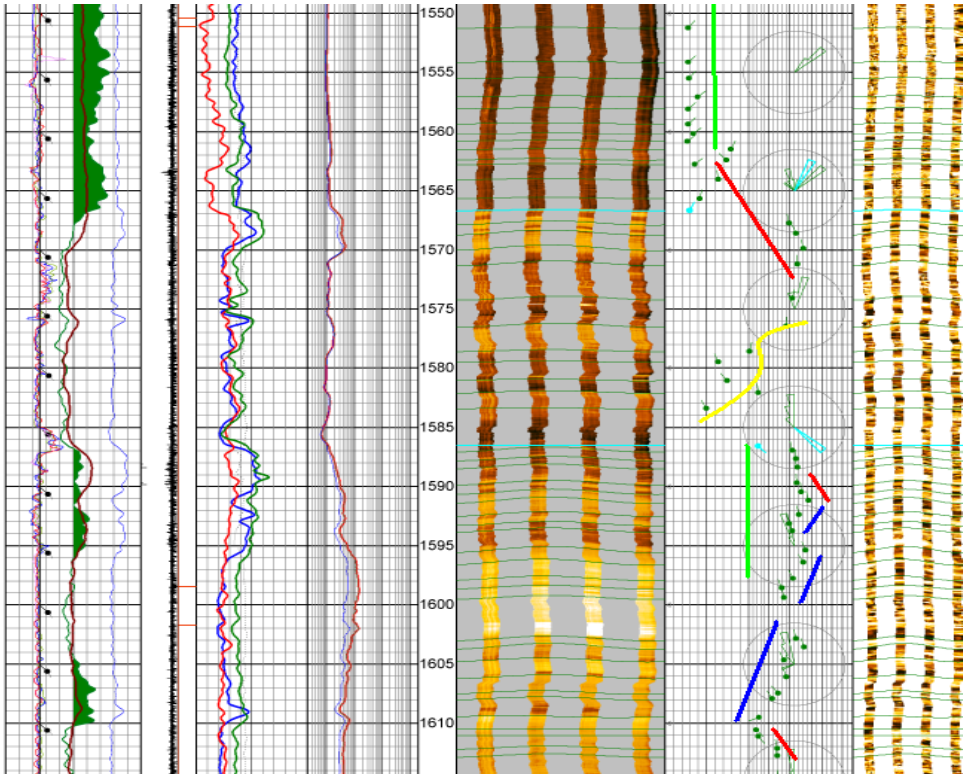


Fig. 5. DIP well log data interpretation

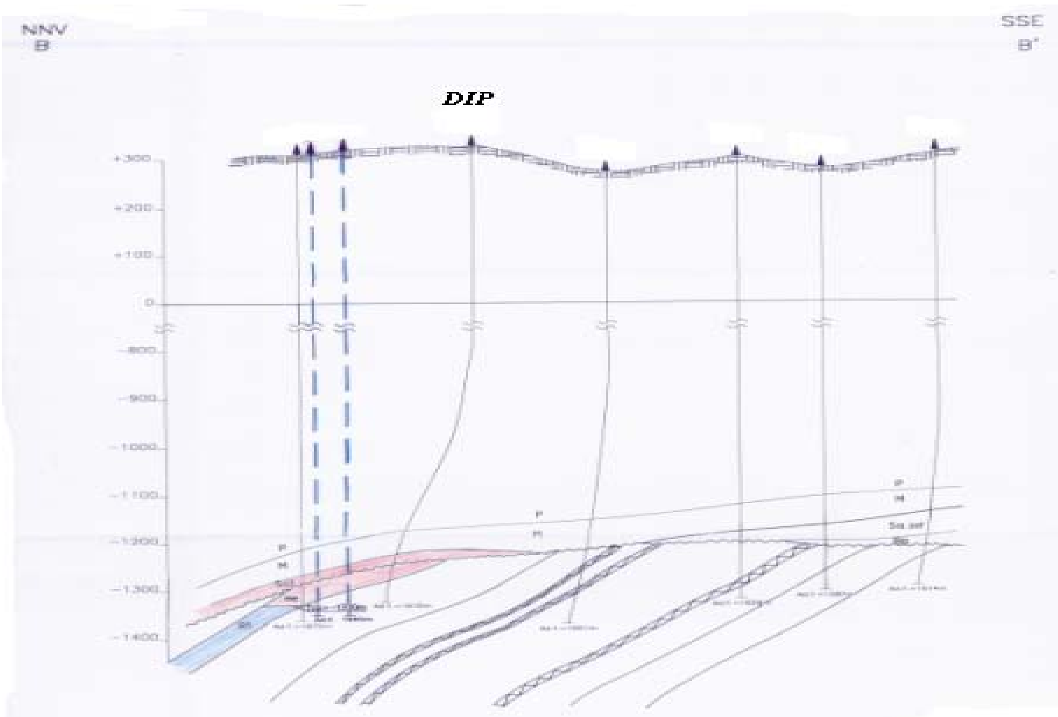


Fig. 6. Corrected geological model (after dip meter data interpretation)

Conclusions

Although is known and applied more than 50 years dip meter is relative rarely used for geological complex interpretation?

Displayed in different ways their data provide more information regarding structural, stratigraphical and sedimentary features of structure and reservoir.

Grouped in the so called color code models (patterns) recorded data have distinct and significant geological correspondents which able us to perform a better structure modeling and also provide clues for the existing sedimentary structures into the main geological units (layers).

The few models represented in the present paper are only some of the most usual ones meet in the geological structural arrangement and they may have a high variety of shapes, values and combinations. In order to perform a good geological interpretation is essential to have a good knowledge of the geological background of the zone/structure.

The worked example emphasizes the initial misinterpretation of filed data and the significant improvement provided by the dip meter data interpretation.

Running dip meter logs in the well even is a complex and difficult task (reported to borehole conditions) provide, sometime essential clues for a better geological interpretation of the studied structure /reservoir.

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Folosirea diagrafiilor de pandajmetrie în studiile structurale şi sedimentologice

Rezumat

Interpretarea diagrafiilor de pandajmetrie reprezintă un important instrument pentru caracterizarea aranjamentului spaţial şiidentificarea structurilor sedimentare şi tectonice ae formatiunilor geologice.Datele de pandajmetrie pot fi grupate in modele distincte, representative, considerate corespondentul geofizic al al poziţiei stratelor şi care pot evidenţia importante trasaturi structurale ale acestora ca falii, discordanţe stratigrafice, etc .De asemenea modelele de ordinal doi, cu o extindere mai redusa, sunt efectul sunt efectul existenţei structurilor (secvenţelor) sedimentare ce se individualizează in cadrul formaţiunilor studiate. Studiul de caz prezentat in aceasta lucrare, bazat pe date reale, arată cum datele de pandajmetrie pot clarifica modelul structural al unei structuri petrolifere prin evidenţierea modelului structural-sedimentar, interpretare ce modifică modelul geologic al rezervoarelor de hidrocarduri putând explica în acest mod comportamentul sondelor în exploatare şe ceră premisele modelării corecte a proceselor de factor (EOR) respectiv exploaterea optimă a zăcămintului.