GEOFIZYKA TORUŃ

DIPMETER MEASUREMENTS, HISTORICAL DATES, DIPMETER TYPES, PROCEDURES, METHODS OF INTERPRETATION

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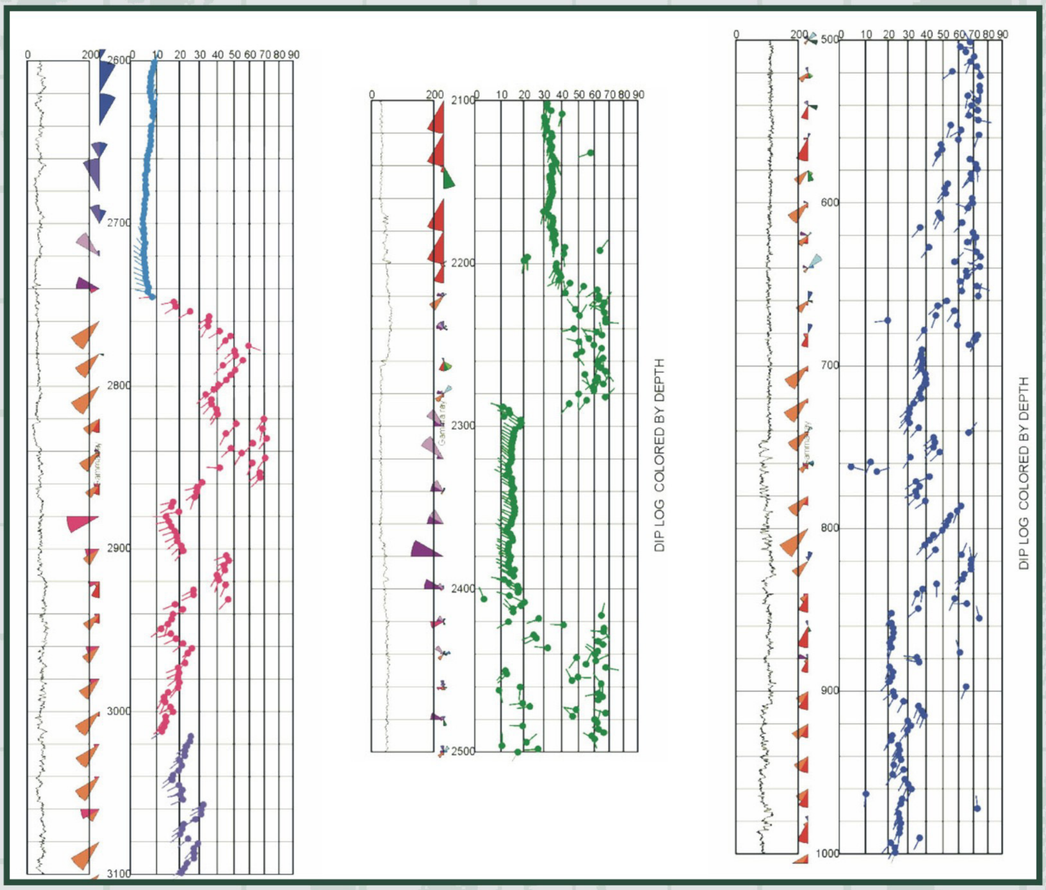

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Well Log Analysis Centre

DIPMETER MEASUREMENTS,

HISTORICAL DATES, DIPMETER TYPES,

PROCEDURES, METHODS

OF INTERPRETATION

by

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HISTORICAL DATES

The dipmeter methods had been employed for 60 years by 2002. The most important dates in their evolution are given below:

- 1942 - the 1st 3-arm dipmeter (a perimeter) used to continuous recording of spontaneous potentials (SP);
- 1943 – the 3-arm dipmeter (with a photoclinometer) measurements of spontaneous potentials (SP);
- Doll H.G. published the principles of the 3-arm dipmeter operation;
- 1947 – the 3-arm dipmeter continuous micro-resistivity measurements;
- 1952 – the industrial application of the dipmeter microresistivity; measurements;
- 1953 – De Chambrier P. published the principles of the 3-arm dipmeter micro-resistivity measurements;
- 1955 - the 1st 3-arm dipmeter continuous microlaterolog;
- 1967 – the 4-arm dipmeter microlaterolog;
- 1969 – a new generation of 4-arm dipmeters for continuous microlaterolog;
- the 70-ties – the implementation of automatic correlation procedures;
- since 1985 – the industrial application of the single and double 6-arm dipmeters and development of calculation procedures;
- since 1991 – the development of pre-interpretation and semi-interpretation procedures.

APPLICATION OF DIPMETER MEASUREMENTS

The dipmeter measurements provide information related to [1 – 44]:

- formational geology; it allows to determine micro-horizons as well as collector and non-collector horizons, direction of geological parameter changes, saturation of the reservoirr horizons with hydrocarbons and formation water, diagenetic changes in deposits;
- sedimentology; it includes determination of the deposits genesis and environment, geometry of sandy, clayey and some carbonate bodies, type of lamination, direction of parameter changes, linear/arrow and point inclusions (porosity, sand and clay content, lithology and thickness), deposit transport direction, approximate direction of paleo-shores during deposition;
- structural geology; it enables the determination of the formational or seismic structure, components of rocks which have been changed thermally, calculation of structural dip angle and azimuth;
- tectonics; it allows to determine the post-depositional dip of each complex, type and direction of faults as well as near-fault and fault zones, unconformities and discontinuities, folds, breakouts and fracture zones;
- regional structure, in order to determine the regional situation of the above mentioned parameters, direction of dip or rise of the interpreted lithophysical unit foundation, boundaries of lithophysical units (lithostratigraphic units) of different order.

The structural and stratigraphic interpretation of dipmeter measurements should be tightly connected with composite interpretation of geophysical logging. It is often difficult to obtain the above information from the other, particularly geological sources. The results of the interpretation often provide information which facilitates elaboration of a new structural conception of the studied region, which allows to control the geological exploration and, from the economical point of view, reduces costs and increases the exploration effectiveness. Obviously, the determination of the earlier mentioned parameters is not always possible. The range of interpretation also depends on time being at disposal and most of all, on specific geological information contained in the rock formation.

DIPMETERS

The following dipmeters have been applied by now [1 – 44]:

- 3 directional measurements of the rock anisotropy (not applied for a long time),
- 3 directional measurements of spontaneous potentials (not applied now),
- 3 or 4 directional measurements of micro-resistivity (not applied now),
- 4 or 6 directional microlaterologs,
- single or double, 4 or 6 directional micro-conductivity logs,
- 6 directional micro-acoustic logs.

For more than 10 years the 6-arm dipmeters have been most often applied in the world.

GEOLOGICAL BASIS OF INTERPRETATION

The geological interpretation of geophysical logs and dipmeter measurements can be carried out on condition that there is a distinct layering and contrasts in each sedimentary complex. It is synonymous with a change of petrophysical parameters of the rock. From a point of view of geological interpretation it means, that within sedimentary complexes should exist numerous lithofacial units and planes of different order and genesis. To facilitate considerations, the lithofacial units are replaced by surfaces or simplified (mathematical) lithological planes. At present stage of well logging it is a necessary assumption. Taking into consideration the genesis and thereby the type of geological information, the lithophysical planes can be divided into 3 basic groups containing tectonic, structural and sedimentary information. It seems, that the above division is impossible, because the lithological, structural, sedimentary and even tectonic information is always mixed, but in fact, it is possible and even necessary at the stage of interpretation work. So, the profile of each borehole, both represented by cores and petrophysical parameters is a set of coded structural, stratigraphic (sedimentological), tectonic and formational information in macro-, medium- and micro-scale.

In order to use geophysical logs for structural and sedimentological purposes it is necessary to know the general geological principles, problems and processes as well as their relations to all measured petrophysical parameters. In other words, we need to know:

- a character of particular geological processes and problems contained not only in each geophysical (petrophysical) log, but in setting of logs as well,
- universal theoretical relations between petrophysical parameters,
- empirical relations between selected petrophysical parameters established for a given region,
- relations between geophysical logs and geological problems,
- relations between dips and particular geological phenomena,
- relations between resistivity and acoustic imaging and microimaging and particular geological problems and phenomena.

It results from the analysis of basic processes and geological problems, that in most cases they may be determined by:

- numerical values of petrophysical parameters,
- characteristic shape (image) of recorded curves,
- anomalous indications of at least one petrophysical parameter,
- characteristic trends of petrophysical parameters variability with depth in horizons of identical lithology and/or the same genesis,
- characteristic dips (dip patterns and their azimuths),
- functional relations between particular petrophysical parameters,
- images of microacoustic parameters,
- images of micro-resistivity,
- images of other petrophysical parameters.

SEARCHING PARAMETERS

In order to decode automatically the geological information contained in primary dipmeter measurements it is necessary to choose suitable searching parameters: length, step and angle or length, step and window. The choice depends on a type and scale of studied geological features and on calculation procedures. But before processing the geophysicist has no information on the scale of geological features. Besides, the measurement interval is rather often a sum of several units of different genesis and internal structure (geometry), or it is a part of one such unit. Because of that, the choice of parameters is an intended or not intended filtration of geological information and we can say, that the searching parameters are the parameters of searching of real geological information contained in the coded micro-resistivity records. It is related with the basic aim of the interpretation and its particular stages.

On the one hand (from a geological point of view), each profile is a mixture of the structural, sedimentological and formational information in a macro-, medium- and micro-scale and, on the other hand (from a well logging point of view), it is a sum of mathematical planes and lithofacial units of different order, thus, it is impossible to fit one set of searching parameters to the studied interval (there are also point and linear/arrow inclusions, that are generally not taken into account by algorithms but are clearly visible on the inter-point plots). It is a reason of the application of 2 – 3 sets of searching parameters at the 1st stage. Such a procedure enables the transformation of the micro-resistivity curves into vectorial records and then, more detailed analysis of particular genetic units.

The length of searching can vary even from a dozen or so meters to several centimeters. The step is usually 1/3 – 1/2 of the correlation length, but the angle depends on angles occurring in the profile – usually in the 1st stage of the processing it ranges from of 35^0 to 55^0. Thus, the choice of parameters is difficult and labour-consuming and because of that the above problem should be discussed separately.

METHODOLOGICAL BASIS OF GEOLOGICAL INTERPRETATION

Methods of dipmeter data interpretation

Generally, 4 methods of geological interpretation of the dipmeter data are employed:

- so-called “express” method,
- quantitative method,

- stereographic projection,
- micro-geometric analysis.

As a rule, each of these methods uses different calculation procedures and partly different plots for a graphic presentation of the results.

In case of faults and/or folds in the studied borehole profile it is necessary to apply 2 – 3 interpretation methods simultaneously. The interpretation results are presented on several plots, related and not related to depth. If we are interested in the sedimentary structures, the quantitative method allows to make the profile analysis, however, the micro-geometric method allows to show it in details. In such a case, the results of the interpretation should be presented on several or more plots, both related and not related to depth, in a vertical scale of different minuteness of detail.

In the ***"express" method*** the images of particular phenomena and geological processes are recognized on vectorial plots. It should be noted, that we have to do with the apparent dips at this stage of the interpretation. It allows to identify quickly main structural/tectonic features just after geophysical measurements. We use the analysis of vectorial plots based on the SHIVA procedure. It allows to include the dipmeter measurements in a set of standard geophysical logs. This method was early applied by Schlumberger, Baker Atlas and HLS.

The **quantitative method** uses the techniques (statistical curvature, residual dip and synthetic dip deviation analyses), which have been worked out and implemented by Bengtson C.A. [2, 3], Berg Ch. R. [4 - 7] and Hurley N.F. [24]. This is a more analytical method than the previous one and less complicated and labour-consuming than the stereographic projection method. It uses the vectorial, angular and azimuthal plots, transversal and longitudinal dip components, intersection of planes at any azimuth or along the borehole, cylindrical and polar plots, dip versus azimuth plots and others (including SCAT, SODA and DAPSA type plots). The method takes into account the structural dip effect and thus, it enables calculation of true dips (or residual dips) and determination of their components. Its qualities (particularly the graphic effect) allow to use it during interpretation work and in this case, the procedures like DIPROT and RDA should be employed.

The stereographic projection method enables the analysis of dip images in details. The structural phenomena can be presented by means of the stereographic nets of diferent type, which are sometimes called stereographs or polar plots. Contingently upon the projection type (stereographic, reversed stereographic, orthographic, Vulff, Schmidt, modified Schmidt, tangential, Dimitrijevic or Kalsbeek projection) numerous types of polar plots are used. According to Henry J. "*stereographic projection is a presentation and geometrical construction, which allows to analyze the orientation of tectonic elements in space, independently of their geographic positions"* [15, 38].

Thus, it is a very precise method, but requires a lot of time and use of digital techniques. It should be employed for the detailed interpretation work. The stereographic projection allows to move various structural elements (lines and planes) while keeping them parallel to each other so that they touch or intersect the top of corresponding hemisphere, leaving a trace on a horizontal plane. This plane contains the N-S axis. The intersections of the lines and planes with the hemisphere can be stereographically projected onto a horizontal plane in relation to the South or North Pole on the whole sphere. The inversion which has occurred, is a geometrical transformation, which preserves the dip angles but looses all information on the geographic position of structural elements. Such a procedure is useful, when the strike and dip of the surface or line can be represented as a single point. Then, the angular relationships of a large number of planes can be analyzed. This method is even necessary for determination of folds and very helpful in identification of numerous faults. The RDA procedure can be used to perform some tasks.

The ***micro-geometrical analysis*** makes it possible to determine the sedimentary and post-sedimentary, micro- and meso-structures (continuous, point and linear) based on the microlaterolog corelation. It allows to plot the interpoint graph (the representation of the true spatial image on a plane) and/or a type of the cylindrical plot (the imitation of the spatial plot on a plane). The above tasks can be carried out by means of the following procedures: CSB, DIPMETER ADVISOR, EZDIP, GAODIP, LOCDIP, MSD, STRATADIP and (partly) RESMAP. The method is rather often employed for the analysis of thin beds, micro-resistivity maps of the borehole wall, oriented micro-laterolog and oriented indications of micro-caliper logs [32].

Methods of interpretation of dipmeter data

To prepare the primary measurements or processing results for interpretation it is necessary to apply suitable techniques of their analysis. At present, the following techniques of the analysis are known (they will be discussed below) [12, 15, 19, 25, 26, 32, 38, 39, 43, 44]:

- recognition of images (CLUSTER, CORDIP, CSB, CYBERDIP, DIPINT, DIPLOG, EZDIP, GEODIP, LAC, LOCDIP, MSD, NEXUS/GEO, OMNI, PRODIP, RGDIP1, SHIVA, STRATADIP and STRATAGON procedures),
- statistical analysis of the curvature (DIPMETER ADVISOR, DipMeter 1.0 and RDA – SCAT procedures),
- analysis of residual dips (RDA procedure),
- analysis of the dip synthetic deviation (GEOFRAME, INCLINE II and RDA – SYNDEV procedures),
- analysis of micro-resistivity maps of borehole walls (FACIOLOG, GEOFRAME, INCLINE II, LOCDIP, RESMAP and STRATIM procedures),
- analysis from “the observer position” (GEOFRAME and INCLINE II procedures),
- analysis of the oriented microresistivity curves (FIL and ORATOR procedures),
- analysis of the oriented microcaliper logs,
- analysis of the non-oriented microresistivity curves (FRACTURE LOG procedure),
- analysis of the oriented or non-oriented microresistivity indications (EzDip, DIPMETER ADVISOR, GEODIP, LOCDIP, MSD, STRATADIP).

The above analyses are successively presented below.

The recognition of images is an oldest method of the dip image analysis. It uses traditional vectorial plots obtained from the application of specific calculation procedures, e.g. SHIVA or OMNI. The principles of the method were described for the 1st time by Gilreath J.A. and Maricelli J.J. [16) in 1964.

The Shiva procedure is based on the assumption, that all geologic surfaces can be replaced by planes (simple mathematical geological surfaces). Each point of intersection of such geological mathematical surface with each vertical plane can be described in a spatial polar coordinate system by 3 coordinates (depth of intersection, dip angle and dip azimuth). Such a point complies with the requirements related to vectors and thus, it can be recorded as a dip vector (it is still a "mathematical" dip = apparent dip). If there are several parallel mathematical geological planes in the vertical profile, their intersections with each vertical plane are most often visible as a pattern of increasing or decreasing dips (inclined planes) or as a point record (plane surfaces). Obviously, it is the approximation of variable accuracy, but it allowed to construct the vectorial image of dips for particular models of structural phenomena (angular unconformities, faults, folds) as well as some processes and sedimentological phenomena in a macro-scale [32]. The basic form of the graphical representation of the processing results are various vectorial plots.

The OMNI procedure is based on the assumption, that in each sedimentary profile there are geological surfaces of different and variable degree of complexity. As the dipmeter measurements do not indicate precisely the spatial position of geological planes, they can be approximated only by mathematical planes (4 types). In this case, the intersections of mathematical geological surfaces with each vertical plane can be shown as 1 – 5 dips at the same depth, often differing in values (several vectors). The dip pattern does not make sense here and looses its meaning (not in the case of true geological planes) and becomes a spatial image of dips. Obviously, it is still the approximation, but allows to construct a set of vectorial dip images for particular models of structural phenomena (angular unconformities, faults and folds) and a lot of sedimentological processes in a macro- and medium-scale [23 – 33]. The basic form of the graphical representation of the processing results are multi-vectorial plots (standard presentation of several dips at the same depth).

The statistical curvature analysis (SCAT) is a convenient tool of structural interpretation of dipmeter measurements. Changes of the dip as a function of the dip azimuth are connected with a volumetric curvature of the geological feature. The volumetric curvature as well as longitudinal and transversal structural directions of each borehole position can usually be determined by the statistical analysis of the dipmeter data curvature. The volumetric curvature can be determined by one of four categories: planar, single curvature, inverse immersion and volumetric curvature of the dome fold. The statistical curvature analysis as well as the longitudinal and transversal directions give the possibility to determine true structural dips from erratic and sometimes not very clear dipmeter data. It also enables the determination of the strike and the fold crest and axis immersion directions. The above possibilities are usually applied to draw the partial maps and sections based on well data. The analysis is very important for structural interpretation of dip images [6, 7].

The residual dip analysis [4, 5] is a faster and more effective method of the dip images interpretation than the other, traditional methods. It is based on a removal of structural dip effects on the total dip image. As a result, the image of residual dips can be obtained. The removal of the structural dip is connected with rotation of "other" dips, but the dip plane is horizontal. Although the dip rotation is often used to remove the structural dip effect on sedimentary dips (e.g. cross bedding), its help in the structural interpretation is not widely known. When the fault dip direction is different than that of the structural dip, the characteristic drag pattern of the fault plane increasing dips may have a scattered form on a typical vectorial plot. The removal of the structural dip effect from the total dips can restore the "theoretical" dip patterns and facilitate opinions about geological informativity of particular dip patterns. The vectorial plot containing residual dips is called a residual dip plot. The polar plots, that practically have been carried out both for not rotated dips and residual dips, allow to make a detailed analysis of dip patterns. One of the characteristic features of folds, including isoclinal folds, are their co-planar dips. It means, that they should be situated on a large circle of the polar diagram (sometimes called a large circle technique) containing non-rotated dips. On the polar diagram of residual dips the large circle represents vertical planes which become straight lines. After removal of the structural dip effects the plane perpendicular to this plane determines the fold axis. In case of isoclinal folds, the axis is parallel to intersection of the fault plane.

The complementary and unusually informative method of the residual dip analysis are various plots of the SCAT type, fold axis plots, dip "rose" plots and various types of stick-plots. It is possible to cope with all these tasks by means of DIPROT and RDA procedures. They allow to remove the structural dip effect and besides, the RDA procedure makes it possible to construct almost all plot types.

The dip synthetic deviation analysis is a continuation of the residual dip analysis. The synthetic deviation plot is based on the assumption, that a dip is a borehole deviation (the dip azimuth is replaced by the borehole azimuth and the dip angle used instead of the borehole inclination). An easy method of synthetic deviation visualization is based on the assumption, that the borehole is always perpendicular to bedding. The synthetic deviation is considered here compatible with bedding surfaces, which usually are employed for the graphical or mathematical representation of dips. The synthetic plots can enhance subtle geological features, as small faults, angular unconformities and boundaries of sedimentary sequences, apparently not visible on standard vectorial plots or combined displays. The "imagined" borehole can be shown on the plots just as in case of the borehole deviation. The results are presented in a form of numerous synthetic plots. The method is particularly useful for the structural interpretation of dip images. The plots of the synthetic deviation extend and unify the abilities of combined displays (combined dips) and fill up the gap between combined and vectorial plots as well as between dip angles and azimuths, taking advantage of 3-dimensional character of the dips [6, 7].

The analysis of micro-resistivity maps of the borehole walls uses cylindrical micro-resistivity maps of the borehole walls, which are the result of the horizontal and vertical interpolation between microlaterologs. As the logs are "hanged" in the space 60^0 apart on the cylinder surface, the interpolation is carried out on that surface. Such an approach is connected with the conception of lithofacial planes, which leave the traces of their intersection with the cylinder surface (fault planes, folds, unconformity surfaces). After spreading such a cylinder on a plane the edges should be in a form of a line and/or sinusoid. However, it is not always like this, because a simple interpolation between successive resistivity logs causes the equalization of resistivity an thus, obliteration of not very distinct geological features. Besides, the same resistivity images can be created by different geological phenomena. In such a case, more sophisticated algorithms should be applied which give the possibility to recognize the model indications of at least a part of geological features. It is the imitation of the resistivity imaging but should not replace it, if the imaging or microimaging method is used. The procedures: FACIOLOG, GEOFRAME, INCLINE II, RESMAP and STRATIM [12, 15, 19, 32, 38, 39, 44] make it possible to draw the above maps.

The analysis from the "observer position" allows to situate the active observer or interpreter in the position with the best "view" in relation to the analyzed problem or geological phenomenon (most often it is a fault, fold or angular unconformity). It should be changed many times during interpretation in order to choose the best position to observe the desired segment of the borehole profile. The above task can be fulfilled by the use of diverse calculation and interpretation procedures and methods (e.g. GEOFRAME procedure). The experienced interpreter is also required as well as the knowledge of the regional geological feature and/or conditions of deposition. But the interpretation techniques and programs used up to now are very modest and can not replace the imagination, knowledge and experience of the interpreter (or petrophysicist) [38, 39].

The analysis of the oriented micro-resistivity curves helps to determine the fractured zones and major fractures which intersect the borehole. The conception is similar to that of determination of litophacial planes. The fracture which intersects the cylinder imitating a borehole has to be detected by microlaterologs, unless its filling is the same as surrounding rocks (lack of the resistivity contrast). The principle is very simple, because it consists in superimposing the nearest oriented resistivity curves (creation of 6 pairs of curves) and observing the (positive or negative) changes of the resistivity, thickness of local resistivity anomalies and direction of those changes. It should be noticed, that the resistivity changes are caused not only by fractures (the narrow anomalies usually visible on 3 – 4 sets of the resistivity curves), but by various lithological changes as well (point lithological changes visible on 1 – 2 sets of the resistivity curves, linear lithological changes noticeable on 2 – 3 sets of the resistivity curves). When studying the micro-resistivity curves it is necessary to separate the effect of lithological changes from he effect of fractures. The special procedures, like DCA and ORATOR and the calculation moduli, being a part of FACIOLOG and GEOFRAME procedures, are employed for this purpose.

The analysis of the oriented micro-caliper logs makes it possible to determine the breakouts. The conception of this method is like the previous one. The breakouts usually cause the characteristic, oriented interval chipping of the borehole wall rocks. They are recorded by the dipmeter arms (both micro-resistivity tools and profilometers) as the changes of the borehole diameter. The dipmeter arms measure the directional physical parameters, thus the recorded changes of the diameter are directional (spatially oriented). The results of the analysis can be presented on the cylindrical (3-D projection), spread cylindrical (2-D projection) and oriented diameter diagrams (2-D projection) or borehole diameter maps (pseudo-projection 3-D).

The analysis of the non-oriented micro-resistivity curves allows to determine the fracture zones and major fractures, which intersect the borehole. The conception is similar to that of litophacial planes. The fracture intersecting the cylinder, which imitates the borehole has to be detected by the micro-laterologs, unless it is filled with the same lithology as the surrounding rocks (lack of the resistivity contrast). The method was generally applied to measurements which had been taken by the 4-arm dipmeter. The principle of the method is very simple, because it consists in superimposing of the nearest micro-resistivity curves (creation of 4 pairs of the micro-resistivity curves) and observing the (positive or negative) resistivity changes as well as the thickness of local resistivity anomalies. The changes in the resistivity image are caused not only by fractures (the narrow anomalies usually visible on 2 – 3 sets of micro-resistivity curves) but also by various lithological changes, noticeable on 1 – 2 sets of the micro-resistivity curves. When studying the micro-resistivity curves it is necessary to separate the effect of lithological changes from the changes caused by fractures. A considerable limitation of the method is impossibility to determine spatially the fractures and lithological changes. For many years the special procedures like Fracture Log and Fracture Identification Log (FIL) have been employed for this purpose but after introduction of the 6-arm dipmeters they are rarely used now.

The analysis of the oriented or non-oriented micro-resistivity indications is based on searching and correlation of similar resistivity changes by means of the following micro-laterolog sets: 6, 2 x 6, 8 or 2 x 8. The boundaries determined this way may be related to

- continuous micro-geometric boundaries, visible on all micro-resistivity curves; they most often correspond to the boundaries of beds, thin beds, bedding and lamination as well as fractures which intersect vertically or almost vertically the borehole axis,
- non-continuous micro-geometric boundaries, visible on several micro-resistivity curves, most often corresponding to the boundary of point and/or linear lithological inclusions, small fractures, conchoidal fractures, etc.

There are the following commonly known calculation procedures: EzDip, DIPMETER, ADVISOR, GEODIP, LOCDIP, MSD, STRATADIP. The correlation results are presented on the non-oriented inter-point diagrams and/or on the spread, and oriented cylindrical plots.

CALCULATION PROCEDURES / SOFTWARE

The most known and most often applied are the calculation procedures of primary dipmeter measurements SED-4 and SED-6 (the basic application and predominant graphical presentation is given in parentheses) [32]:

- CLUSTER and CORDIP - standard procedures of correlation of 4 X MSL characterized by moderate vertical resolution (determination of lithofacial planes, identification of sedimentary environment and structures, vectorial plots);
- CSB – a continuous processing with a good quality correlation for 3 cm distance between indications of two button electrodes situated on the same dipmeter arm and measuring 2 x 4 x MSL (inter-electrode and/or inter-point correlation, determination of litofacial planes, identification of sedimentary environment and structures and lithofacial/electro-facial formation, combined two-resistivity plot, two-vectorial plot);
- CYBERDIP – a standard correlation of 4 x MSL and 2 x 4 x MSL logs of a high vertical resolution (determination of lithofacial planes, recognition of sedimentary structures and environments, vectorial plots);
- DIPINT – a statistical procedure of a high vertical resolution applied to the dip calculation (determination of lithofacial planes, recognition of sedimentary structures, vectorial plots);
- DIPLOG – a standard correlation of 4 x MSL logs of moderate vertical resolution (removal of the structural and/or regional dip effect and/or post-tectonic dip, determination of lithofacial planes, identification of sedimentary environments, vectorial plots);
- DIPMETER ADVISOR – an interactive system, which allows to correlate 4 x MSL and 6 x MSL logs (application of standard geophysical logs, determination of methematical surfaces and lithophysical planes, identification of sedimentary environments and structures, vectorial + inter-point + stick-plots and others, related or not related to depth).;
- GEOPDIP – a method of recognition of images, high-resolution technique of correlation of 4 x MSL logs (precise examination of sedimentary formations, recognition of sedimentary structures, inter-point correlation, determination of lithofacial planes, vectorial + inter-point plots);
- LAC – a correlation technique, which is similar to that applied in the PRODIP program, but enables more elastic changes of searching parameters (destined for the processing in the interpretation center);
- LOCDIP – an inter-point technique of correlation of a high vertical resolution, applied to 2 x 4 x MSL, based on similar rules as the GEODIP procedure

(determination of lithofacial planes, identification of sedimentary environments and structures, vectorial + inter-point plots + micro-resistivity map);

- MSD – an inter-point technique of correlation of a high vertical resolution, applied to 2 x 4 x MSL, similar to that of CLUSTER procedure (determination of lithofacial planes, vectorial + inter-point plots);
- NEXUS/GEO – a standard technique of correlation of moderate vertical resolution, applied to 4 x MSL (identification of sedimentary environments and basic structures, removal of the structural and/or regional dip effect and/or post-tectonic dip, determination of lithofacial planes, vectorial + stick-plots and others, not related to depth);
- PRODIP – a procedure linking the features of DIPLOG and STRATADIP programs (a set of constant searching parameters, usually applied at the stage of the “express” type processing, which is carried out in recording stations just after measurements);
- RGDIP1 – a standard correlation technique of a high vertical resolving power, applied to 4 x MSL in the small-diameter boreholes (determination of litofacial planes);
- STATADIP - an inter-point correlation technique of a higher vertical resolution, applied to 4 x MSL (determination of lithofacial planes, identification of sedimentary environments and structures, vectorial + inter-point plots);
- STRATAGON – a standard correlation technique of a high vertical resolution (the interpretation procedure at the1st stage of the dipmeter measurement processing, removal of the structural and/or regional dip and post-tectonic dip effects, vectorial plots);
- STRATIM - presentation of the micro-resistivity map of the borehole wall rock (vertical and horizontal interpolation), based on 2 x 4 x MSL as well as calculation programs/procedures of GEOFIZYKA Toruń;
- SHIVA 4 and 6 – a standard technique of correlation of a very high vertical resolving power, applied to 4 x MSL and 6 x MSL logs, permitting identification of sedimentary environments, precise examination of the formation internal structure, recognition of sedimentary structures and determination of lithofacial planes;
- DIPROT: a standard calculation technique, which allows to remove the structural and/or regional and post-tectonic dip effects (the 2nd stage of processing, after application of the SHIVA 4 or SHIVA 6 or equivalent program);
- OMNIDIP- a correlation technique of a very high vertical resolution, applied to 6 x MSL; it allows to study precisely the sili-clastic formation, recognize sedimentary structures and determine mathematical lithophysical surfaces;
- ORATOR – a technique of presentation of the oriented micro-resistivity; it allows to determine the fractured zones and location of oriented fractures;
- RESMAP – a unique method of presentation of the micro-resistivity map of the borehole wall rocks, based on 6 x MSL logs and characterized by a high vertical resolution (horizontal and vertical interpolation – micro-resistivity images); it allows to determine some sedimentary structures.

INTERPRETATION PROCEDURES / SOFTWARE

In consideration of complicated and variable internal formation the automatic, universal system of dipmeter measurement interpretation does not exist (and probably will not exist for a long time). The main constructional problem of such a system will consist in the “dimension incompatibility”. The geological phenomena are spatial (3-D), but the dipmeter measures the geological data in two dimensions. In case of complicated geological formations it can lead to many versions of the solution. However, for some time the special procedures (e.g. “expert” type) have existed. They are destined for the solution of selected sedimentological problems and graphical presentation of the interpretation results. These are the following procedures [4, 7, 27, 28, 32, 38, 39]:

- RDA – a procedure applied to the pre-interpretation, processing, elements of structural interpretation and graphical visualization (though destined mainly for the structural interpretation, it may be useful for the stratigraphic interpretation and pre-interpretation); it allows to use numerous plots related to depth in the following variants: the measured depth, vertical depth (corrected for the borehole deviation effect), vertical true thickness, true stratigraphic and expressed in a time-scale thickness as well as numerous plots, which are not related to depth (semi-interpretation procedure);
- EZDIP – a procedure applied to the processing and some elements of sedimentological interpretation and visualization of the interpretation results; it is based on the extended system of multiple correlation of a very high vertical resolving power, applied to 4 x Post, 2 x 4 MSL and 6 x MSL; it allows to study precisely the sedimentary (especially sili-clastic) formations, recognize sedimentary structures, lithofacial/electrofacial formation and deposit genesis, remove of the structural and/or regional and post-tectonic dip effects; it also enables the modeling of dip images and determination of lithophysical planes; the results are presented on a combined plot, which comprises the vectorial and inter-point plots (pre-interpretation procedure).

Besides, the oil and geological companies apply the following procedures:

- DIPMETER ADVISOR – an “expert” type structural interpretation, useful in part for stratigraphic interpretation (vectorial + inter-point + stick-plots);
- DipMeter 1.0 – a pre-interpretation program which allows to construct the cumulative, SCAT-type and vectorial plots;
- RGDIP2 – an interactive program of the composite interpretation of the dipmeter data processing results obtained from the RGDIP1 and BHTV procedures and coring data (identification of sedimentary structures and environment, construction of the vectorial plot + stick-plots);
- SYNDIP – a high vertical resolving power allows to study the sedimentary formations and recognize sedimentary structures (determination of planes and mathematical lithophysical surfaces, construction of plots related and not related to depth);

COMPOSITE INTERPRETATION OF GEOPHYSICAL LOGS AND DIPMETER MEASUREMENTS

For some time the work has been done on construction of a uniform, interactive system of formational, structural and sedimentological interpretation. For many reasons it is not easy, because such a multi-function system should [32]:

- take into account the application of standard and complementary geophysical logs differing from each other e.g. about a vertical resolution, penetration range and geological information,
- use the acoustic, micro-acoustic and micro-resistivity imaging and micro-imaging methods of variable range of penetration, different vertical resolutions and different sensitivity to particular geological information,

- have the possibility to use the pre-interpretation procedures,
- integrate photographs and results of the core laboratory tests (geological standardization),
- have a capacious library of functional relations and allow to make their suitable selection,
- contain a capacious library of petrophysical and lithofacial data as well as various theoretical and true tectonic and sedimentary structures,
- cooperate with the geological and petrophysical data base.

These are the reasons that few systems are known to satisfy the above requirements [12, 15, 19, 32, 38, 39, 44]:

- FACIOLOG – a very modern, elastic, interactive system of lithofacial and sedimentological interpretation (cross plots + combined plot of petrophysical parameters + vectorial plot + inter-point plot + facial geo-profile + volumetric profile of lithological model);
- GEOFRAME – an interactive and the most composite processing, pre-interpretation and interpretation system of the standard and complementary geophysical logs, SPA, imaging/micro-imaging methods and dipmeter measurements together with a capacious and effective petrophysical data base and numerous models of tectonic and structural phenomena and geological data; the system allows to carry out the formational, structural and sedimentological interpretation and presentation of the interpretation results both in a depth and time scales (cross plots + combined plot of petrophysical parameters + inter-point plot + facial geo-profile + volumetric profile of lithology + various plots related and not related to depth as well as the polar plots (diverse projections), azimuth frequency plot, histograms and other plots);
- INCLINE II – an interactive system destined for processing, pre-interpretation and interpretation of 4 x MSL, 2 x 4 MSL and 6 x MSL logs, based on the micro-acoustic and micro-resistivity imaging and photographs of cores, integrated with standard geophysical logs and results of formational interpretation (the determination of mathematical surfaces and lithophysical planes, removal of the structural and/or regional and/or post-tectonic dip effects, investigation of sedimentary formations, recognition of sedimentary structures, particularly in siliclastic deposits, construction of plots related and not related to depth, cooperation with the RECALL data base, IMAGE procedure and system of interpretation of standard geophysical logs PETROLOG; now the work is being done on its integration with a new interactive system of standard geophysical logs interpretation);
- RECALL – a very modern, interactive system which is linked with the data base containing the results of processing and interpretation (by the use of IMAGE, INCLINE II and PETROLOG procedures) as well as photographs and results of the core analysis; it allows to carry out the sedimentological interpretation within the structure/formation/region and depth-to-time transformation of the interpretation results (construction of the well petrophysical and inter-well correlation profiles).

Some oil companies have such systems for their use, the systems being a part of the capacious system of composite geological interpretation of geological and petrophysical data, including standard and complementary geophysical logs, dipmeter measurements as well as imaging and micro-imaging methods [32].

INFORMATION ON SEDIMENTOLOGICAL INTERPRETATION

The dipmeter data interpretation carried out in order to determine the type of sedimentary environment of a faulty section is not so easy but nevertheless possible. In selected parts of the profile a chaotic image of dips is a result of several factors: faults, diagenesis and deposition. Besides, such interpretation is a separate methodical and geological problem and should be a subject of a separate elaboration. At first, the effect of the post-tectonic dip, thrust and gaps in the section should be removed and then faults should be determined. Such a procedure allows to reconstruct the original sedimentary section. However, it should be noted, that this is still a "modified" profile of deposits which have been influenced by diagenetic processes (they could modify dips to some extent). In case of this type of interpretation we should have at our disposal:

- setting of standard geophysical logs (particularly GR, DRHO and SGR),
- results of the multi-component formational interpretation,
- setting of geophysical logs from several nearest wells (the dipmeter measurements in the nearest wells not only facilitates interpretation but increase its reliability as well). It is necessary to carry out simultaneously the lithophysical correlation, multi-component formational and structural interpretation of dipmeter data within the structure/collector. The results of the core analysis can also be helpful to some extent but most often the coring relates only to a small part of the profile. Thus, the results of coring are of importance for the interpretation of the lithofacial unit from which the cores have been taken. The substantial elements are the measuring interval, choice of processing parameters, method of visualization and methodological experience of the interpreter.

In order to make the sedimentological interpretation in a major part of the profile it is necessary:

- to finish the structural interpretation (to remove the effect of the post-tectonic dip and other above mentioned factors);
- to take into account the results of the formational interpretation;
- to carry out the lithofacial correlation between several nearest wells.

The analysis of the EZDIP, OMNI and RESMAP processing results proves existence of both mathematical and geological planes (i.e. surfaces approximated by equations in the 3-D space). In order to distinguish the plane type we should use several types of plots: the inter-point and vectorial plots as well as cylindrical resistivity maps. On the inter-point plots, apart from a simple correlation visible on 5 – 6 micro-resistivity logs there are numerous, variable correlations related to fractures and/or point or arrow lithological inclusions, because

- the fractures which intersect the well at a high angle can be visible on 1 – 3 micro-resistivity logs;
- the point lithological inclusions are most often noticeable on one micro-resistivity log;
- the arrow (oriented) lithological inclusions most often are on 1 – 2 micro-resistivity logs;
- the planes and surfaces of sedimentary genesis are most often visible on 4 – 6 micro-resistivity logs.

The continuous and half-closed surfaces are of sedimentary origin, however discontinuous and closed surfaces very often are of a diagenetic genesis. As in many cases the analysis of only inter-point plots can give ambiguous results, the vectorial plots should always be used. The role of the cylindrical micro-resistivity maps is complementary. The composite analysis of the vectorial and inter-point plots often enables proper identification of the geological surface type (continuous, discontinuous, half-closed and closed surfaces).

CONCLUSIONS

- The dipmeter measurements are a set of various geological data which are coded in a continuous or discontinuous microresistivity record; the processing and interpretation are to transform it into a record which approximates reality.
- At the beginning the apparent dips are obtained, separately for each set of searching parameters, as a result of application of basic calculation procedures and then, by the selection of suitable searching parameters and calculation/interpretation procedures the conversion from the apparent into real dips can be made (and only then we can it call the real dip logging).
- The dipmeter measurements make it possible to recognize the tectonic feature and give useful information on the deposition genesis and conditions.
- The possibility of any graphical presentation of the results allows to show distinctly various geological features.
- The presentation of the structural and sedimentological interpretation results of the dipmeter measurements in a time scale makes it possible to use the data during the seismic interpretation.
- Taking into account the structural and sedimentological informativity of the dipmeter measurements, they should always be a component of geophysical logging in those stratigraphic units, which are of economic prospects and also are interesting for seismic prospecting.

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