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Imaging Tools are Much More Than Super-dipmeters

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أجهزة التصوير الوصفي هي أكثر من أن تكون أجهزة قياس ميلان متطورة

أرنود إيتشيكوبر و إيلوي دياز

لقد تم تصميم أجهزة قياس ميلان الطبقات بحيث تعطي تحليلاً إحصائياً للميلان، وهي مهمة للحصول على معلومات بنيوية يُعوّل عليها داخل المكمن. غير أن هذه المعدات لا تعطينا وصفاً جيولوجياً واقعياً، وفي المقابل فإن أجهزة التصوير الوصفي التي استُحدثت في العقود الأخيرة مهدت الطريق لاعطاء معلومات حقيقية داخل البئر، فبواسطة الصور الفوقسمعية أو الكهربائية يمكن مشاهدة وتقييم التشققات والنسيج الصخري والبنية الترسيبية كما هو الحال في الصخور المتكشفة.

فبسبب هذه القدرة على المشاهدة المباشرة يمكن استغلال الطرق الجيولوجية المعتادة فمثلاً حساب الميلان التركيبي الفعلي يعتبر أكثر دقة من استخدام قياس الميلان البسيط، فعندما يتم فصل الميلان إلى مركباته الترسيبية والتركيبية فإنه يصبح بالإمكان إعادة تصميم أو إنشاء قطاع ترسيبي أو تركيبي بجوار البئر وكأنه قد تم من صخور متكشفة.

Abstract: *Dipmeter tools were designed to provide a statistical dip analysis. They were essential to obtain a reliable structural information inside the reservoir, but did not provide real geological description. On the contrary, the imaging tools developed during last decades provide the way to perform real geological observation down hole. On ultrasonic or electrical images, fractures, texture and sedimentary structures are directly observable, measurable and interpretable as on outcrop.*

Because of this direct observation capability, it is possible to take advantage of the standard geological methods. For example, the computation of the actual structural dip is much more accurate than from basic dipmeter. Once the dip has been split into its structural and sedimentary components it becomes possible to reconstruct structural or sedimentary cross-section in the vicinity of the well, as it would be done from an outcrop.

INTRODUCTION

Since dipmeter tools have been introduced in the field in the early fifties, geologists have extensively used them. Their main concern was to provide accurate structural dip in order to obtain consistent geological model at reservoir scale. However dip is not enough for an entire geological description. So many geologists attempted to extract sedimentological information, or fracture description from the dips and dipmeter curves. Many methods were proposed for such purpose. Some of them were successfully used in particular environments, however as long as the geologist cannot observe directly the geological features, the confidence level in such interpretations remains low. The development of imager tools has

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perfectly continuous and automatically oriented. If images allow detailed geological description they contain also quantified information that can be used to quantify the geological description. This is a great improvement for reservoir description. This paper will describe new methods that turn dipmeter curves and borehole images into quantified geological models. Three different uses of images or dipmeter curves will be examined in turn: the geological observation capabilities, the structural reconstitution, the facies determination and quantification. If most of these methods were developed to analyze images, many of them are also applicable to old dipmeter data, renewing interest for these logs.

GEOLOGICAL OBSERVATION ON BOREHOLE IMAGES

Images have totally modified geological interpretation in boreholes, as they make possible an observation of the borehole wall. This is true in vertical wells but even more in horizontal ones where dipmeters do not provide any help. Whatever is the image type, electric or acoustic, it makes possible to identify and classify the geological features as on a core or an outcrop. The goal of this document is not to establish a catalogue of different nice geological features visible on images, but to convince geologist that these features would have been either ignored or misinterpreted from conventional logs or dipmeters. This is particularly obvious on the following examples (Fig. 1).

One major interest of such digital images comes from the fact that they are easy to manipulate. Compressing the vertical scale allows figuring out events slightly oblique to the well. Playing with electrical contrast allows detecting features that are not obvious on the standard images. Figure 2. shows how the choice of the electrical contrast can enhance either sedimentary features or a secondary fault sealed by calcite. This image shows also that the calcite infilled differently the two fault sides.

Obviously the fact that images are perfectly oriented and indexed in depth allows determining the dip planes with a high accuracy. Based on such high quality dips it new methods have been developed to determine precisely tectonic and sedimentary structures.

Fig. 1. Electrical images (FMI) in a horizontal well showing three different geological feature types: Layering (green); Foresets (red); Open fractures (blue). No other tool would allow such a differentiation.

RECONSTRUCTING STRUCTURES FROM IMAGE DIPS

The common mode of representing dips is the tadpole plot. This mode reflects the evolution of the dip inside the well but does not provide great help in splitting structural and sedimentary components. It neither provides a clear representation of sedimentary nor tectonic structures. So new methods have been developed recently to offer better structural dip determination and structure representation in the vicinity of the borehole. Such methods are complementary to seismic.

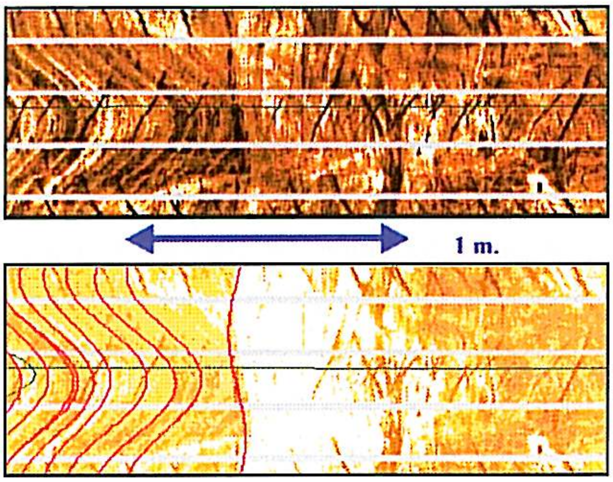

Fig. 2. Cemented fault (pink) identified using different contrasts of a FMI image.

A New Method to Compute the Structural Dip Component: SediView

This method can be used whether the dips are computed from dipmeter curves or picked on borehole images. However when dips come from automatic processing of dipmeter curves, a filtering based on the continuity of the dip trend is applied prior to the structural dip determination. The method is not based on averaging but on the analysis of the local curvature axes (LCA). The local curvature corresponds to a change in dip organized around a single axis, as a piece of cylinder. The origin of such a curvature can be the deposition process, in a foreset for example, or deformation as flexures or drags.

The first step of the method consists in retrieving the different LCA through an automatic dip interpretation on the Schmidt net performed in a sliding window as shown in the second column of figure 3.

The second step is an interactive Schmidt analysis of the LCA. As long as the LCA inside the window open by the user, fit the same great circle the structural dip is constant (visually interpreted by noting that the great circles corresponding to each LCA cross each other at a single point on the net). When the user is satisfied with the fit on the screen, he releases the mouse button and the structural dip is automatically computed. The assumption behind this method is that the local curvature axes that are, in fact, sedimentary or micro structural axes, were initially horizontal. Only studies on present day structures could assess this point. However, when over long intervals, sometimes hundreds of meters, the LCA fit a single plane, it is difficult to imagine that this plane was initially inclined. This method allows detecting very low angular unconformities (Fig. 3).

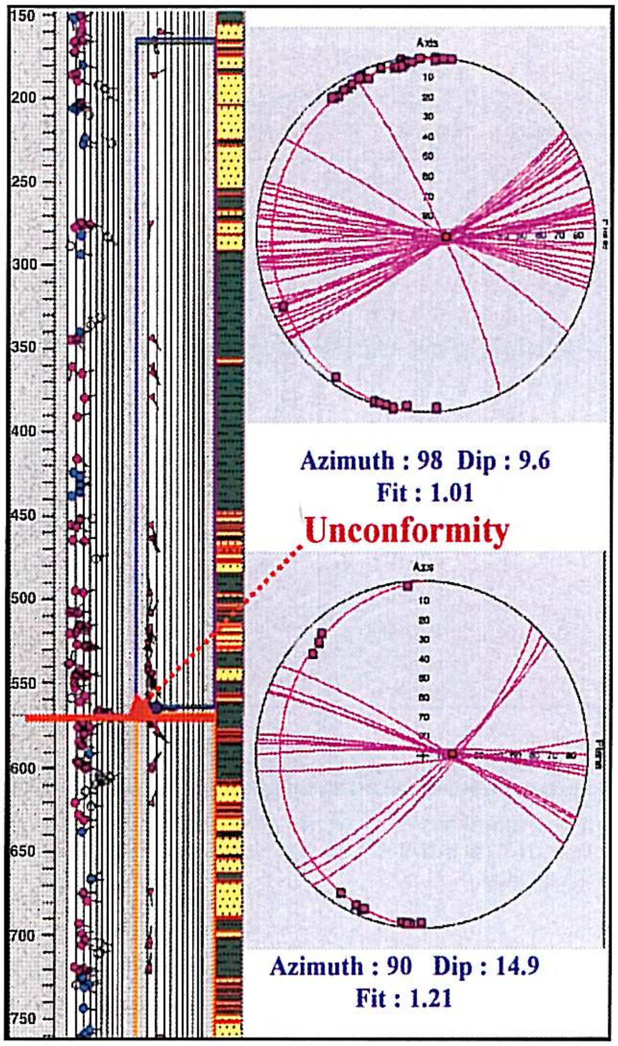

Fig. 3. Low angle unconformity detected using the local curvature method

- Track 1: depth
- Track 2: dips after filtering and automatic Schmidt net analysis. Hollow- dips rejected; pink- dips whose poles fit a great circle and contribute to a Local Curvature Axis computation; Blue- dip with good continuity but not fitting a great circle.
- Track 3: Local Curvature Axes
- Structural dip change at a main unconformity detected through an interactive Schmidt analysis of the LCA. Pink squares and great circles correspond to the LCA. The red GC and square correspond to the STRUCTURAL DIP best fitting the LCA. The value of the fit is a quality indicator of the structural dip determination.

Once the structural dip is computed, it is automatically removed. Allowing retrieving the initial sedimentary orientation and organization. It also becomes possible to create some elementary sedimentary cross-sections using the StrucView software originally designed for computing structural cross-sections (Fig. 4). The basic assumption behind this sedimentary cross-section is that during deposition, each new lamination would be nearly identical to the previous ones in parallel to the structural dip. This is a bit crude but provides a fast estimation of the sedimentary structure thickness and orientation.

A New Method to Model the Structure Around the Well: StrucView

StrucView is firstly a method to filter and regroup dips according to the structural axes

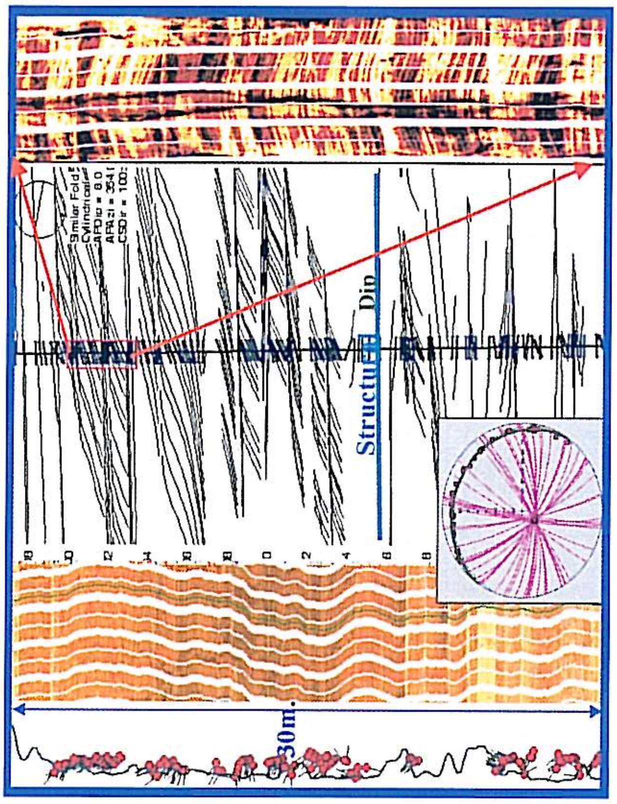

Fig. 4. Sedimentary cross-section obtained from dips in fluvial sands after the structural dip has been determined using the LCA method.

identified through an automatic Schmidt net interpretation. Secondly for each of these structures, Strucview creates cross-sections fitting dips at the well with respect to the structural model chosen by the user. This method can be used whatever the origin of the dips: computation on dipmeter curves, picking on borehole images or cores.

This method relies on the basic idea that structures such as fold, drag or rollover can be described in first approximation as part of a cylindrical or conical surface that correspond respectively to great or small circles on a Schmidt net. Based on this simple assumption, StrucView performs two tasks. The first one is an automatic Schmidt plot analysis that retrieves the different structures crossing the well; their axes and their corresponding dip sequences. The second task of StrucView is the cross-section construction itself after the user has chosen the structural model he wants to apply (Fig. 5). This construction relies on standard structural rules.

For each dip set corresponding to a same structural axis, the user has the choice in between the following models: Similar fold, Parallel fold, Normal fault, Reverse fault, Rollover, Monocline. According to the chosen model the user is asked for different parameters. For example, if he has chosen a model "fault" he will be asked to pick an undisturbed dip zone that will be used as a

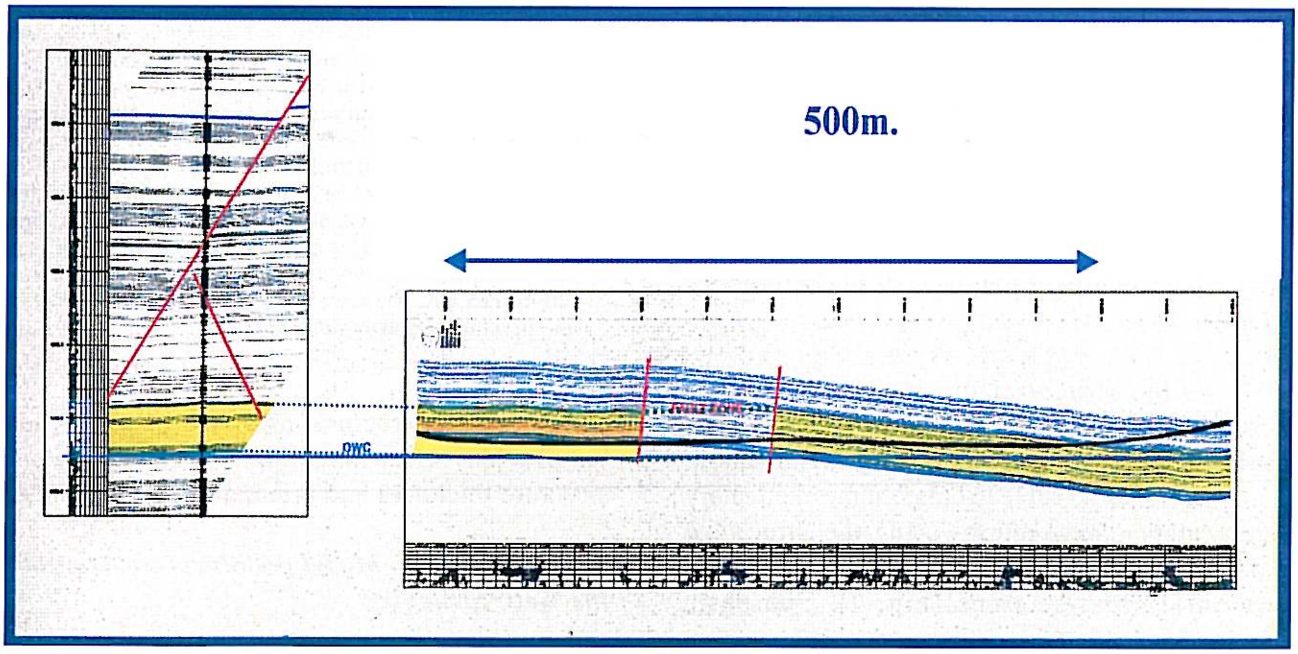

Fig.5. Cross section obtained from dips recorded in a vertical pilot hole and a horizontal well. The reservoir sand is yellow; the faults are coloured in red, their throws in the vertrical well have been computed from correlation to other wells.

reference. As the computation is very fast, it is always possible to perform multiple tries with different models. It is even possible to compute different cross-sections for the same zone of the well.

This structural approach using dips is perfectly complementary to the seismic one, as it is powerful when the structural dip is high or varies a lot, but limited in its lateral extension.

IMAGES AND FRACTURES

Fracture analysis is one of the main image applications, as they allow a full description of the fracture sets (Fig. 6). Each fracture can be identified, oriented and their aperture computed from the electrical contrast between the fracture trace and the matrix.

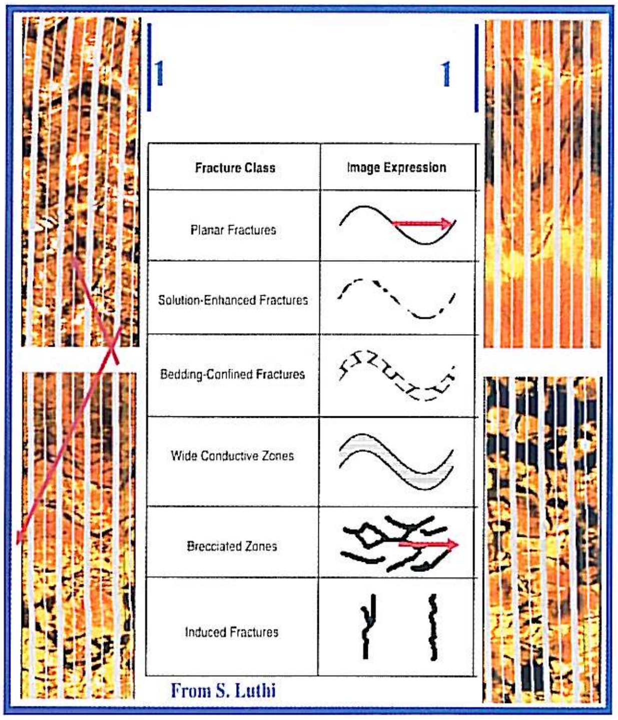

Fig. 6. Fracture classification in a carbonate well where dissolution occurred.

From such images it is obvious that the term "fracture" may cover extremely different features, particularly in carbonates where both dissolution and cementation occur. Many statistical tools exist now to provide a description of fracture at reservoir scale.

IMAGES AND STRESS

The in-situ stress regime appears more and more as a key factor for reservoir monitoring. Imaging tools may greatly help in stress tensor definition; particularly the ultrasonic tools that provide a very precise topography of the borehole wall (Fig. 7).

In a vertical well it is well known that breakouts or induced fractures indicate the minimum and maximum horizontal stress. What is less known is the fact that in a deviated well, the orientation of these features relatively to the borehole axis depend on the three main stresses. This means that the breakout or induced fracture orientation depends not only on the stress orientation but also on the ratio between their relative magnitudes. Shear movements at preexisting fractures can be detected from transit time images (Fig. 7). They correspond to micro-faults that can be inverted in terms of stress.

In favorable cases of deviated wells, using inversion method, it becomes possible to determine the main stress orientations, which stress is vertical, and the magnitude of the intermediate stress relatively to the maximum and minimum. Such information is fundamental for

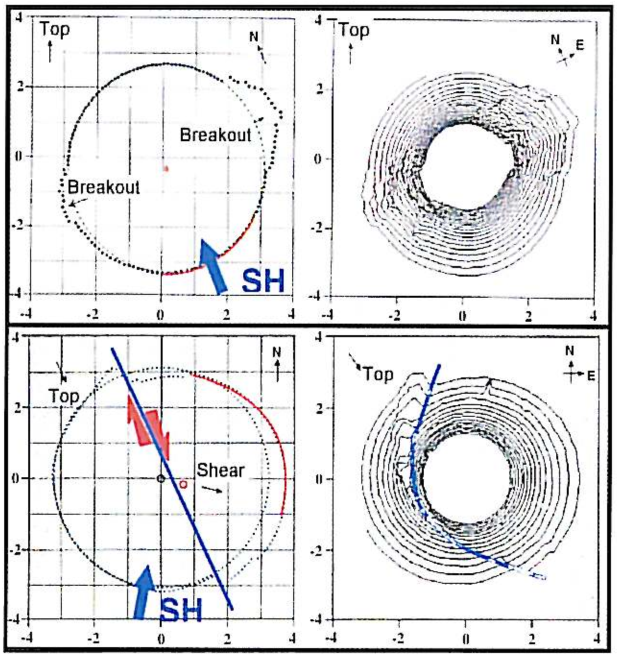

Fig.7. Stress induced damages at borehole wall from ultrasonic transit time:
Top- breakouts; Bottom- shear at preexisting fractures.

borehole stability, to predict fracture efficiency or to set injector wells relatively to producers. A lot of production problems come from misinterpretation of the state of stress at the present day. For example it has been recently observed in North Africa that fractures parallel to Shmax are sometimes 100 times wider than fractures perpendicular.

IMAGES AND FACIES

Another great interest of electrical images comes from the fact that they provide high-resolution measurement from which quantification of the image is possible. BorTex, a new method based on that concept, has been developed to extract morphofacies.

BorTex performs three tasks: firstly it provides layer delineation, secondly it characterizes heterogeneities, and thirdly it quantifies these results as summary logs. These steps are briefly described here below in a very simple way.

Layer Delineation

This delineation is obtained in two steps. The first step is the computation of the background conductivity after the image has been rescaled relatively to a shallow resistivity measurement. It is obtained by averaging the image conductivity with respect to the dip after removal of the elements that do not cross the image.

The second step is interactive. The user chooses a minimum resistivity contrast. Then the well is split into consecutive layers when resistivity contrast is greater than the chosen Threshold.

Heterogeneity Analysis From Images

This analysis is based on the same resistivity contrast principle rather than the layer delineation. The delineation of the heterogeneity is obtained by mapping the resistivity gradient in the image. If the resistivity contrast at the spot limit exceeds the threshold chosen by the user the spot will be classified into conductive or resistive heterogeneities (Fig. 8).

Summary Logs Computation

In order to use the image analysis in conjunction with open hole data, summary logs are derived from the image analysis. This is achieved by averaging, inside a sliding window the image parameters extracted during the previous phase such as: background conductivity; layer contrast; layer thickness; percentage and size of conductive/resistive anomalies...

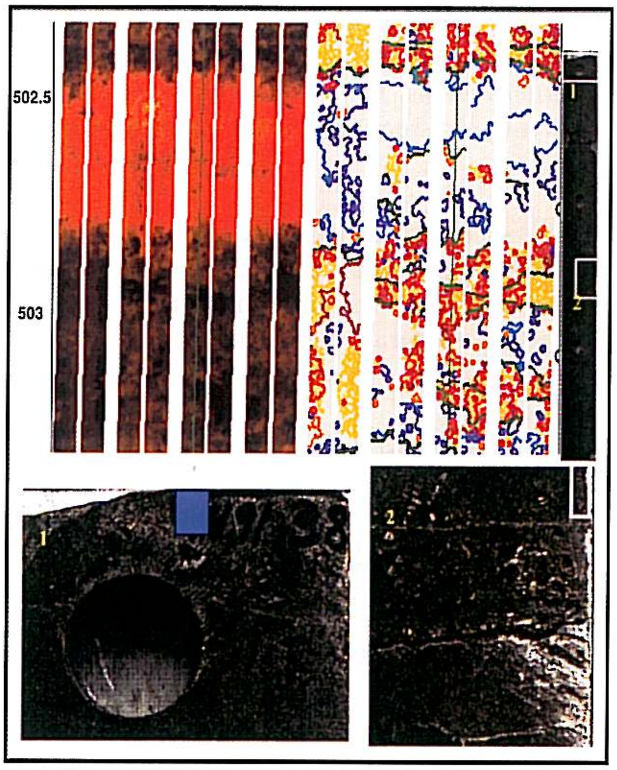

Fig. 8. Carbonate heterogeneity analysis from FMI image compared to cores.Note the fit between the vuggy zones of the core and the conductive anomalies (red/orange spots) in the BorTex display. The blue spot correspond to cemented zones due to diagenetic processes.

This approach brings much higher resolution in facies determination than the use of conventional logs alone.

CONCLUSION

Images are much more than standard dipmeter tools for geological application. This is also true for many other applications. Through the cross-section computed from dips, seismic can take advantage of the images. The stress analysis is extremely important for drilling or for reservoir monitoring... Image is not a single application tool and should circulate much more in between the different services of an oil company.