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The Dipmeter Advisor*
A dipmeter interpretation workstation

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Abstract: The Dipmeter Advisor is a knowledge-base system, linked to a computer work-station, designed to aid in the interpretation of dipmeter results through interaction between the interpreter and the "expert" system.

The system utilizes dipmeter results, other wireline log data, computer processed results such as LITHO*, and user-input local geological knowledge as the framework for the interpretation. A work session proceeds through a number of phases, which leads to first a structural, then a stratigraphic interpretation of the well data.

Conclusions made by the Dipmeter Advisor can be accepted, modified, or rejected by the interpreter at any stage of the work session. The user may also make his own conclusions and comments, which are stored as part of the final interpretation and become part of an updated knowledge-base for input to further field studies.

INTRODUCTION

The Dipmeter Advisor system is the result of a five-year effort to apply expert system technology to the problem of dipmeter interpretation. The project began at Schlumberger Doll Research in 1981. In 1982, the Dipmeter Advisor program was rewritten on the Xerox 1100 (Dolphin), and the Dolphin based version of the program was transferred to the engineering centers for testing and evaluation of applications in the field. From August 1983 to October 1985, the system has undergone further modifications as final preparation and support for its release to select field test sites throughout the world. Three sites in Asia currently have the system : Kuala Lumpur, Tokyo and Jakarta. For a more detailed historical review of the Dipmeter Advisor system, refer to the case studies by Smith and Baker (1983), and Langley (1985)

THE INTERPRETATION PROBLEM

Although dipmeter logs have been in existence for many years, the geological interpretation of processed dipmeter results is rarely straight-forward, and is often the responsibility of geologists who are not extensively trained in dipmeter processing and interpretation technique. The Dipmeter Advisor system is an attempt at addressing this problem by applying a systematic set of guidelines and rules for dipmeter interpretation, in combination with additional knowledge from other open-hole logs and the interpreter. The development of this systematic approach is based on techniques used by dipmeter interpretation experts.

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The most common use of dipmeter results is to define the structural dip occuring in the strata cut by the well bore, and to recognize significant changes in structural dip which may represent folds, faults, unconformities, or major depositional trends. Figure 1 illustrates the lower portion of the dipmeter sonde and its micro-resistivity measurement sensors, and Figure 2 graphically illustrates the computed dips on an "arrow" plot.

In the interpretation process, most interpreters group sets of tadpoles together into patterns, with respect to lithology changes and dip variation. Figure 3 illustrates the most commonly encountered patterns and their generalized interpretation. Four distinct types of patterns are observed Delfiner *et al.* (1984):

Green Patterns : Dip magnitude and azimuth are constant with changing depth, often representing structural dip.

Red Patterns : Dip magnitude increases with depth, with constant azimuth, often representing deposition on a sloping surface ("slope pattern") or drag associated with faulting.

Blue Patterns : Dip magnitude decreases with depth, with constant azimuth, often representing foreset deposition by river or ocean currents ("current pattern").

Yellow Patterns : Scattered dip magnitude and azimuth, often representing high energy deposition or post-depositional deformation.

By recognizing dipmeter patterns corresponding to different lithologies, the Dipmeter Advisor, and the interpreter, first determine structural dip zones, and zones having large-scale structural variations (red and blue patterns). This interpretation leads to an understanding of the post-depositional tectonic effects present in the well. In order to evaluate paleo-current directions of reservoir sands and their geometries, it is often necessary to remove the effect of post-depositional uplift by removing the structural dip component. After structural dip removal, current (blue) patterns within the sands should be a good indication of paleo-current directions. Slope (red) patterns in shales above the sands may help confirm their "bar" nature, while slope patterns within the sands may indicate they are more "channel-like". The Dipmeter Advisor takes into account the experience gained from expert interpreters and applies the interpretation rules systematically on the dipmeter results.

DESCRIPTION OF THE SYSTEM

The Dipmeter Advisor system attempts to emulate human expert performance in dipmeter interpretation. It utilizes dipmeter patterns together with local geological knowledge and other open-hole measurements.

The program is written in INTERLISP-D, and now operates on an upgraded Xerox 1109 Scientific Information Processor (Dandelion). The dipmeter results and open-hole logs are processed in a main-frame computer and are retrieved to the Dandelion.

The system is made up of four components :

(i) *Graphical User Interface* : a menu-driven user interface allowing interactive communication between the user and the system, and providing displays of the data in various formats.

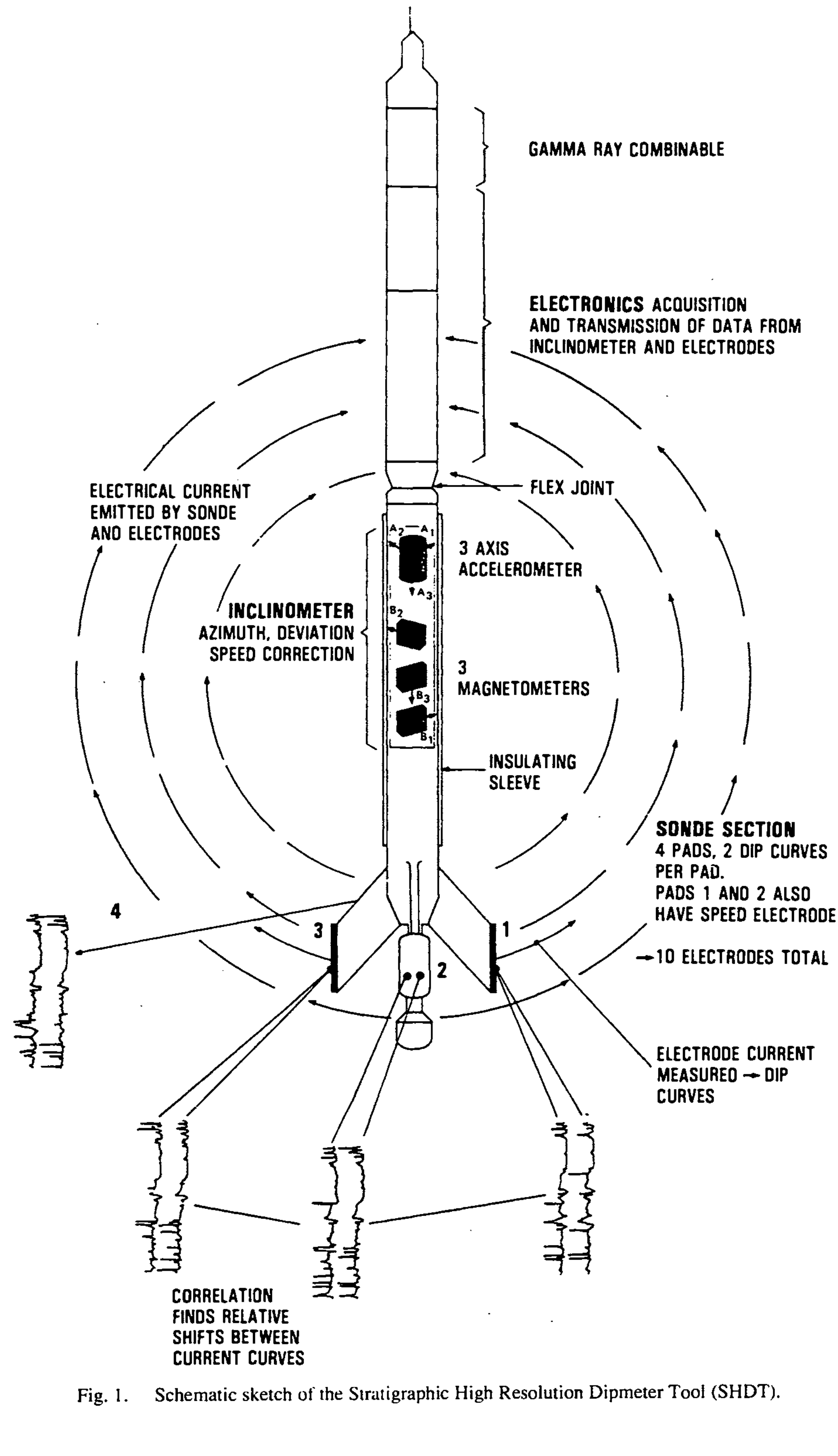


Fig. 1. Schematic sketch of the Stratigraphic High Resolution Dipmeter Tool (SHDT).

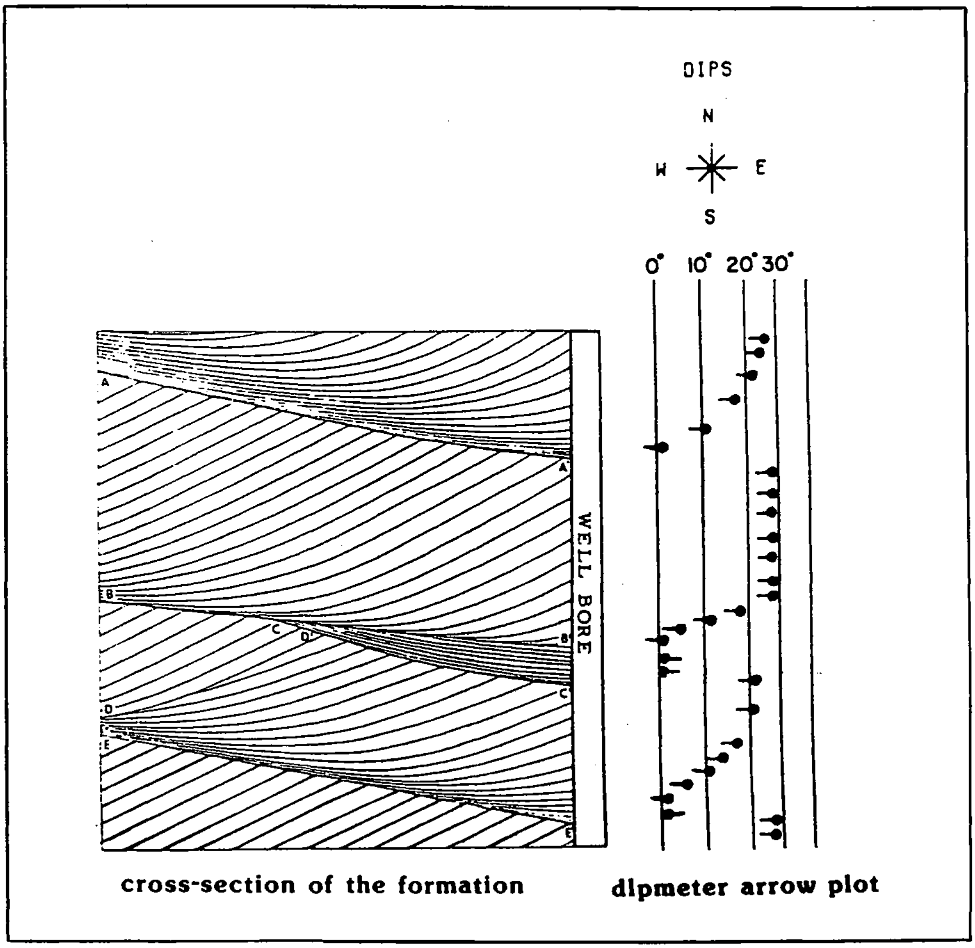


Fig. 2. Dipmeter arrow plot (Tadpole Plot) made from the computer processing of the dipmeter raw data (From R. Nurmi, 1984).

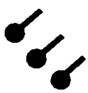
(ii) *Feature Detection*: a set of feature detection algorithms that examine both dipmeter and other log data to detect tadpole patterns and lithologic zones. Each feature is stored as a "token", which is a small table specifying its top, bottom and its main characteristics.

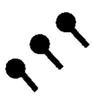
(iii) *Production Rules* : sets of rules partitioned according to their functions, such as structural or stratigraphical. These rules recognize tokens, interprete their occurrence, and generate conclusions in the form of "result tokens".

A rule is composed of an "if" part and a "then" part. The "if" part is a series of clauses that must be true before the "then" part, a series of assertions, is applied. A sample of rules is shown in Figure 4.

Adjacent tadpoles form dip groups which are the building blocks of mega-patterns. The dips forming such groups are derived from the internal structure of sediment layers deposited under uniform conditions.

The groups are :

1)  (colored red) Result of deposition on a sloping surface or post-depositional deformation.

2)  (colored blue) Result of current bedding or weathering.

3)  (colored yellow) Result of deposition in a high energy environment or post-depositional deformation.

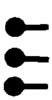
4)  (colored green) Result of horizontal deposition in a low energy environment or parallel cross-bedding.

Fig. 3. Dipmeter Patterns and their generalized interpretation.

IF:

—there exists a delta-dominated,continental-shelf marine zone, and

—there exists a sand zone intersecting the marine zone, and

—there exists a blue pattern within the intersection

THEN:

—assert a distributary fan zone

top — top of blue pattern

bottom — bottom of blue pattern

flow — azimuth of blue pattern

Fig. 4. An example of a rule.

(iv) *Inference Engine*: applies the rules in a forward-chained manner, utilizing the most restrictive ones first, in order to draw conclusions based on the rules in the knowledge base and input data.

The last two components comprise the Artificial Intelligence part of the system, and represent its first application to well-logging interpretation.

DIPMETER INTERPRETATION

The task of dipmeter interpretation is divided into twelve succesive phases (Figure 5). The user can start with any phase, though certain phases require results from other phases. At the beginning of each phase, the user examines parameter values in order to choose appropriate values best suited the area studied and the type of dipmeter processing being analyzed. Following each phase, the user can examine, delete, or modify conclusions reached by the System. If the user decides to go back to a former phase, it can be rerun several times if desired (Figure 6).

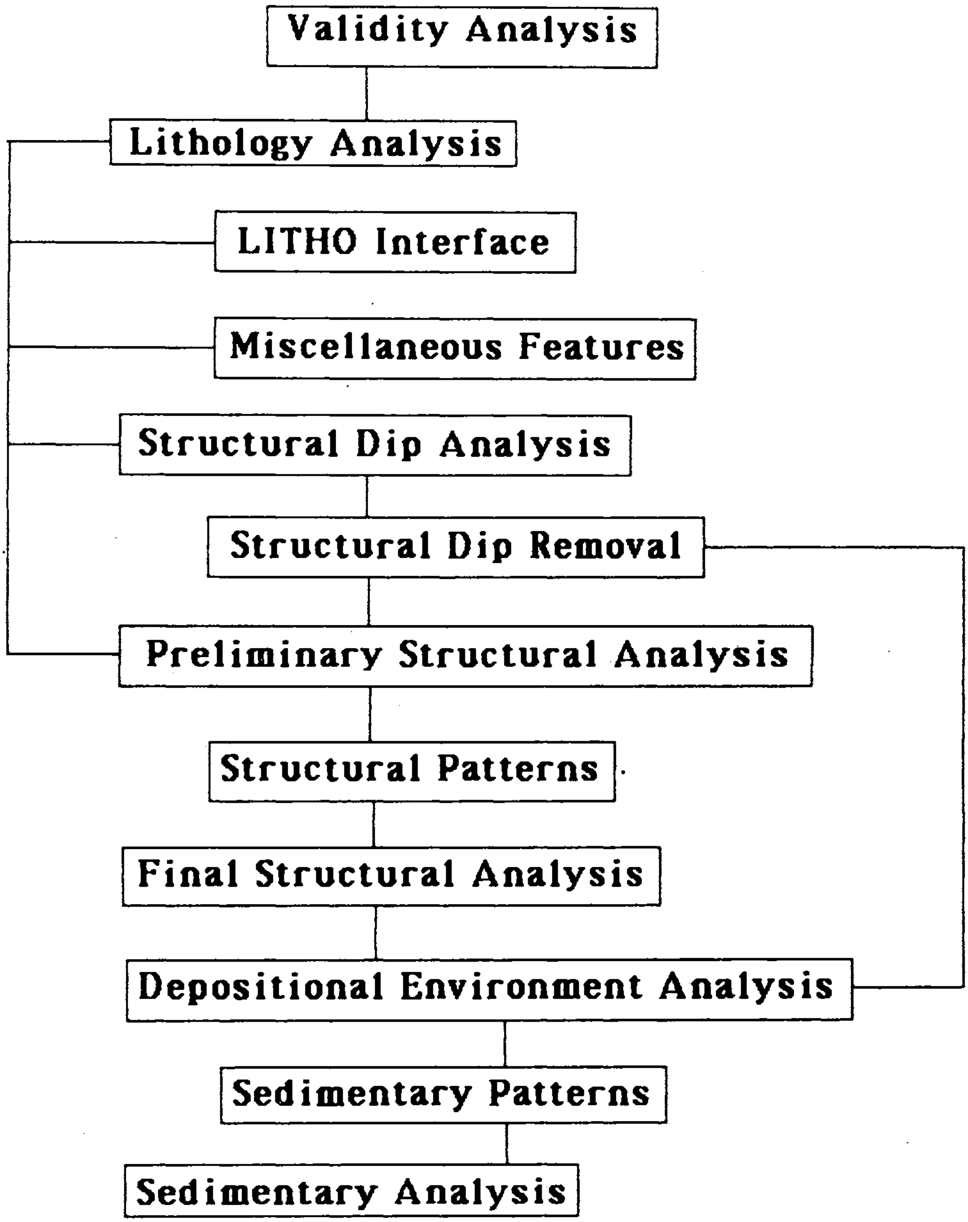


Fig. 5. Dipmeter Advisor interpretation phases.

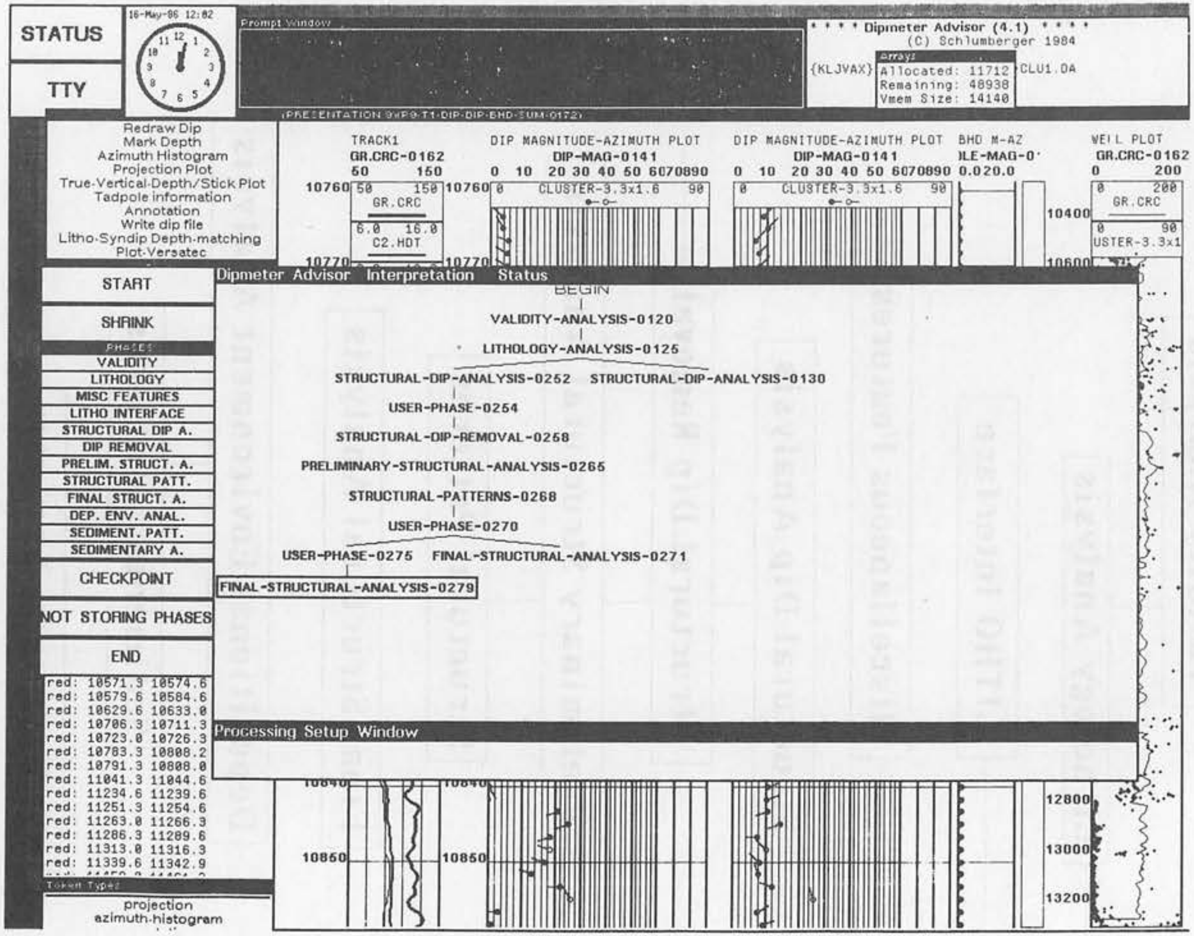


Fig. 6. An example of rerunning final structural analysis.

Here is a brief description of each phase, after INITIAL EXAMINATION, in which the user views the available data and selects logs for display :

VALIDITY ANALYSIS : The System identifies lithology using the open-hole logs such as gamma ray, SP, resistivity, etc.

MISCELLANEOUS FEATURES : The System detects features such as fining-upward and coarsening-upward sequences.

LITHO INTERFACE : The System accepts lithological information obtained from LITHO* (Gilreath, 1976) program which defines bed boundaries based on open hole log values and an electro-facies database.

STRUCTURAL DIP ANALYSIS : The System identifies green patterns, merges these patterns to determine zones of constant structural dip.

STRUCTURAL DIP REMOVAL : The System removes structural dip for structural and stratigraphic analysis.

PRELIMINARY STRUCTURAL ANALYSIS : The user examines information about structural setting for the area.

STRUCTURAL PATTERNS : The System examines the dipmeter data for red and blue patterns to detect structural features.

FINAL STRUCTURAL ANALYSIS : The System applies a set of rules and information from previous phases to identify structural features such as faults.

DEPOSITIONAL ENVIRONMENT ANALYSIS : The System applies a set of rules based on user-specified conclusions about the depositional environment.

SEDIMENTARY PATTERNS : The System examines the dipmeter data for red, blue, green pattern in intervals where the depositional environment has been identified.

SEDIMENTARY ANALYSIS : The System applies a set of rules to draw conclusions about sedimentary features such as channels, fans, and bars.

EXAMPLE

Figure 7 shows a sample Xerox 1109 screen following a structural dip analysis phase. On the extreme left are command menus, panel types, token summaries, and token types which are used by the interpreter throughout a work session. Track 1 displays the gamma ray and calipers with depths. Tracks 2 and 3 display the CLUSTER* results from a High Resolution Dipmeter Tool. Track 2 is the "active" track in which structural dip removals, pattern plots and result tokens are displayed. Track 4 displays the borehole deviation. The small box indicates that portion of the entire well expanded in Tracks 1-4, and the well plot (extreme right) displays dip magnitude and gamma ray for the entire well. The overall display format is flexible and variable, depending on the data set available and the interpreter's preference.

Figure 8 shows the user setting sand parameters for the lithology analysis phase. At the beginning of each phase, parameters must be examined and edited to match with the local geological condition.

In Figure 9, structural dip intervals defined by the System are shown. The System first detects green patterns, then groups shorter green patterns into longer constant dip zones

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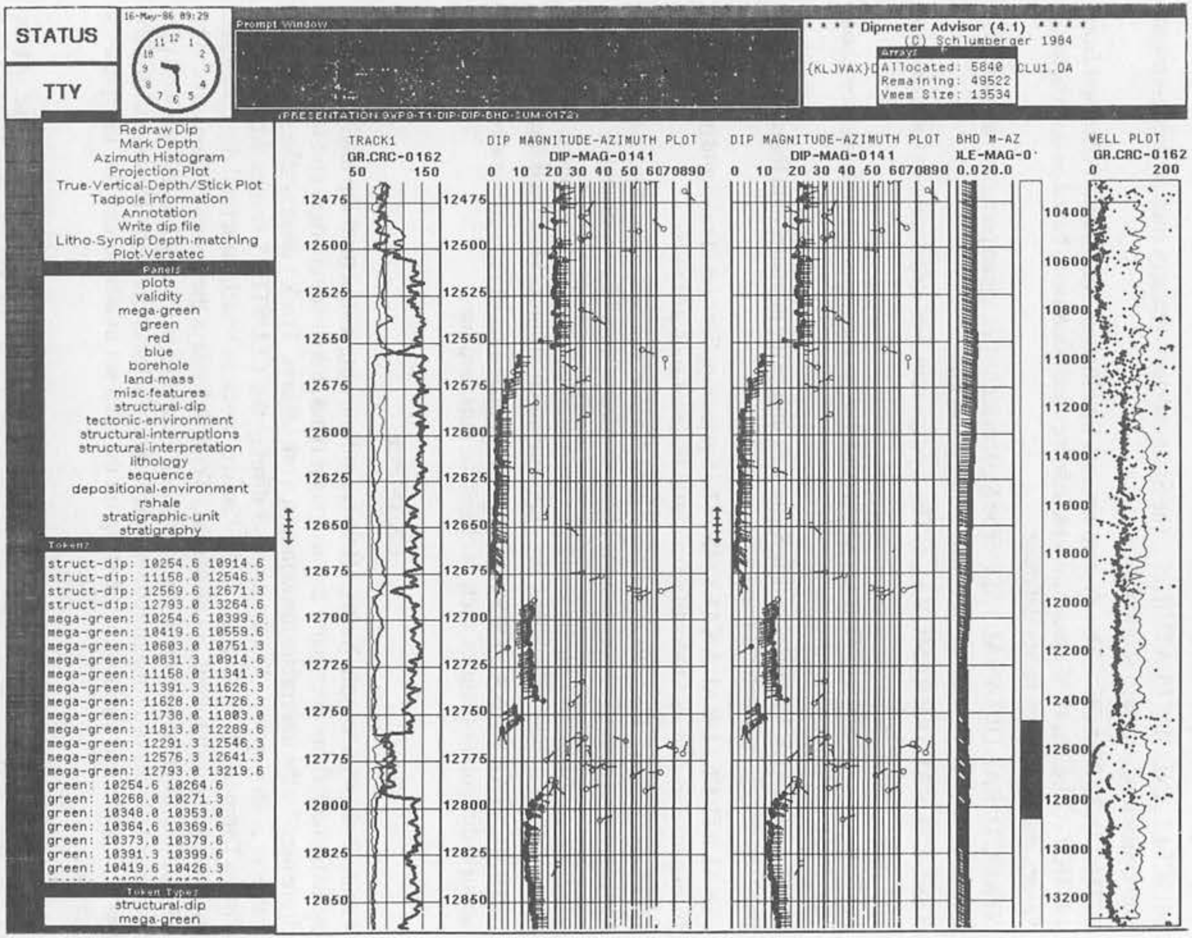

Fig. 7. A data display on the Xerox 1109 screen.

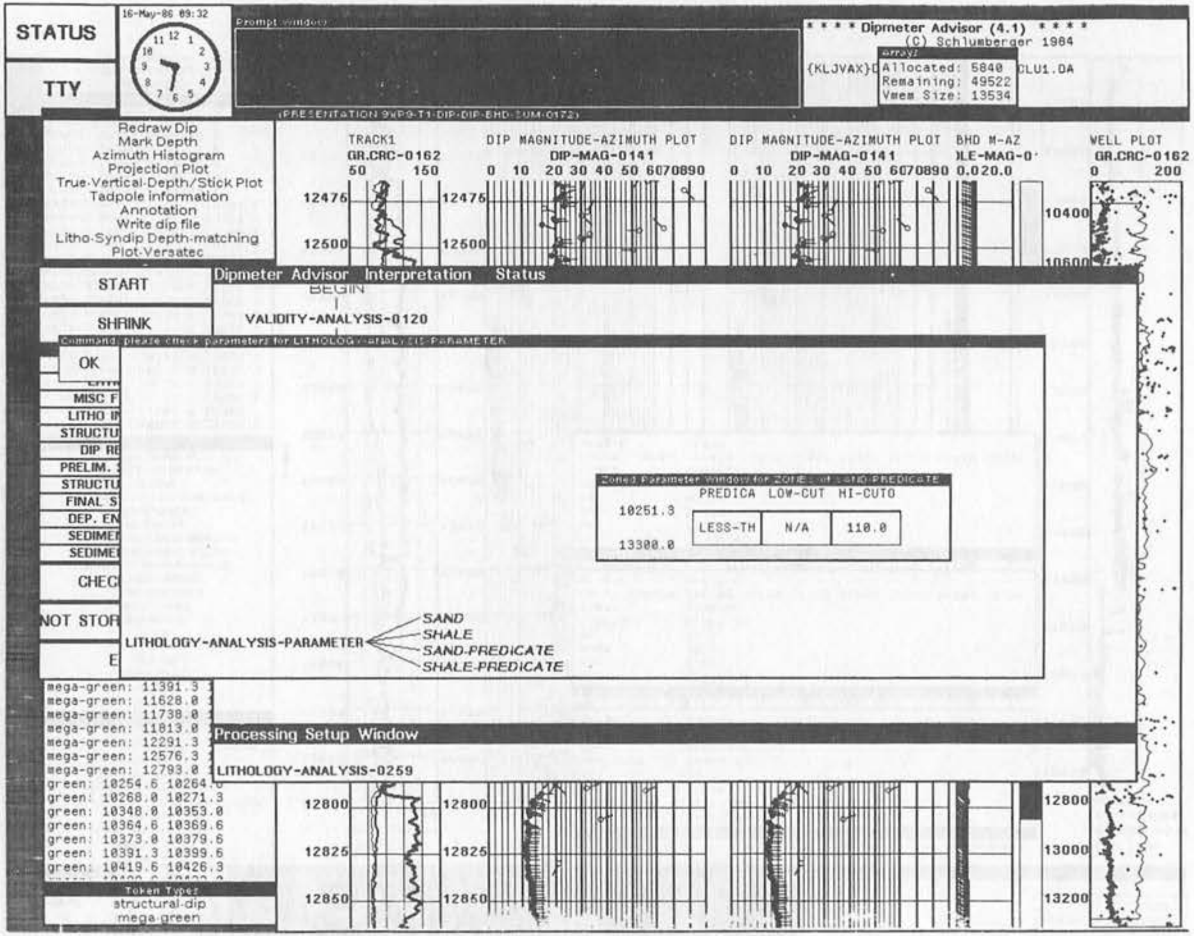

Fig. 8. Parameter selection for the Lithology Analysis phase.

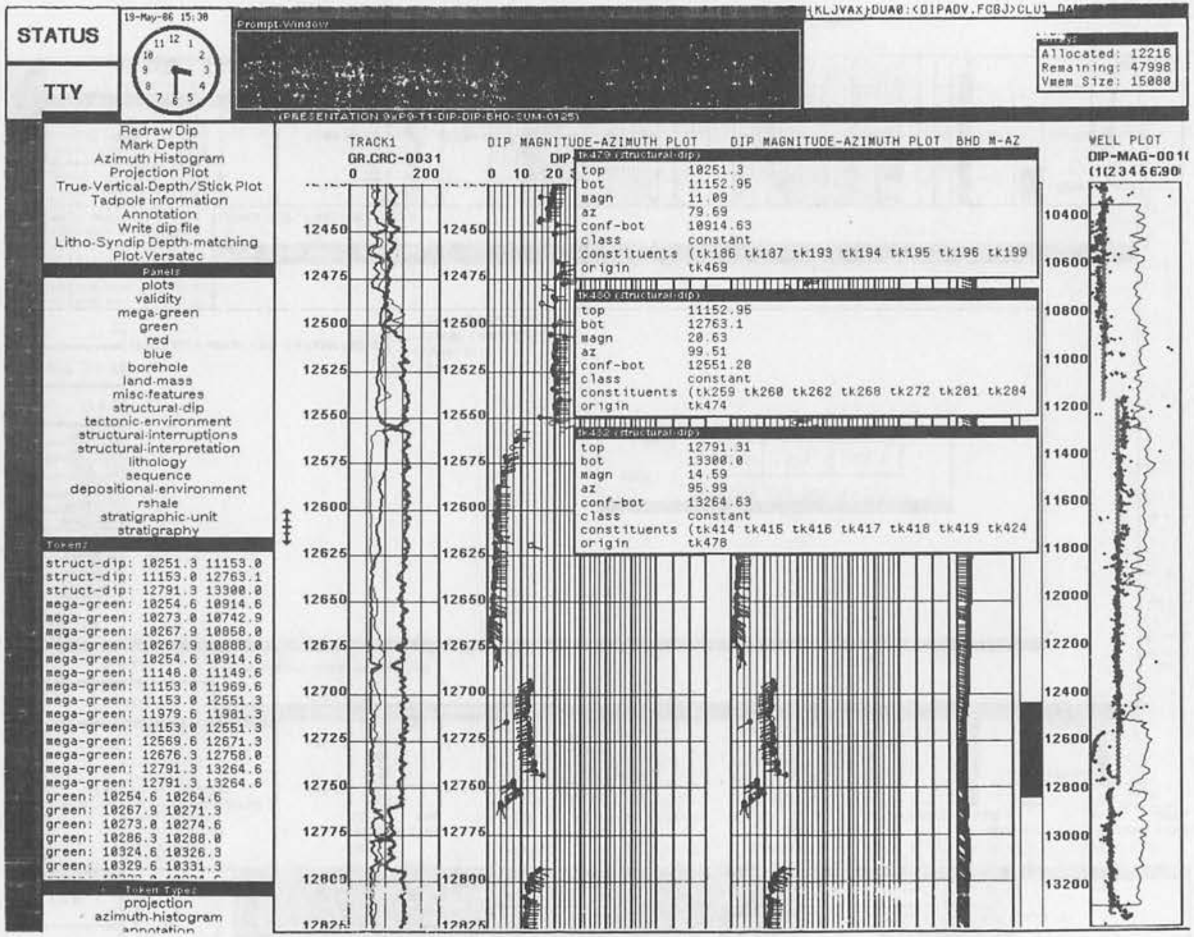

Fig. 9. Structural Dip Zones defined by the Dipmeter Advisor.

("mega-green") if dip magnitude and azimuth variation are within user-defined tolerances. Structural dip is then defined by examining mega-green patterns and their differences. The structural dip zones are plotted in the 'well plot' track on the extreme right. An option to display only high quality tadpoles has been employed.

Figure 10 shows a projection plot and azimuth histogram, after structural dip removal, which are examples of the user-interface function. By using these plots, the user can easily examine structural dips defined by the system, plot palaeocurrent directions of blue patterns within sands, drag patterns near faults, etc. In the example, the plots highlight the rollover (red) pattern above the growth fault.

The result after structural dip removal is shown in Track 2 of Figure 11. The removal of the structural tilt from the dipmeter data is often critical to the analysis of the sedimentary and stratigraphic structure. However, the removal of structural dip also makes more apparent the smaller scale structural events, such as rollover or drag near fault zones. Therefore, structural and sedimentary analyses are generally carried out after structural dip removal. This interactive dip removal capability greatly speeds up the dipmeter interpretation.

Figure 12 displays one of the structural anomolies detected by the Advisor, after dip removal. In this example, a growth fault is picked at 12,742 ft., at the base of the mega-red pattern. The strike, dip and minimum throw (based on missing section between structural dip zones) are indicated in the normal fault token. The red pattern is plotted on the screen and can be plotted on the final hardcopy prints if desired.

In Figure 13, a distributary channel is identified by the System. Information about channel geometry and paleocurrent direction is also provided. An accurate determination of reservoir geometry using these results is critical in the initial reservoir development. In addition, accurate definition of reservoir geometry is equally important in later stages of reservoir analysis, such as water flooding and enhanced oil recovery.

CONCLUSIONS

The Dipmeter Advisor System has been developed into a strong interpretation tool for the exploration and production geologist. The graphics capability of the System enables the interpreter to view the data in a variety of ways, quickly generate polar plots and azimuth frequency diagrams in the zones of interest, try different values of structural dip removal, confirm tectonic features and their orientation, and ultimately determine palaeo-depositional trends within a specific palaeo-environmental model. The System's inter-activity makes it very flexible as an interpretation tool and as a training device. Development of the System is a continuing effort, and as more of the Systems are installed in Southeast Asia, the interpretation expertise in the various geological provinces will steadily increase.

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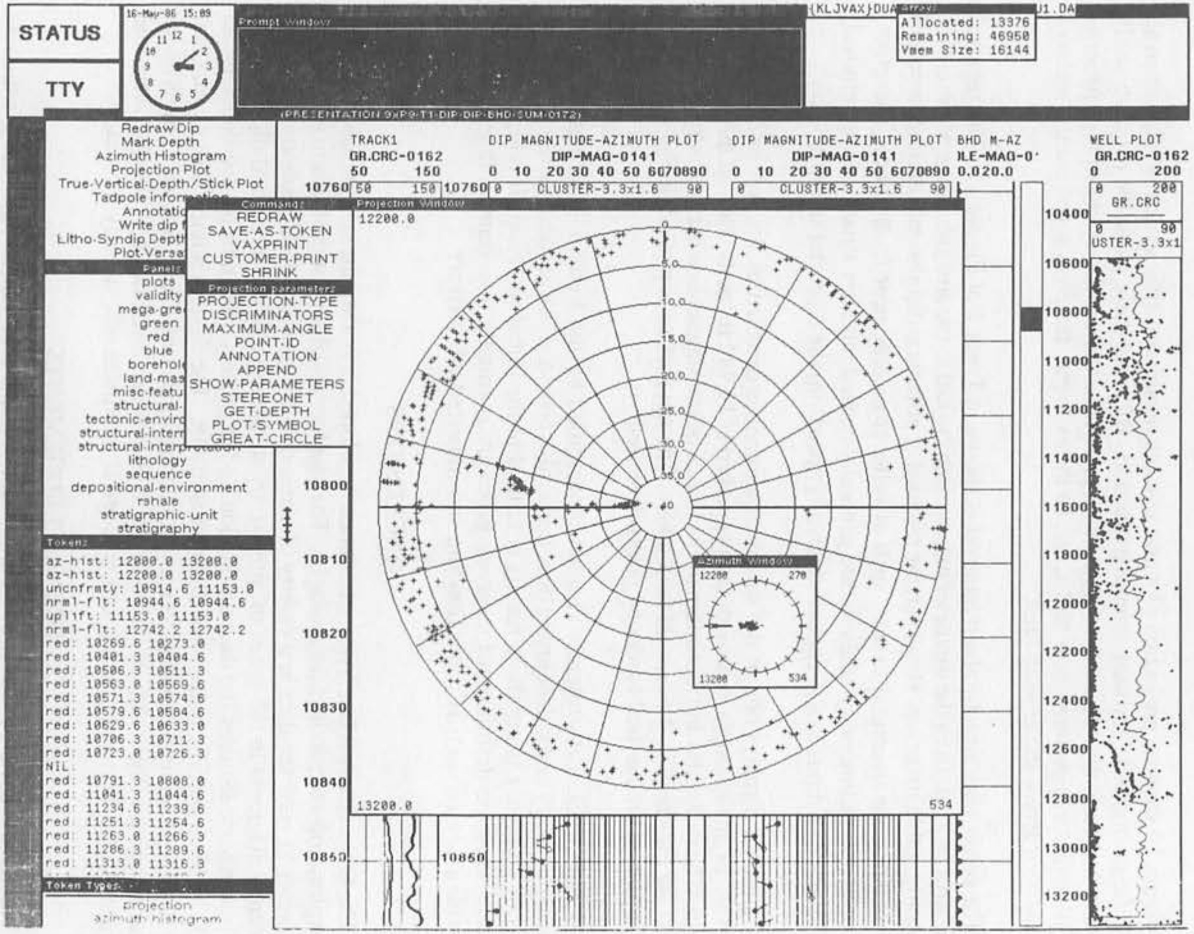

Fig.10. Project Plot and Azimuth Histogram.

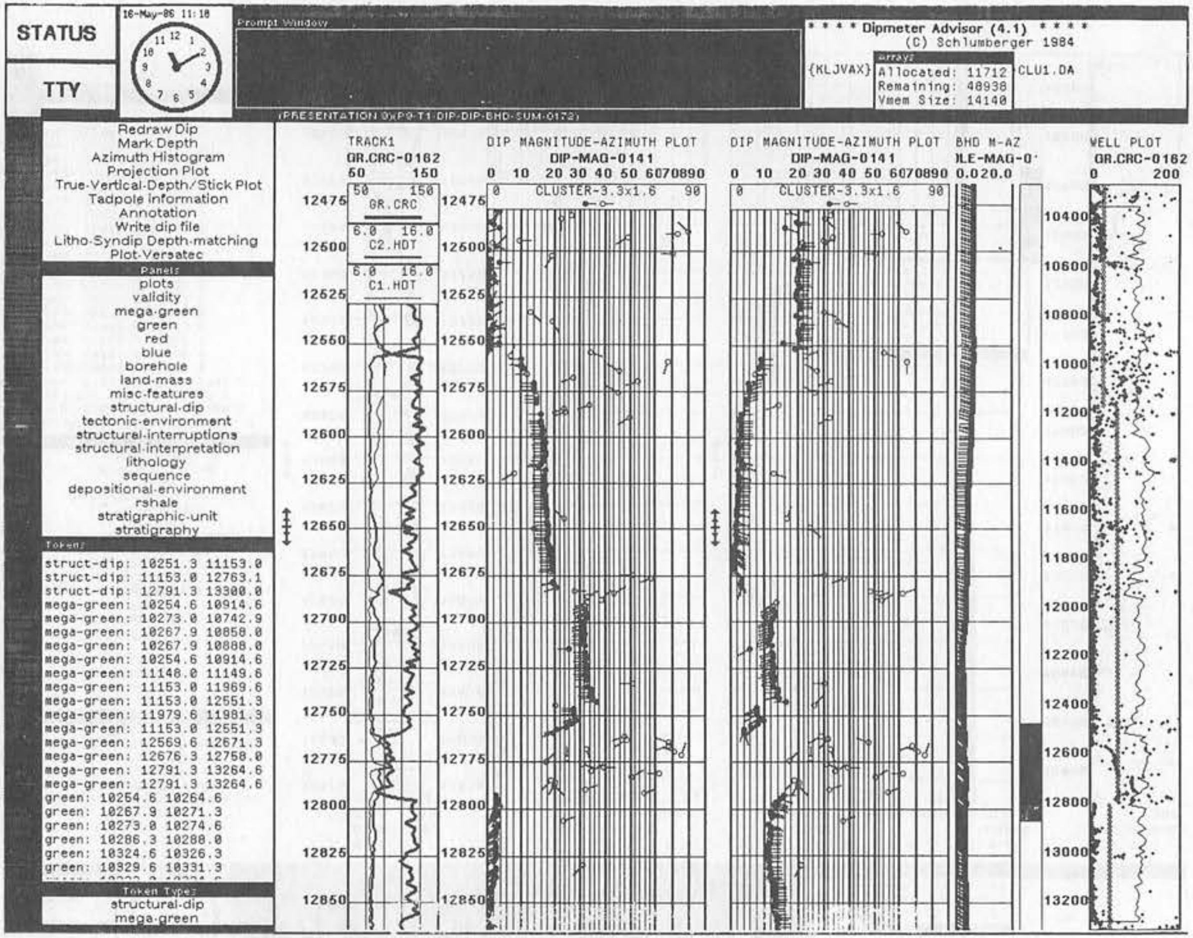

Fig. 11. Display after Structural Dip Removal phase.

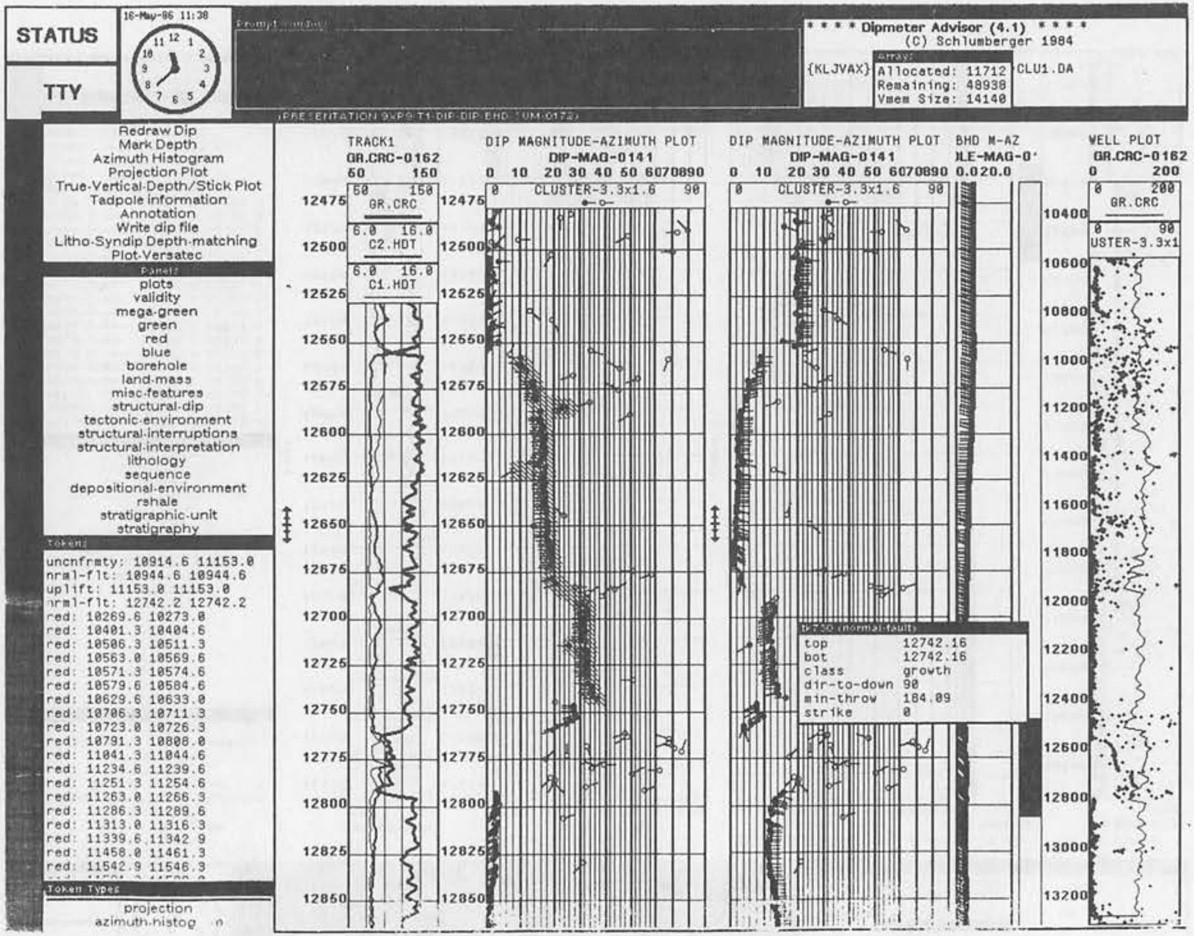

Fig. 12. Structural Interpretation by the Dipmeter Advisor.

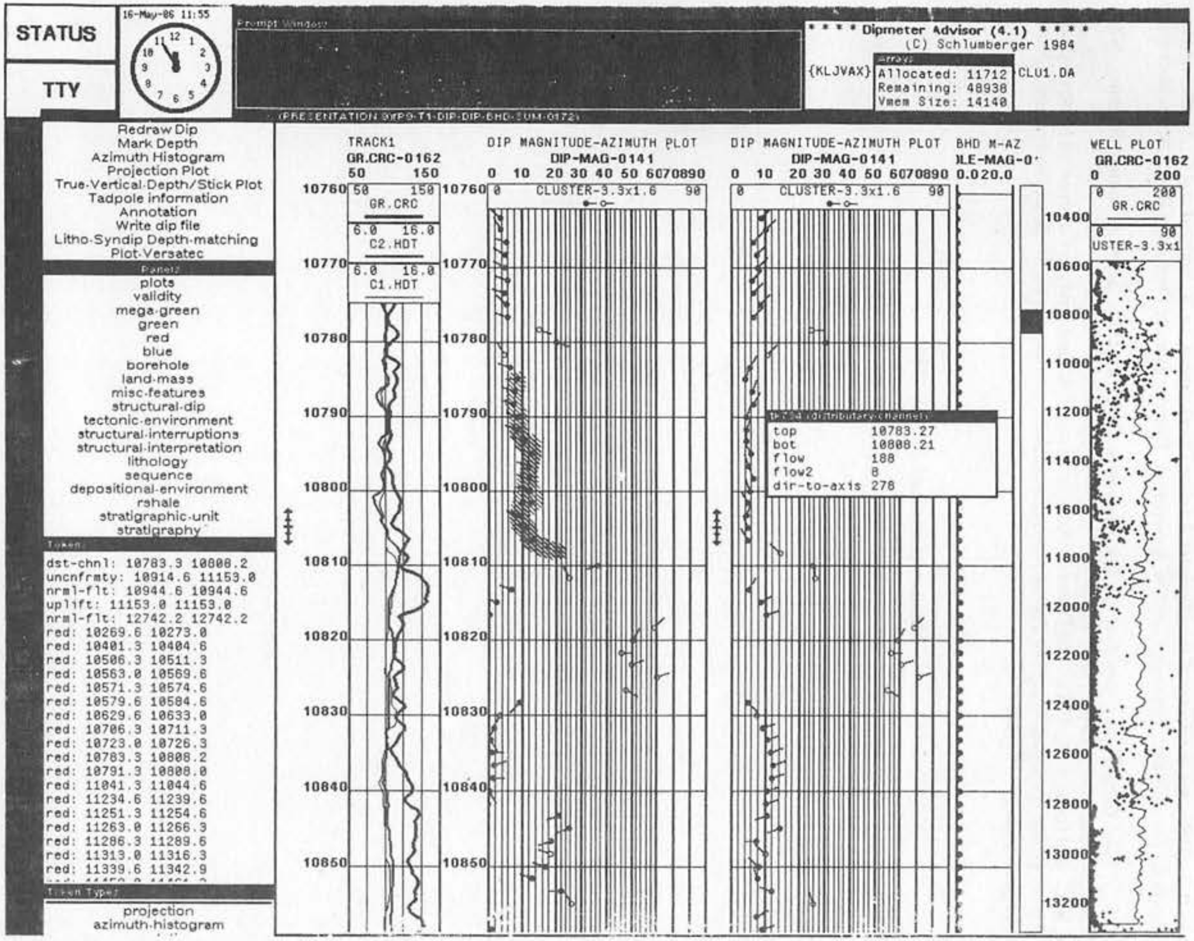

Fig. 13. Sedimentary Analysis by Dipmeter Advisor.

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