A LOOK AT MISUSE AND MISUNDERSTANDING OF LOG-DERIVED DIP INFORMATION

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ABSTRACT

Wireline measurements intended to resolve questions related to formation dip are routinely misused or abused. Voluminous amounts of acquired dip measurements and computed dip data are often unused. Numerous rules regarding dip analysis continue to plague analysts, although critical examination of those rules has condemned their useful relation to sedimentology.

Methods to measure geological features and process measured data into meaningful dip information have progressively improved over the past 25 years; however, much of the information is often misunderstood or not utilized. Important geological information may be overlooked due to common errors and misconceptions of processing techniques.

Recommendations for examining and processing dip data will be discussed. Rules for interpreting computed dips will also be discussed. Dip analysis is not simple; it is not routine; it is not a stand-alone device. Analysis of dip data is a combination of art and science, which can, when properly used, provide a wealth of geological information.

INTRODUCTION

Log-derived dip data cannot be routinely analyzed with decadent processing parameters if meaningful geological analyses are to be expected from those computations. Dip must be processed from acquired data with an understanding of the sediments being measured and the purpose for which the computed dips will be used. The interpretative message from computed dip data is bound to information derived from other sources, i.e., logs, cores, seismic, local geology, etc.

Many pitfalls exist in this unique niche of log analysis. *Assembly-line processing parameters rarely resolve geological peculiarities of reservoir rocks.* Mathematical models and geology do not routinely conform to one another, therefore we must resolve specific mathematical principles and tailor them to individual geological problems. *Computed dip data are not meant to be a stand-alone interpretative device.* It is imperative that other data be incorporated into the analysis of computed dips. *Many archaic rules for dip analysis remain today although critical examination of their relation to sedimentology should eliminate their simplistic approach.*

Acceptable well data can be processed in numerous ways to provide a myriad of dip measurements, many of which are no more than artifacts of the computer-processing scheme. It must be recognized that conventional dip processing methods correlate digital data, which may or may not correlate with the same degree of confidence one may have with optical analog curve fits.

Colored dip patterns (Fig. 1) *are intended to be used as a method of organizing dip patterns into a hierarchy of similar dips and dips of similar direction whose dip angles either increases or decreases with depth.* The colored pattern concept serves no other purpose beyond that just described. These dip patterns must be compared to other information if the user is to determine the proper message.

Different depositional environments result from similar processes, e.g., erosion, sediment transport, and sediment deposition. Wind, rain, storms, tides, waves, currents, chemical reactions, plate tectonics, diagenesis, time and type of burial, etc. all play a role in some sedimentary deposits. Recognition of the physical influences, or knowledge that some particular physical influences are noticeably absent, is important to an understanding of the environmental setting at the time of burial or at a more recent time of burial. Presence of particular minerals, flora or fauna, and specific descriptions of rock type, grain size, texture, maturity, etc. are important clues to a reservoir's history.

As earth scientists, we are essentially a blend of historian, detective, and investigative reporter who attempt to resolve nature's buried secrets. Log-derived dip information is only a piece of the evidence.

WELL-SITE CONSIDERATIONS

The location and drilling of a well are planned. Services to be run in that well, including wireline logging programs, should be a very important part of the plan, and log responses within the borehole environment are used to compute dip. It is imperative that adequate quality control be administered in the acquisition of such data. Oil company and service company well-site representatives should be certain the best possible data are obtained.

QUALITY CONTROL OF DIPMETER DATA

Tool type and model may change the specifics of quality checks, but in general, the following items should be monitored and fall within tolerance levels:

(1) Cable speed during recording

(2) Azimuth of pad trace no. 1

(3) Drift azimuth trace

(4) Deviation

(5) Dual calipers

(6) Activity of dip pad traces

(7) Repeatability

(8) Surface verifications and calibrations

(9) Downhole instrumentation centered as effectively as possible

Acceptable data are acquired not only when the instrumentation is electrically and mechanically sound, but when the logging engineer monitors the log closely during logging operations. The acquisition of dip data is uniquely different from more conventional logs due to the fact that bedding features within the penetrated geological formations often demonstrate a variety of resistivity/conductivity characteristics from one horizon to the next. Scale and/or sensitivity require almost constant monitoring to acquire quality correlative data. Unfortunately, many well-site personnel assume that digital data completely supplant the need to gather quality analog data with dipmeter equipment. Ultimately, the only acceptable comparison to digital correlations is a comparison of analog pad trace data to the computer-derived correlation results (Fig. 2).

COMPUTER PROCESSING METHODS

Typically, the acquired dipmeter data are first processed for structural information. Most contractors will use a conventional set of input control parameters routinely on each job, e.g., Atlas Wireline typically employs a 2 m (8 ft) window length, 0.5 m (2 ft) step length, and a search distance equivalent to about a 35° search angle. In greater than 90% of the wells processed, acceptable structural results are derived by such *assembly-line procedures.*

Conventional parameters provide a nice, comfortable mode of operation, simplify the day-to-day work, and require little, if any, analytical thought from the processor. This results in more time to process a larger number of jobs.

If quality dip computations are to be obtained, it is *very important that the processing group understand the purpose* for running the dipmeter. It is also important to have an idea of the maximum expected dip angle to enable the search parameter to be properly selected. This requires some communication between the user (the client) and his contact with the service contractor, and some communication between the processor and either the client or his service company contact.

When effective communication occurs, it is imperative the processor be well versed in dip processing. *Too often, processing personnel have been trained to perform by a programmed routine, which today overemphasizes computer control over the human. The processor needs to control the computer, and must be well trained to perform the task.* Decisions are required in conventional computer log analysis systems, and dipmeter data also requires some human thought prior to processing dip results.

Procedural controls are necessary in computer environments, but it is imperative that processors *investigate raw log data thoroughly.* The responsible user group requested the service for a purpose, and they must be cognizant of the fact that routine processing parameters may not provide the dip information they need. Users (typically geologists) must realize different processing parameters or different processing programs can provide very different results (Fig. 3). Dip data are processed differently for two purposes:

- To delineate structure, or
- To identify internal sedimentary features and their particular orientation trends.

Obviously, different input-control parameters affect output. Continuous, smooth trends of dip data are often mistakenly accepted as good data while random dip data are too often mistakenly criticized as bad data. The processed data (Fig. 3) demonstrate the smoothing effect caused by large window lengths, which is acceptable when structural data are the targeted information; however, tectonic features are often missed if proper parameter selection is not carefully investigated. Step length in correlogram programs often creates redundant dips, i.e., the same correlative element dominates two or more successive windows. For structural delineation, a 25% step often enhances the structural computation better than a 50% step (Fig. 4). For delineating the internal bedding feature, step lengths less than 50% often create a number of redundant dips, which are no more than computer artifacts (Fig. 5).

Stratigraphic dip analysis requires detailed processing parameters if a reservoir's internal sedimentary features are to be delineated (Fig. 6). Internal crossbeds, horizontal laminae, bioturbated strata, rip-up clasts, and a number of other random phenomena can be present within a reservoir rock (Fig. 7). As illustrated, cross-bed units seldom demonstrate much thickness. Deposition is episodic, and numerous cross-bed units stacked upon one another provide the accumulation of a single stratigraphic formation.

Recognition of the intricate internal features requires detailed processing. Two approaches are commonly used:

- Correlograms with very fine input control parameters, e.g., 0,2 m WL (6 in.) and 0,1 m SL (3 in.).
- Feature extraction programs—Atlas' STRATA DIP® service uses a point-by-point correlation method.

Detailed processing is typically confined to targeted reservoir(s) and a short depth interval above and, if possible, below the reservoir. If much postdepositional structural tilting (>5°) has occurred, the internal bedding features will be distorted directionally. Most reservoir rocks are deposited on reasonably flat slopes (<2°). Removing structure can therefore be critical to an effective stratigraphic interpretation of the reservoir's actual delineation (Fig. 8). In reality, a few environments are deposited on steeper slopes (>2°), e.g., proximal portion of alluvial fans and turbidite feeder channels.

Quality Control of Detailed Computed Dip Results

A recently developed personal computer program (STRATAGON℠) allows visual quality checks of the computer picks for pad correlation. The pad traces are displayed on a PC monitor in conjunction with the computed dip arrows. The analyst can quickly determine if the program did an acceptable job for each selected dip. By use of a 'point and shoot'' method with a mouse, the analyst can delete invalid correlation picks. He can then superimpose the pad traces over one another, shift one vs. the other, and possibly determine a more valid correlation. If a better correlation is found, it can then be quickly computed and plotted as dip data. *This unique approach significantly improves the quality of detailed stratigraphic dip results.*

STRUCTURAL INTERPRETATION

Structural analysis from computed dip data requires more than a simple examination of the colored dip patterns (Fig. 1). Other log data from the same borehole and, if possible, from other nearby wells, should be examined for thickness of stratigraphic units. Where abnormal thicknesses are missing and/or repeated units occur, they should be compared to the dip information in the depth vicinity of those recognized changes in the stratigraphic column. Processed surface seismic sections can be extremely helpful in resolving many dip interpretations. Information from well cuttings, mud log sample descriptions, core, and drilling records also provides clues to faults, folds, and angular unconformities. Borehole drift information and dual caliper data provided on the computed dip presentation are helpful.

If faults can be recognized by seismic analysis, they should have some effect on borehole responses. The strengths of seismic data are their horizontal attributes; their weakness is vertical depth control, since it is a reflected time measurement. Despite technical improvements to minimize seismic's vertical weakness, borehole data are more reliable in terms of depth. Borehole data suffer horizontally, i.e., logs and wireline tests measure or respond to the immediate borehole surroundings and core is rock successfully removed from its original place in the subsurface.

Case Study 1

A comparison of apparent fault location from seismic-to-borehole dip data (Fig. 9) demonstrates the effectiveness of integrating different types of data to resolve geological questions. When two or more completely different types of data agree, the user has more confidence in his overall analysis. The prediction of growth faulting, strike of the fault, downthrown direction, etc. from dip data correlates to seismic's well-defined rollover zone and indications of faulting.

STRATIGRAPHIC INTERPRETATION

Stratigraphic interpretation from dip data must be recognized as a nodal interpretation method, i.e., each available well is simply a node within a large area (Fig. 10). The tool essentially measures geological features within the immediate vicinity of a specific borehole. It is important to recognize that *borehole dip responses and their subsequent interpretation as paleocurrent directions are subject to change a short distance from the wellbore.* This is also true of core-derived dip information. Accumulation of detailed dip data from several strategically located wells therefore becomes important to a successful reservoir delineation.

Dip data does not describe geology; it only describes dips across the borehole. If log data are processed properly, red and blue dip patterns can legitimately be intermixed (Fig. 11). In the present and past, a great deal of literature devoted to stratigraphic dip interpretation has depicted very generalized geological settings and procedures to orient red dip patterns with respect to blue dip patterns. Channels are often depicted to show a red dip pattern perpendicular to the blue dip patterns in conjunction with a graphic model of channels (Fig. 12). Unfortunately, these graphic models distort the true nature of channel systems. The drawings almost always have severe vertical exaggeration and no consideration is given to the third dimension, which is a function of the fluvial energy. Several important factors lead to the morphological makeup of a channel: type of channel, cross-sectional shape of the channel cut, distance from sediment source area, sediment size and mix, vegetation or lack of it, climate, downslope angle of the channel axis, water discharge rates, etc. Channel- or trough-fill systems can therefore be expected to have thickening patterns that are anywhere from perpendicular to parallel to their axis, whereas blue paleocurrent patterns should for the most part depict transport direction (Fig. 13).

The literature also dramatically depicts *red drape patterns* over sand bars utilizing similar distorted graphical twists to influence thought (Fig. 14). Observation of modern sand bars, especially the braided or meandering stream types, indicates a gradual sloping upwards from channel to bar, and modern systems have not yet been subjected to overburden compaction. When observed, the red drape patterns in such systems will normally occur in very short depth intervals of less than 3 m (10 ft), and be dependent on environment. Such red dip patterns may be anywhere from parallel to completely opposite in direction from the blue paleocurrent dip patterns (Fig. 15).

Colored dip patterns have two meanings: (1) *red patterns* indicate downdip thickening of the specific sedimentary interval they are found within and (2) *blue patterns* indicate downdip thinning of the specific sedimentary interval in which they are found (Fig. 16). *The patterns rarely relate to lateral distance of thickening or thinning.* Distinctive red dip patterns related to compaction in the overburden rock do occur, e.g., above carbonate reefs and banks or above large sand accumulations such as distal shoaling ridges (Fig. 17). Red patterns often occur in the basal portion of channels, i.e., lag deposits that usually flatten upward quickly as the channel scour is filled with coarse deposits (Fig. 18). Red patterns related to scour fill also occur somewhat randomly within a reservoir packet of dip (Fig. 18). *Blue dip patterns related to internal crossbedding typically occur over very short depth intervals,* generally less than 1,2 m (4 ft). Blue dip patterns are also common below the base of channel cuts in the underlying scoured sediment that represents a disconformity (Fig. 18).

Effective identification of internal cross-bed features requires effective processing methods (Fig. 19), i.e., very fine correlation controls are a must. The dip data reflecting paleocurrent direction are most important. Red dip patterns often indicate thickening within the lesser quality reservoir rock, i.e., silts and clays intermixed with the coarser sands. *Thickening patterns often suggest undesirable locations for offset wells.*

Careful attention should be given to lithology, porosity, and any information pertaining to the depositional environment. Environmental setting dictates the manner in which dip data helps delineate the reservoir, e.g., the preferred orientation of porosity and permeability within a deltaic distributary channel with respect to the reservoir geometry will differ from the preferred orientation of porosity and permeability within the morphological makeup of a barrier coast environment (Fig. 20). Geological information derived from surface seismic, vertical and walkaway borehole seismic profiles, well-to-well log correlations, structural and isopach maps, cross sections, fence diagrams, horizontal slice maps, multiset wireline pressure profiles, etc. help describe various attributes of the reservoir geometry. Special core analysis (petrographic, paleonolygy, geochemical) aids in determination of the environmental setting.

Case Study 2

A meandering stream continental environment was the setting for the point bar reservoirs illustrated (Fig. 21). The approach to the given analysis was based on a geological model of meander environments, i.e., the geology dictated the meaning of the dip data, and the dip data, which by themselves would confuse the user, suddenly make geological sense. Individual dips and dip patterns could confuse the user. The comparison to other log data, curve shapes, and the geological sequences expected in meander environments simplifies the significance of individual dips and dip patterns.

SUMMARY

Successful use of log-derived dip data requires quality acquisition from the borehole, close attention to processing methods and the purpose for obtaining dip data, and the integral use of supplementary information to interpret the data's geological meaning.

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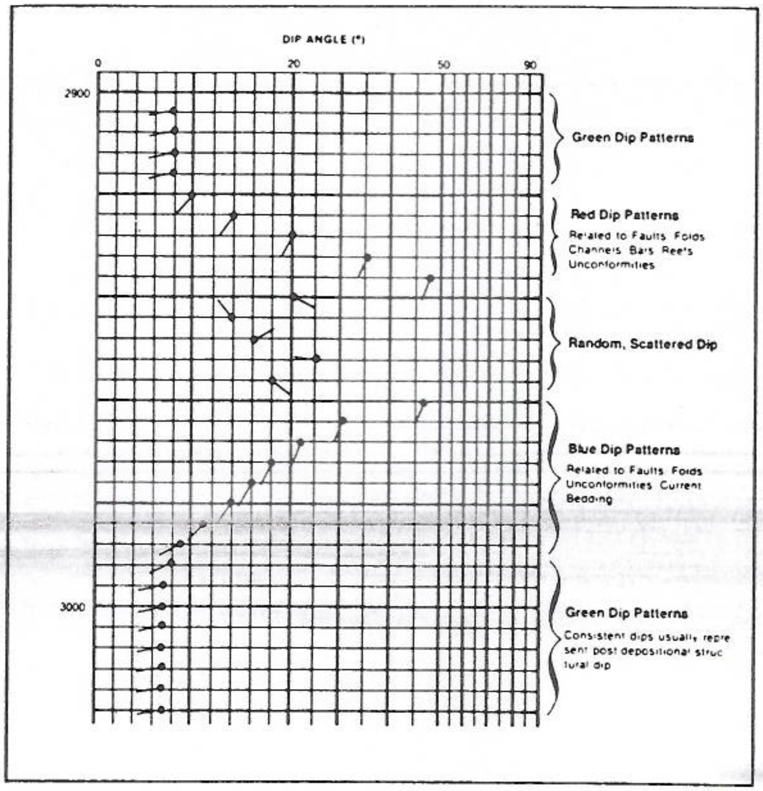


FIGURE 1
Colored dip patterns

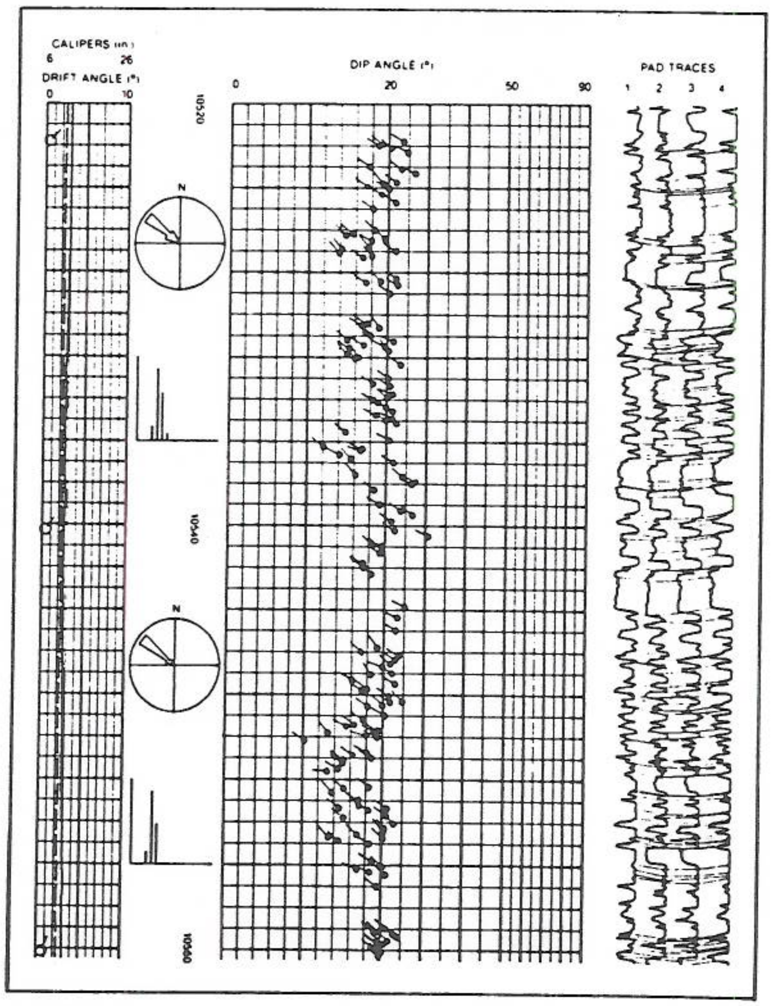


FIGURE 2
Strata Dip® presentation allows comparison of computed dip-to-pad traces

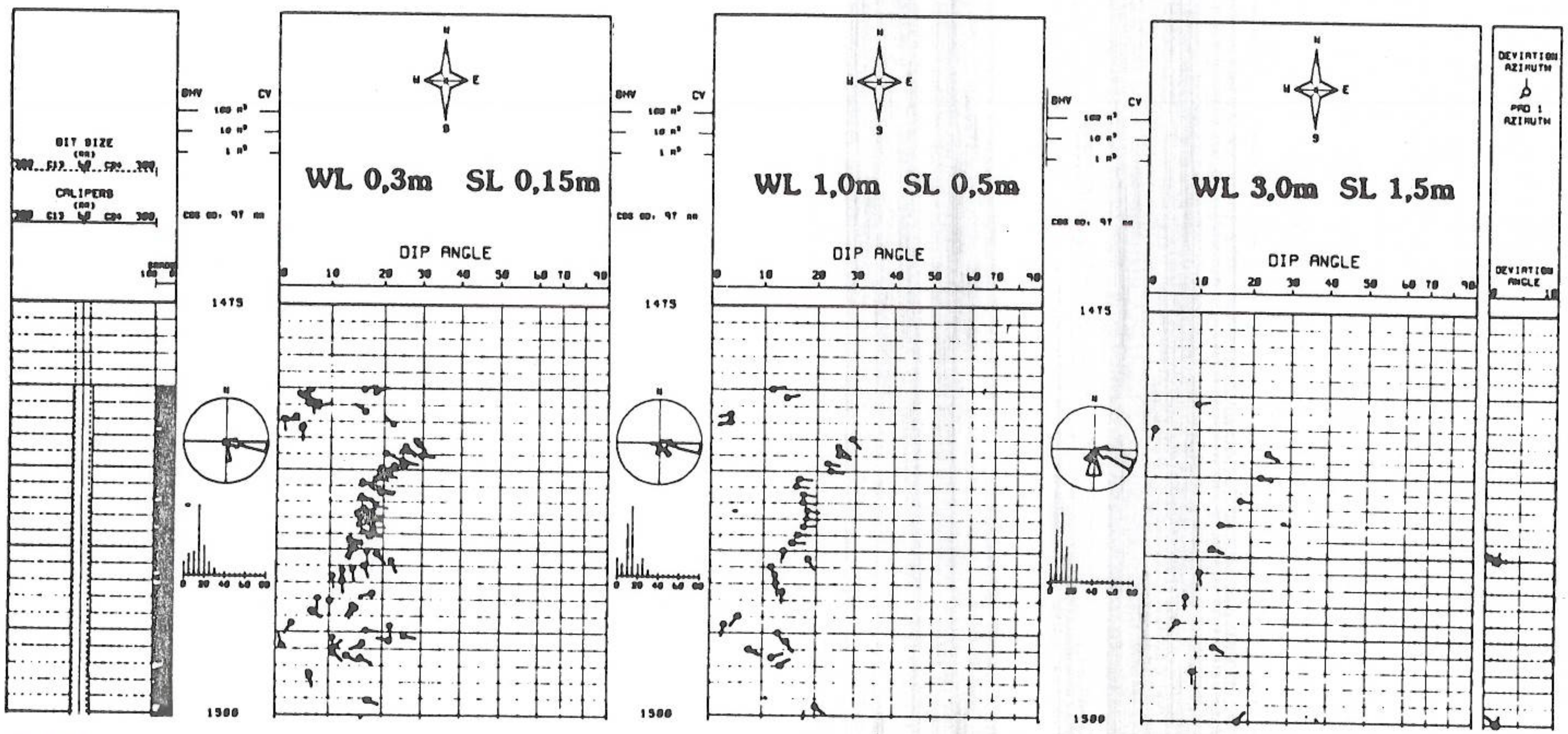


FIGURE 3
Increase in window length (WL) tends to smooth dip results

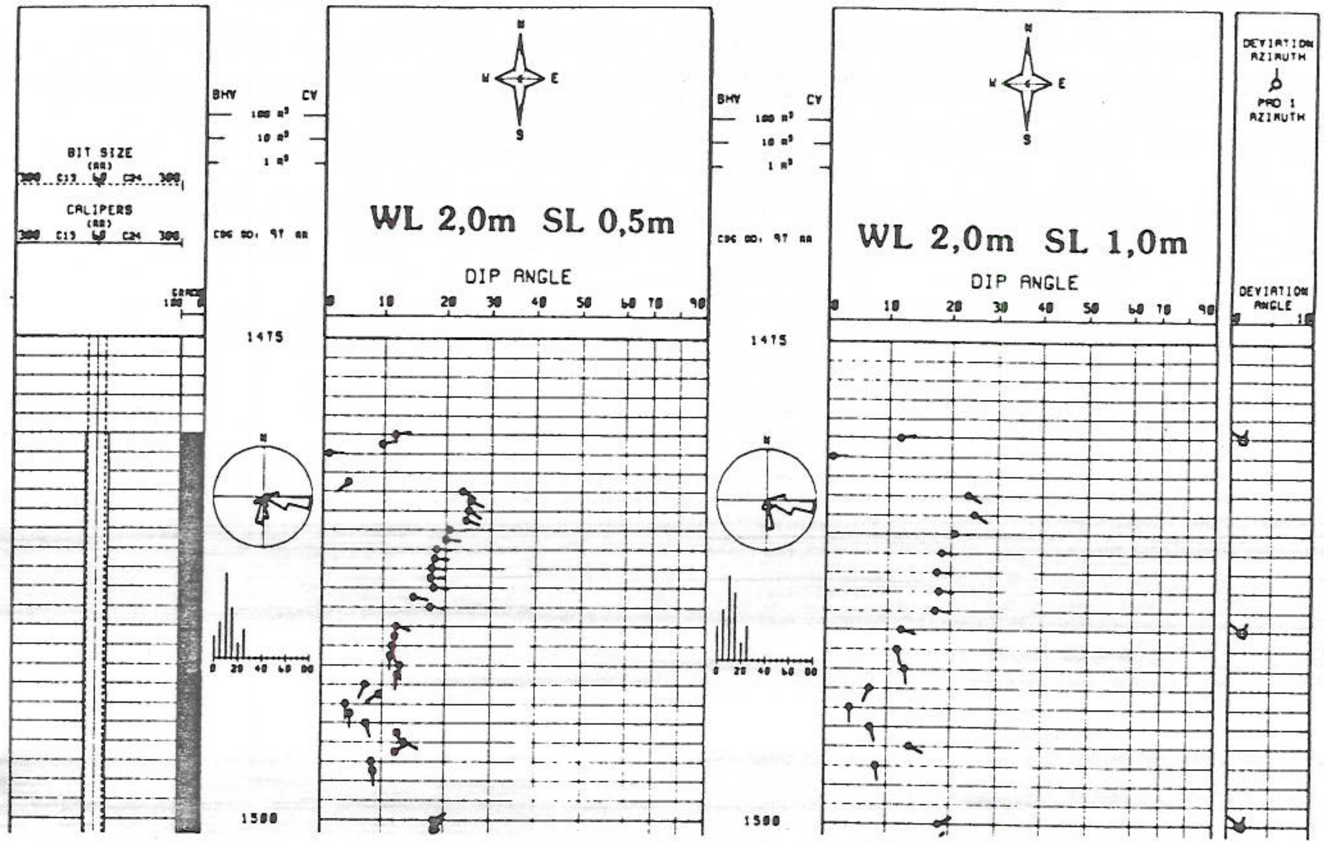


FIGURE 4
Step lengths (SL) of 25% tend to enhance dip results for structure delineation

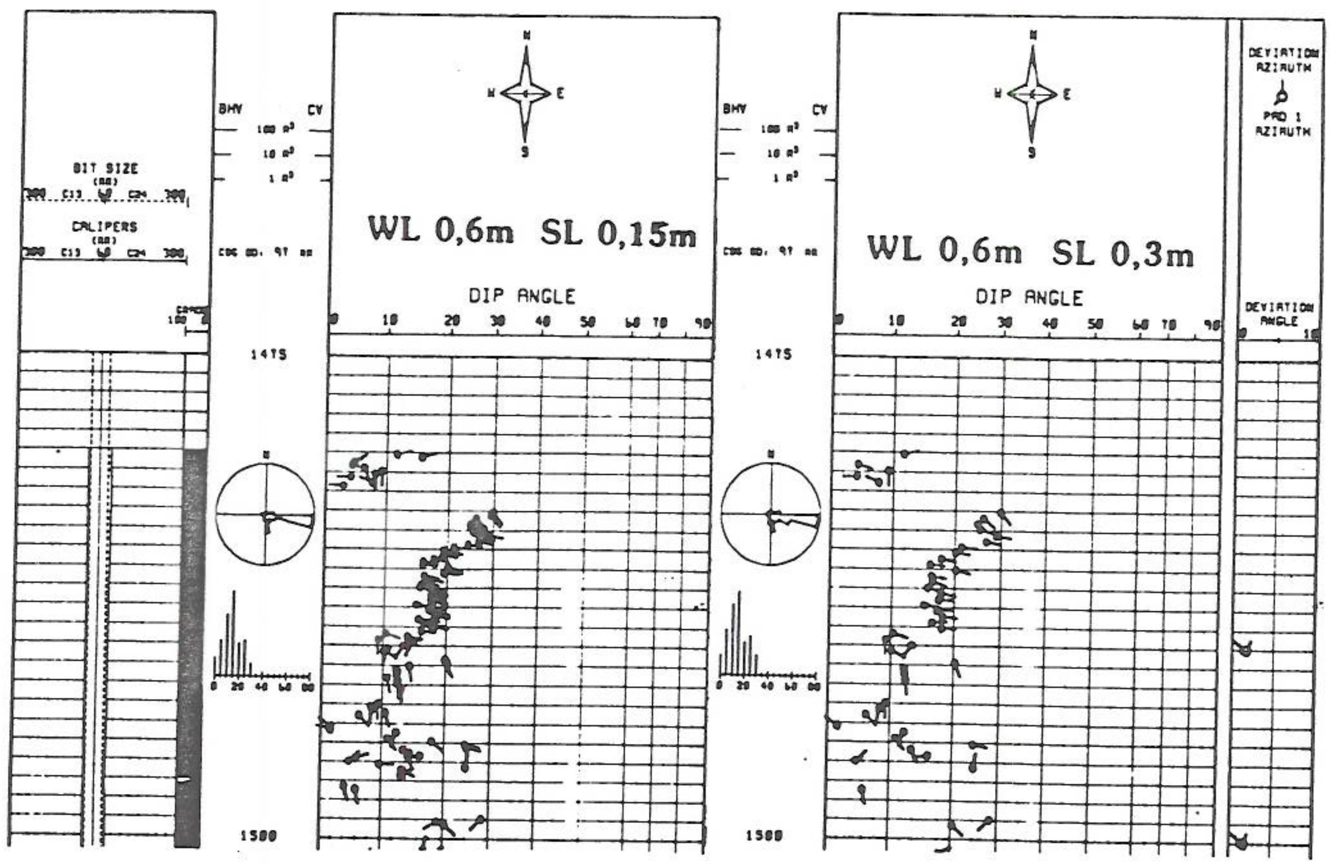


FIGURE 5
Many redundant dips occur when 25% step length is used in detailed stratigraphic processing

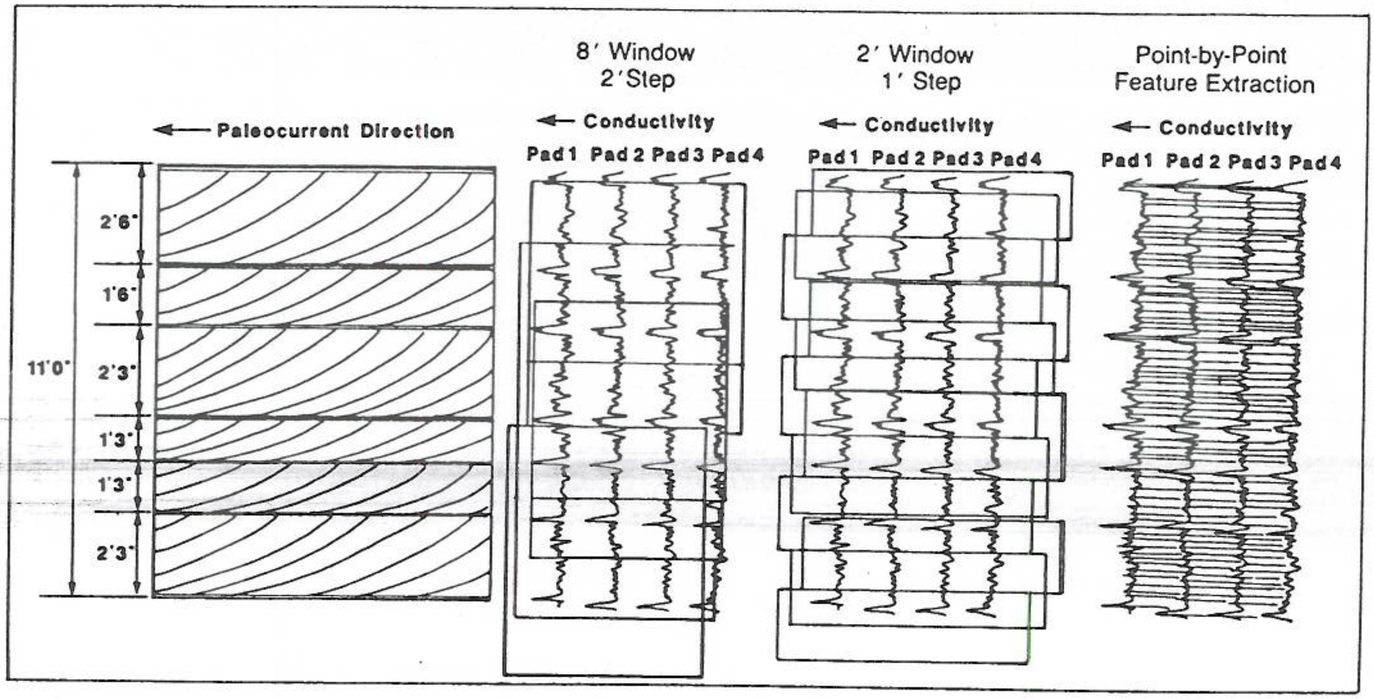


FIGURE 6
Detailed processing parameters are necessary to delineate internal bedding features

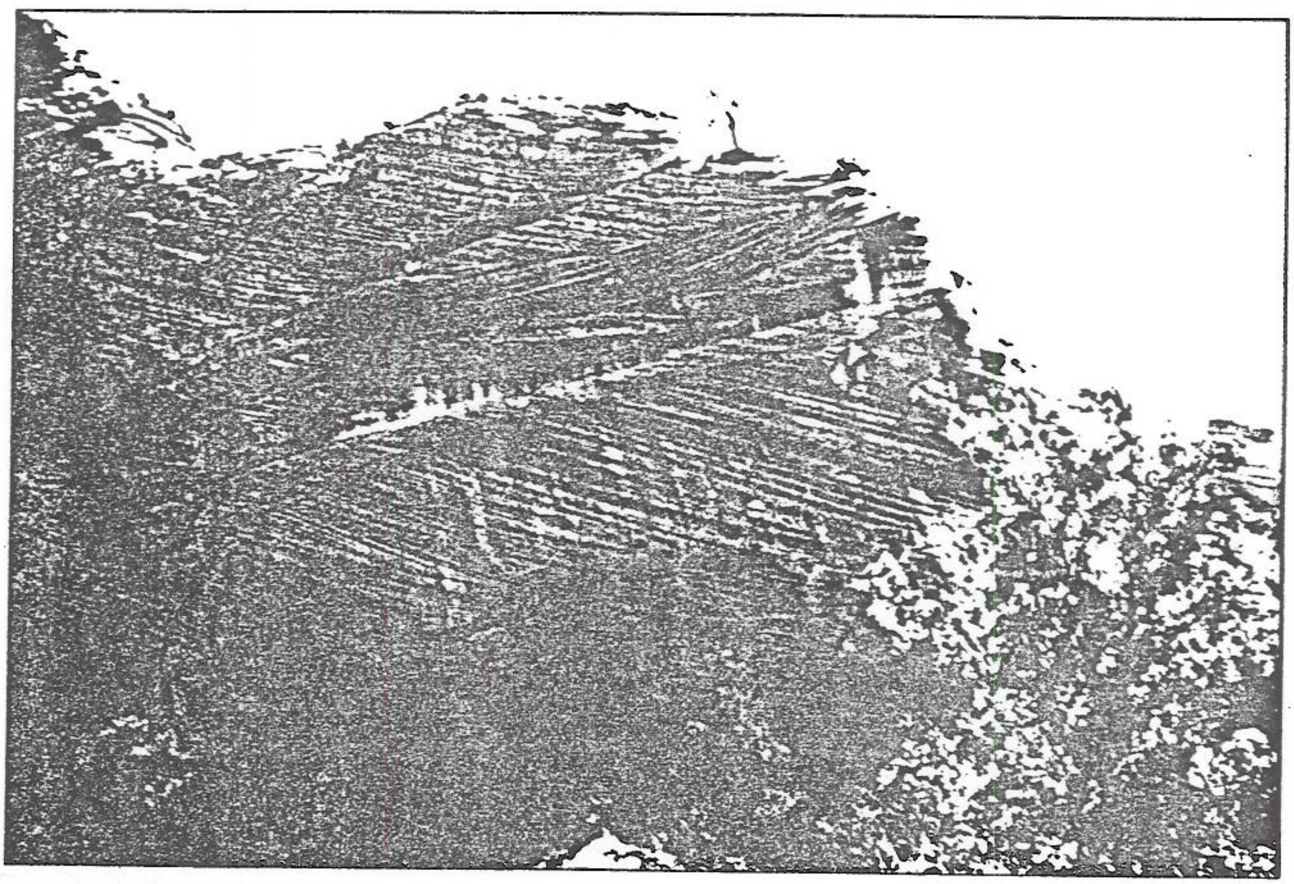
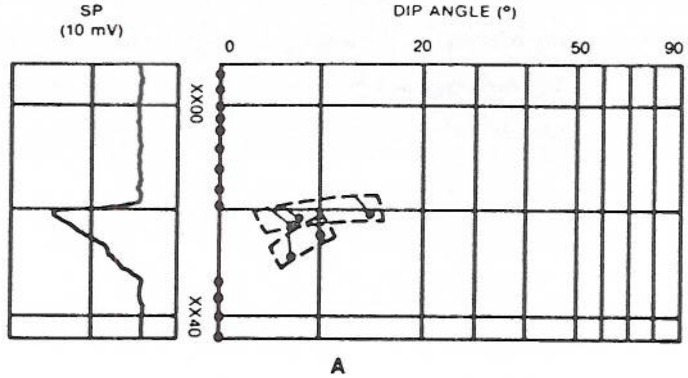


FIGURE 7
Individual cross-bed units often show different orientation and thickness



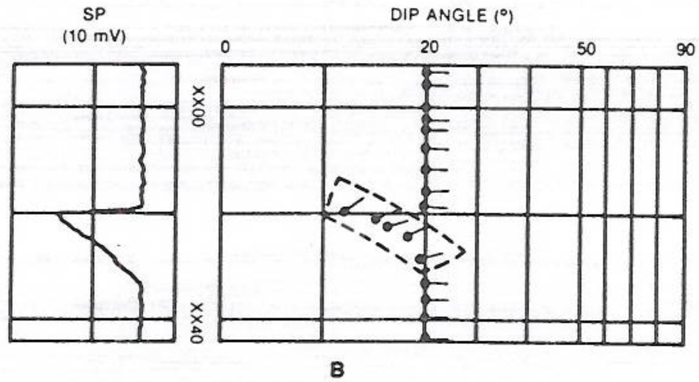
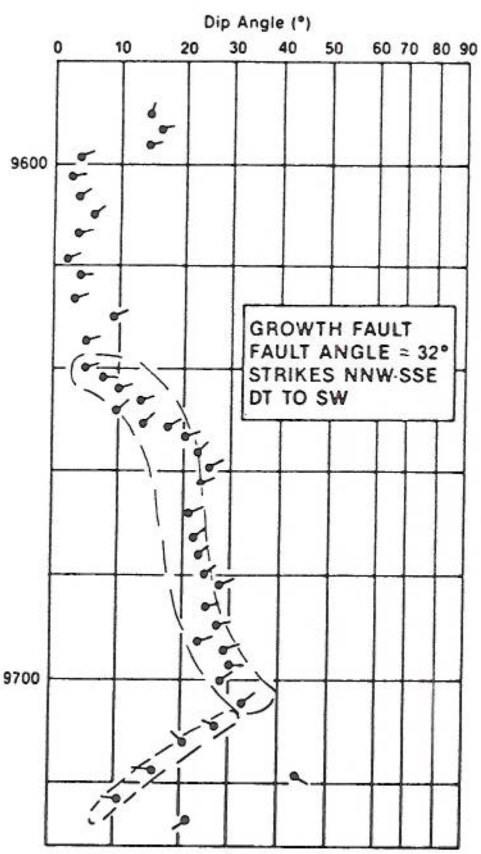


Figure 8
Removing postdepositional structural tilt is important



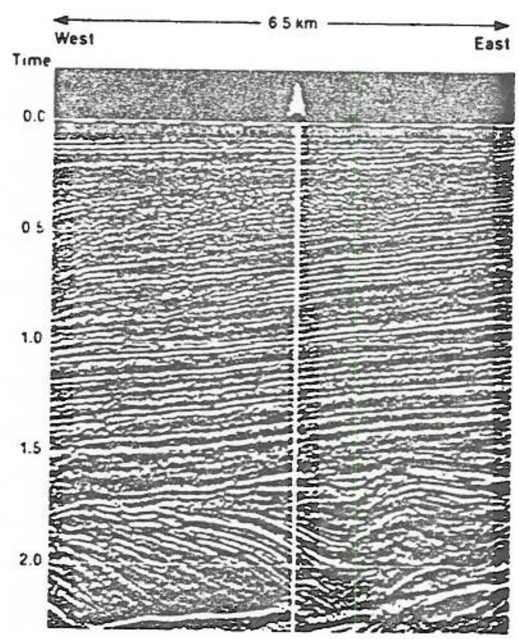


FIGURE 9
Seismic and dip data confirm growth fault

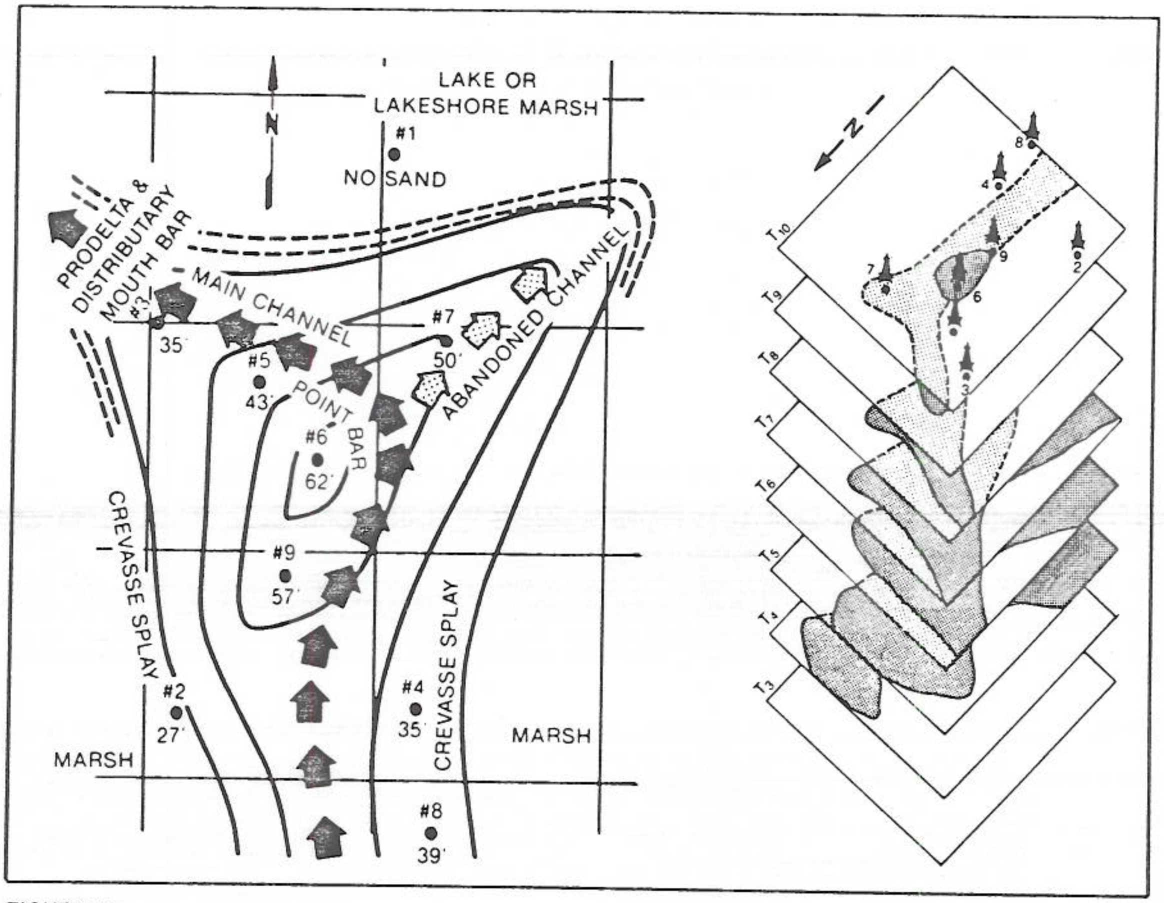


FIGURE 10
Horizontal slice maps and dip data delineate depositional tendencies

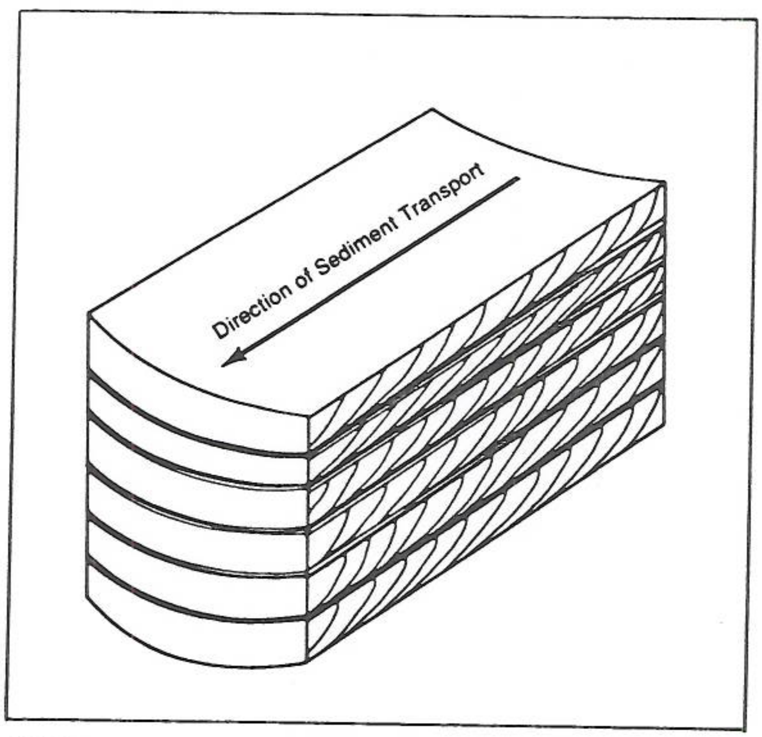
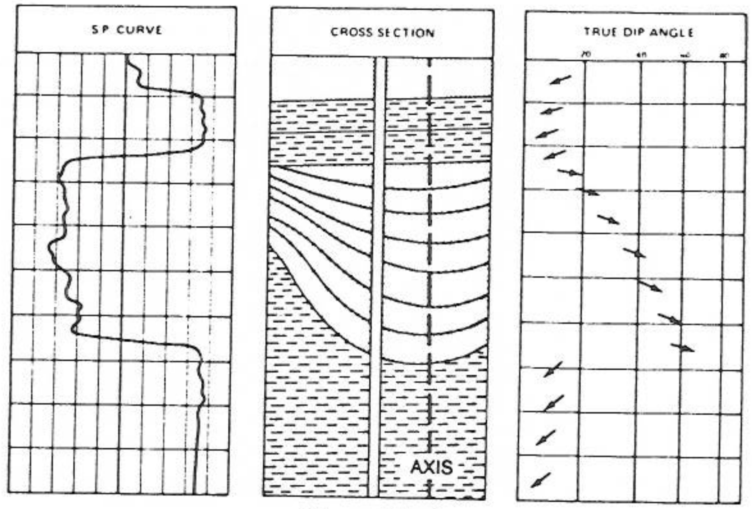


FIGURE 11
Dip planes from crossbeds and the laminae that separate crossbeds are intermixed



Channel Sand

FIGURE 12
Vertically-exaggerated, two-dimensional graphics oversimplify actuality

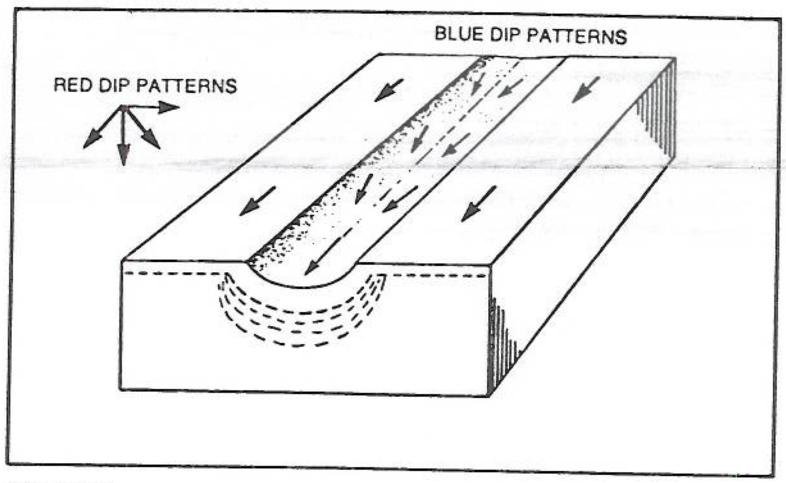
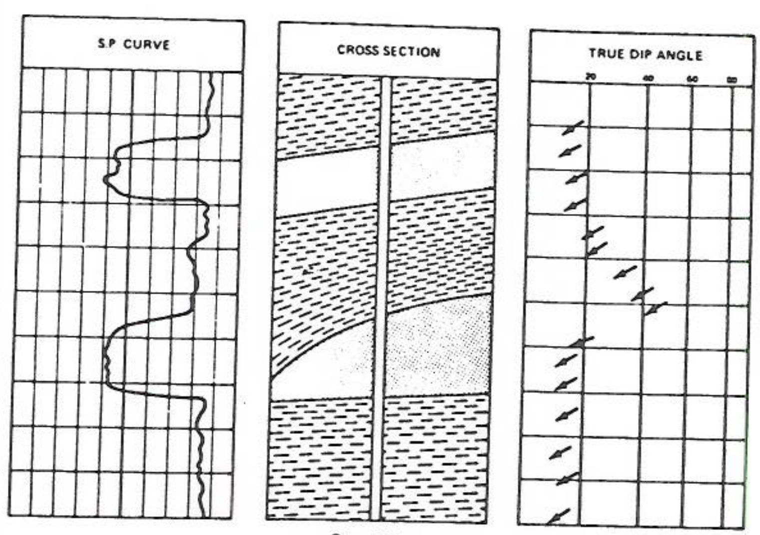
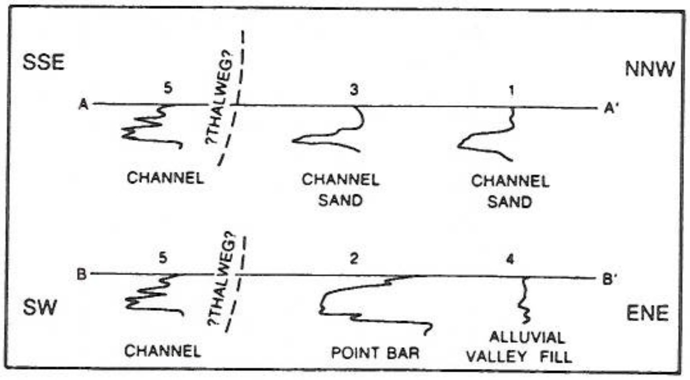


FIGURE 13
Type, shape and slope of channel, climate, vegetation, water discharge rate, and sediment supply all contribute to channel morphology



Sand Bar

FIGURE 14
Vertically-exaggerated, two-dimensional graphics also oversimplify "drape patterns over bars"



PREDICTED POINT BAR SAND
RED DIP PATTERNS
BLUE DIP PATTERNS

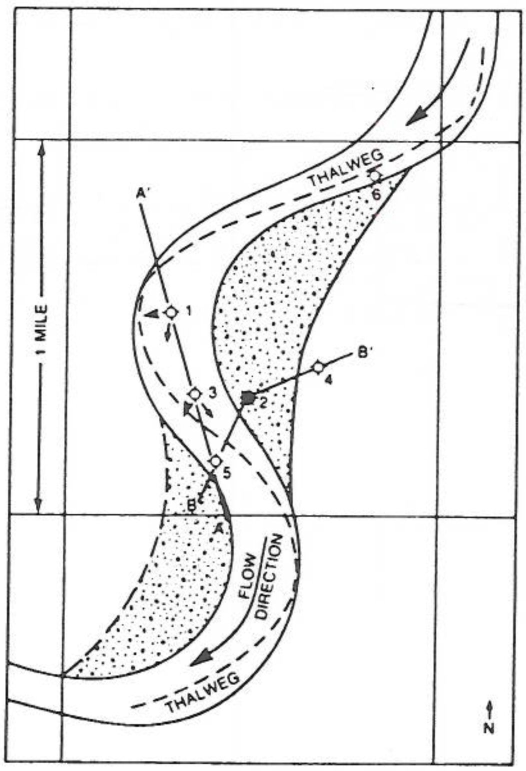


FIGURE 15A
Initial interpretation of meander belt, channel clay-plugged

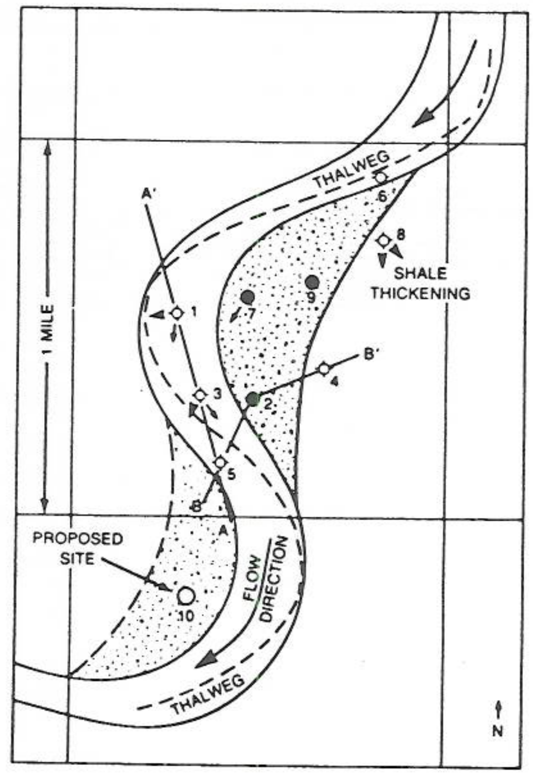


FIGURE 15B
Interpretation after 9 wells — Next point bar downstream is predicted in area of proposed No. 10 borehole

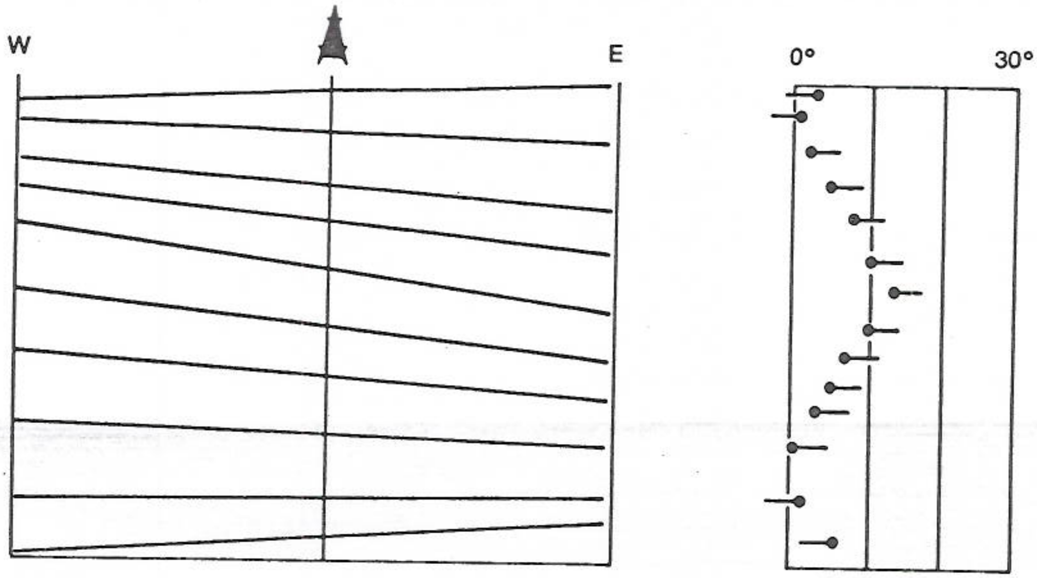


FIGURE 16
Red dip patterns indicate down-dip thickening; blue dip patterns indicate down-dip thinning

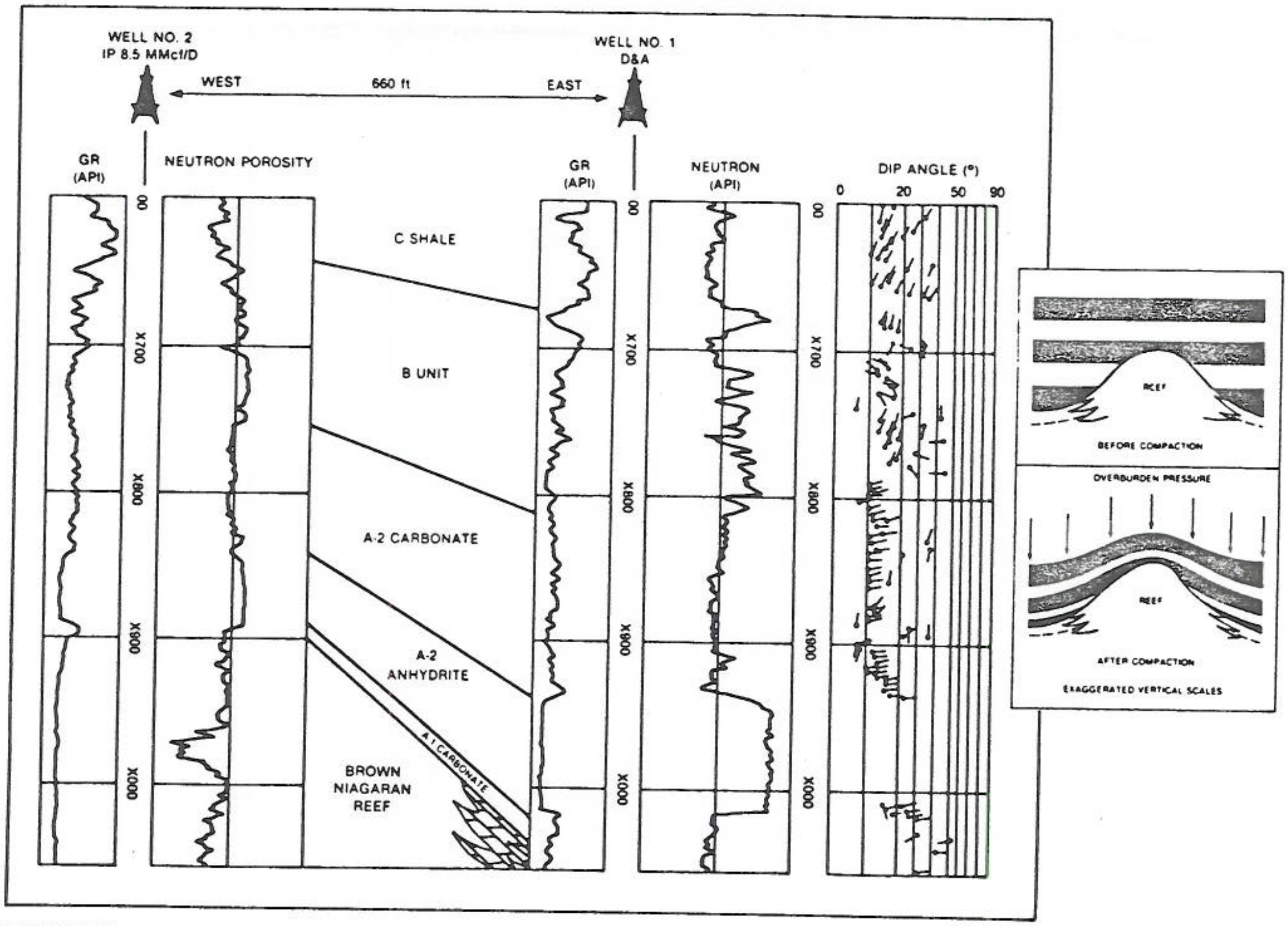


FIGURE 17
Two Michigan wells that illustrate the effectiveness of dip data in reef exploration

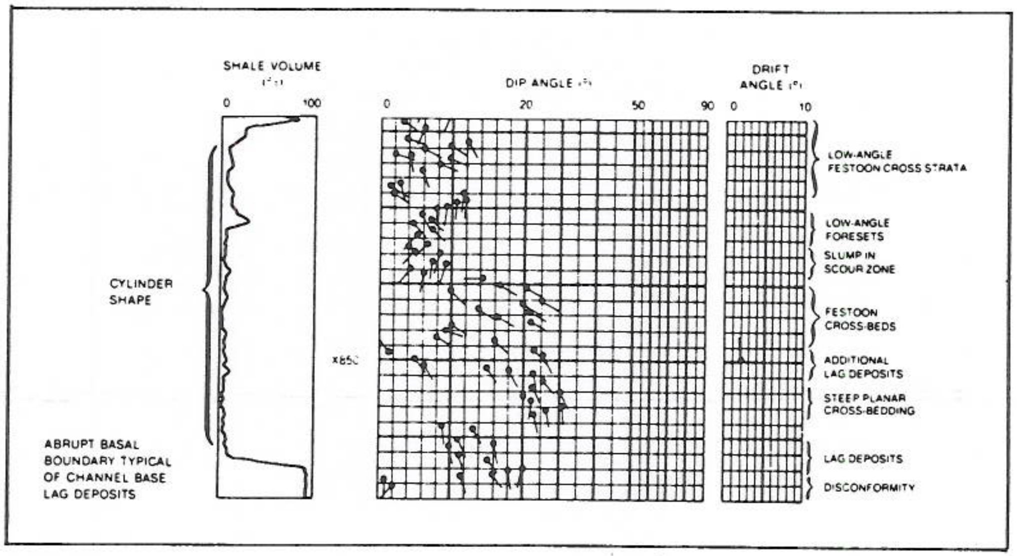


FIGURE 18
Red and blue dip patterns within a reservoir

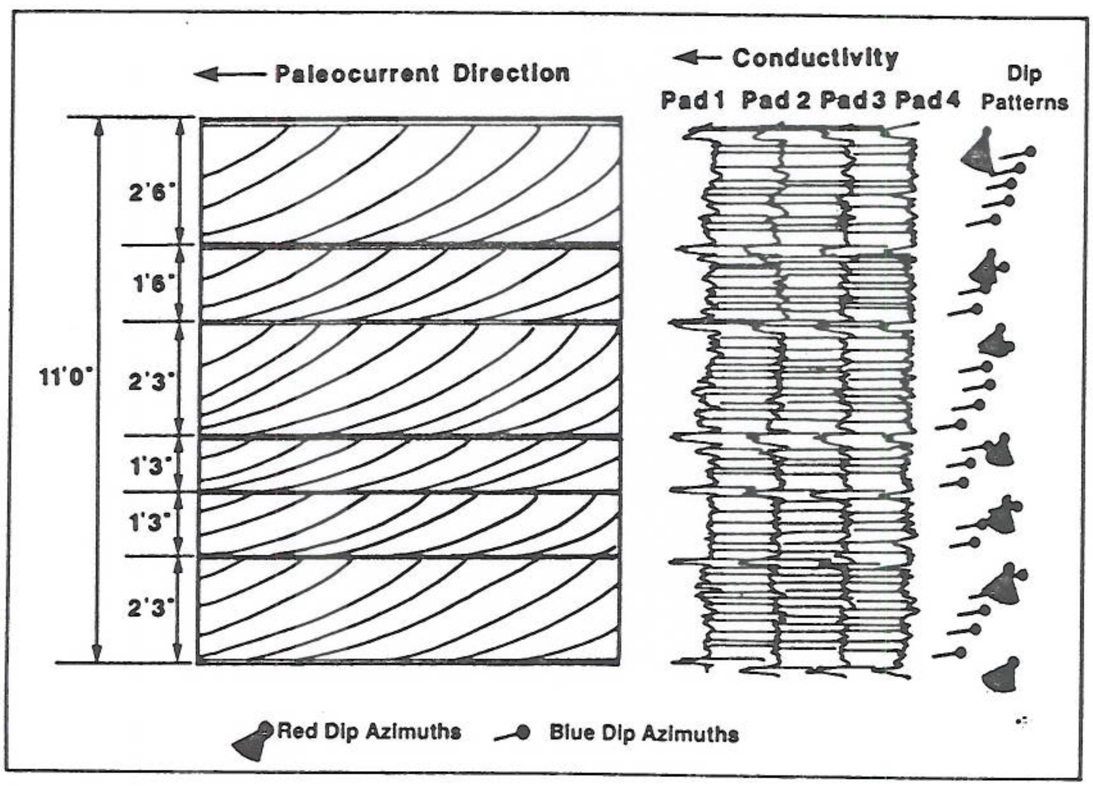


FIGURE 19
Detailed processing is needed to acquire internal bedding features

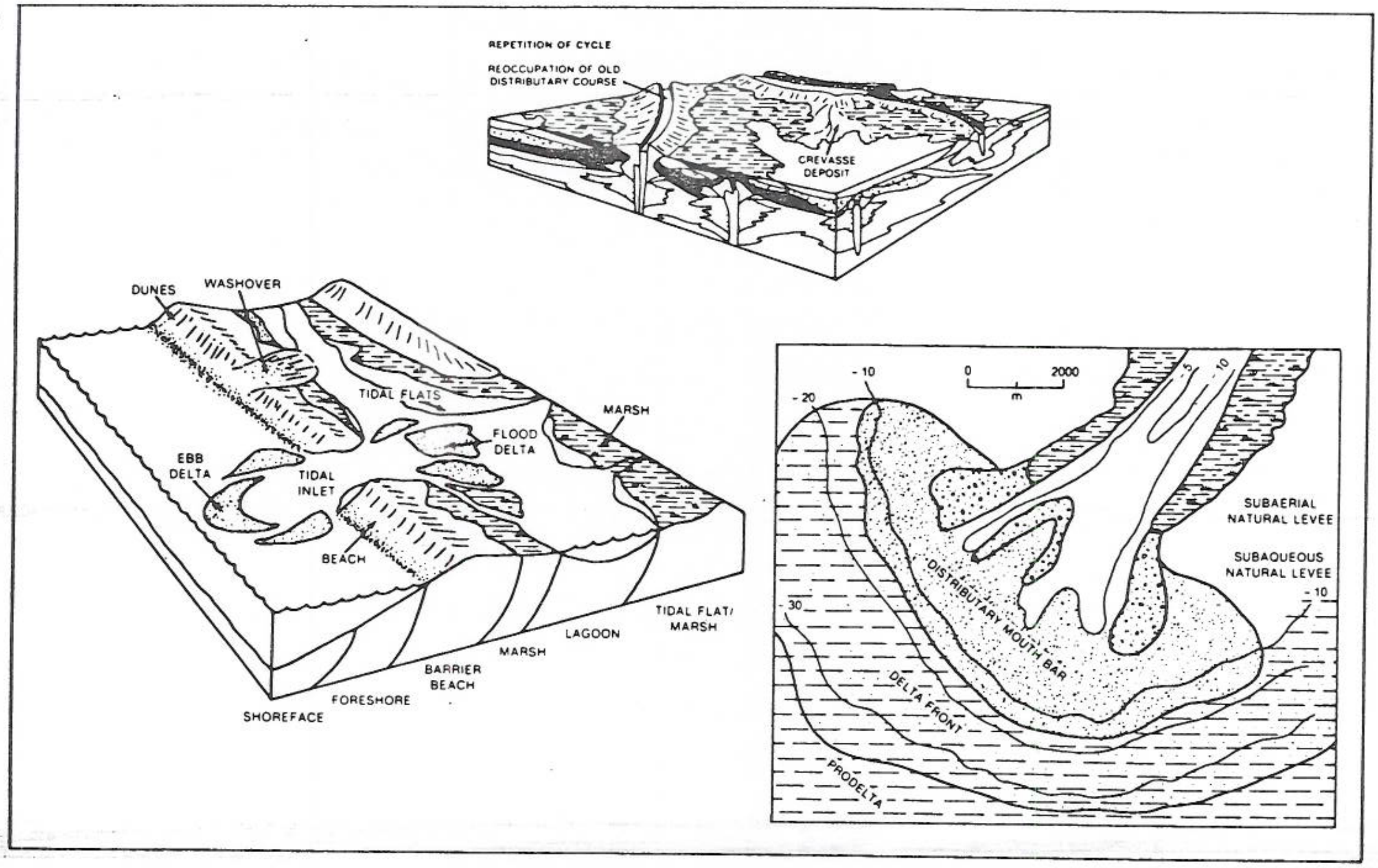


FIGURE 20
Internal sedimentary features vary considerably between barrier coasts and delta distributary systems and affect orientation of porosity and permeability

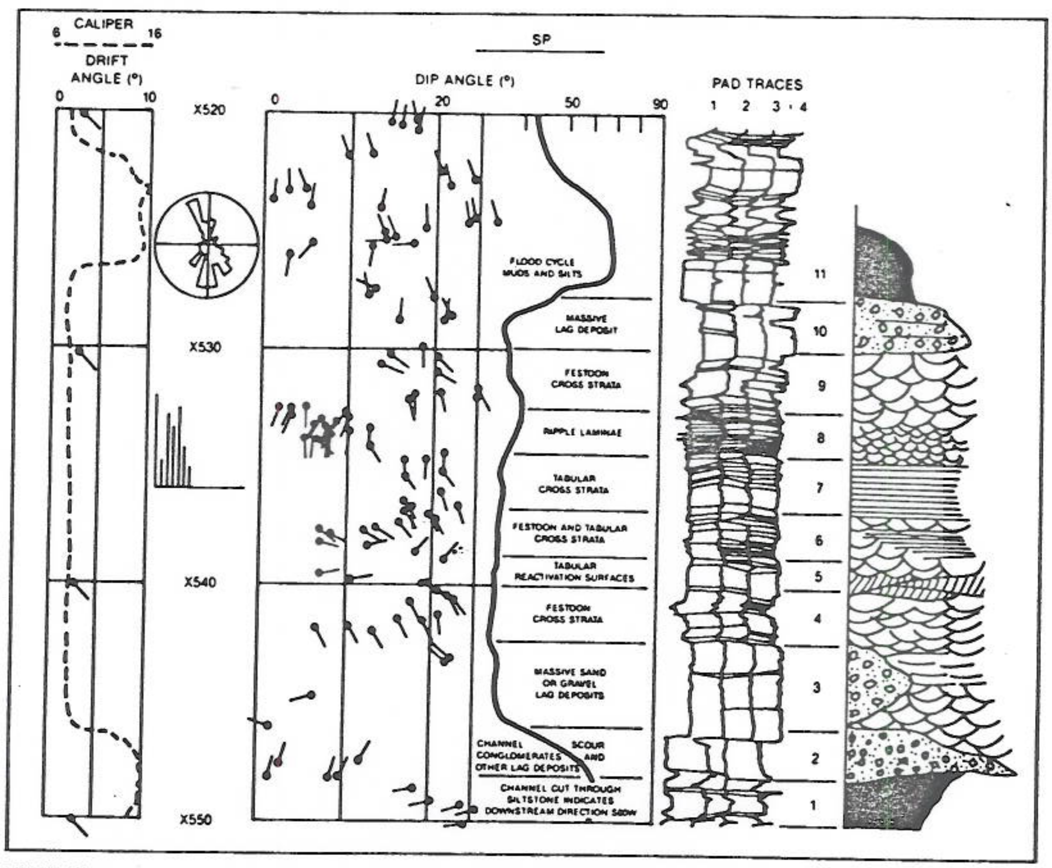


FIGURE 21
Strata Dip® data and subsequent analysis of a meandering stream point bar deposit