A COMPUTERISED ELECTROMAGNETIC GONIOMETER AND ITS APPLICATIONS IN THE STUDY OF RESERVOIR ANISOTROPY

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Abstract Accurate measurement of bedding features and fractures on whole core and slabbed core can be made using an electromagnetic goniometer. Data manipulation and plotting of data in coloured dip logs and stereonet, rose diagram and histogram plots allows the orientation of the features of interest to be identified. This has applications in determining the orientation of features affecting reservoir anisotropy such as fracture patterns and sand body geometry.

INTRODUCTION

The use of a computerised electromagnetic goniometer (EMG) allows precise, accurate measurement of planar and linear features on whole or slabbed core. The compatibility of the goniometer data files with report generation software allows clear presentation and therefore rapid interpretation of the orientation data. Bedding structures and fractures are major contributors to producing reservoir anisotropy. The accurate measurement of these features allows the production of a more detailed reservoir geological model resulting in a more accurate field development program.

THE ELECTROMAGNETIC GONIOMETER

Goniometer Hardware

The hardware of the electromagnetic goniometer consists of five main elements. An electromagnetic source is housed under the core holder and produces a field of sufficient strength to digitize core segments of up to 1 metre long. The core rests on a non-metallic holder consisting of two moveable rollers. The core is digitized in the three-dimensional electromagnetic field using the stylus and foot pedal. The position of the stylus is recorded by the computer when the foot pedal is pressed therefore allowing the linear or planar geological features to be digitized. The digitizer is interfaced with a personal computer (PC) which is operated by menu driven software.

Goniometer Software

Calibration of the goniometer, input of well deviation data and digitization of the geological features is carried out by a user friendly, menu-driven EMG-200 software.

The initial operation required by the goniometer is the calibration of the three-dimensional digitizer. The ends of the rollers on the core holder are digitised using the stylus and foot pedal. The computer records the position of the rollers in the electromagnetic field which allows the position of the features within the core to be recorded relative to the location of the rollers. As a check to ensure that the goniometer is operating correctly, a number of features on a plastic calibration core are measured. These features, which have a range of known orientations, are measured before and after the study. The goniometer is accurate to $\pm$ two degrees for all orientations (Garrett et al., 1988).

The electromagnetic goniometer is capable of measuring core from deviated wells. Once the well deviation data has been input the for core, the goniometer will automatically take this into account when bedding or structural features are recorded.

Prior to the digitizing of the geological features, the core is cleaned, carefully pieced together and described using core data/preservation sheets. These sheets are used to record the lithology, bedform, rubble zones, spin surfaces and core breaks plus any additional information. The core is measured in sections up to 0.7m in length which are placed on the rollers. A reference line on the core (scribeline, line of maximum bedding dip azimuth, or arbitrary line) is initially digitized using the stylus and foot pedal for each section of core and the depth, length and diameter of the core recorded. This locates the orientation of the core in the electromagnetic field enabling the core to be rotated on the rollers to allow bedding features and fractures to be digitised.

The orientation of the bedding features are calculated automatically, the well deviation is accounted for and the depth of the feature recorded. The computer will display the laboratory orientation or subsurface orientation on request. Once the bedding structure is recorded the menu-driven software automatically requires the geologist to input qualifiers to the feature. The qualifier options for the nature of the bedding features includes wavy, planar or discontinuous. The description of the type of bedding are true, cross, planar, shale or regional. The nature the contact is described using the erosional, sharp or gradational qualifiers.

Fractures, faults or slickensides also have a set of menu-driven descriptor options (Norman and Garrett, 1988). The type of fracture is recorded with a wide range of descriptors such as shear-normal, bedding plane and en-echelon. The condition of the fracture is an important feature, therefore the menu requires the geologist to state if the fracture is broken, open, vugular, closed or mineralized (with the mineral type and estimation of the percentage of fill). The presence of dead oil, oil and tar within the fracture is also recorded. The lithology of the host rock is recorded using a number of available options ranging from sandstone to metamorphic. The origin of the fracture is of highest importance so it is vital to distinguish between the fractures induced by coring and those occurring naturally within the rock. The geologist is therefore required to state if the fracture is induced, natural or possibly induced. Slickensides are measured on the surface of a fault using the stylus. The trend and plunge of the slickenside is recorded.

CORE ORIENTATION

Introduction

In order to carry out a successful goniometer study on bedding or fractures it is vital to accurately orientate the core. There are two main methods of core orientation which are either carried out downhole or in the laboratory. It should be noted that these core orientation techniques are not always 100% reliable. It is therefore recommended that every effort should be made to ensure that consistent orientations are produced, if possible by more than one method. A summary of the core orientation methods used in goniometer studies are presented below.

Downhole Orientation

Downhole core orientation has been carried out for many years, but recently measurement during drilling techniques have led to major advances. With modern technology it is possible to continuously measure the downhole orientation of the scribelines on the core. The data provided is subsequently more accurate and enables the core to be oriented more reliably, although there are often problems due to mechanical failure (eg. excessive spiralling of the scribelines). The major problem in the use of downhole oriented core is correlation between the core and orientation survey data.

Laboratory Orientation

Using dipmeter logs or structural maps it is possible to orientate the bedding features or fractures within the core. A reference line is initially drawn along the line of maximum dip azimuth on the core sets. In order to correctly position this reference line, the beds should be clearly visible and the apparent dip must be greater than 5 degrees. The orientation of this reference line is determined from analysis of the dipmeter data or from the structural map.

It is also possible to orientate the core using palaeomagnetism techniques. Although this method has the advantage of not needing any additional data, it does require strongly magnetic minerals within the core and the reference palaeomagnetic pole at the time of magnetism must be known (Davidson and Hazseldine, 1983).

APPLICATIONS OF THE ELECTROMAGNETIC GONIOMETER

Introduction

Fracture and bedding structures are two major elements of reservoir anisotropy. To fully understand the reservoir properties of the oil-bearing formation it is necessary to have the most precise and accurate information on the directional properties of the bedding structures or fractures. The more detailed the information on the bedding or fractures within the reservoir zone, the better will be the geological model leading to a more specific reservoir development plan for the well and field.

Fractures

In many oil producing areas throughout the world fractures are a major controlling element in the reservoir characteristics of the fields. Fractures can restrict or enhance the permeability of the rock or locally may act as the reservoir itself. In some cases the full effect of fractures on the reservoir characteristics of the well or field is unknown until the development program is in progress. It is therefore essential to measure and understand the joints within any fractured reservoir as a part of the development program (Figure 1).

Fractures within reservoirs can be classified into three major types:- regional, fold associated or fault-related joints. Regional fractures which generally occur at a high angle to bedding across a sedimentary basin can have a major effect on the migration of hydrocarbons. For example, in the Spraberry trend of west Texas, oil production is controlled by the regional fracture trend of 025 degrees (Wilkinson, 1953). The goniometer data would allow the subsurface orientation of the regional fracture trend to be quickly identified and illustrated using rose diagram or contour plots of the data. A population of fractures recorded from a cored interval may have a wide range of orientations and characteristics (Figure 2a + b). By using the goniometer software, it is possible to determine the strike and dip which have a particular group of characteristics, for example, oil stained fractures (Figure 2c + d). The geologist can therefore make rapid interpretations about the effect of the fractures on the reservoir characteristics. If the goniometer study was carried on a field wide basis the details of the fracture system could quickly be mapped out in 3-dimensions allowing a detailed development or stimulation program to be evolved.

In several areas the best reservoir characteristics are found where fractures occur associated with folds. A good example of this phenomenon was documented in South Dakota in the Sanish pool of the Antelope field (Murray, 1968). In fields where the reservoir characteristics are controlled in part by fractures associated with folding, the goniometer data will enable the relationship between bedding and fractures to be established.

It has long been recognised that fractures occur in association with major faults. Fractures often occur in such a high density that the reservoir characteristics of the rock are enhanced greatly. For example, Stapp (1977) documented the high density of fracture and brecciation zones on the downthrown side of fault blocks in the Gulf Coast. These fractures within the Austin chalk greatly improved the producing characteristics of the hangingwall wells in comparison to the footwall wells. In addition to the standard plots of the fracture orientations, the goniometer software allows the density of fractures to be plotted against depth. In these plots it is also possible to show the density of mineralised or oil stained fractures as well as total fracture density (Figure 3). This would allow the zone of maximum brecciation to be readily identified.

Regional Structural Applications

The data measured in a goniometer study could be used to interpret the structure of the field, especially if multiwell goniometer studies were carried out. For example, the recognition and measurement of microstructures such as small faults or slickensides can give important indications of the structural evolution of the field. The use of detailed goniometer data as input for geological cross-section construction programs would have a distinct advantage over dipmeter data. The geologist using the cross-section construction program would, by using accurate, precise data, know exactly what type of bedding features are present in the well. The information on the microstructures within the cored interval would also be useful in making the best interpretation of the structural processes which could have occurred during the evolution of the area covered by the cross-section.

The electromagnetic goniometer can also be successfully used to validate dipmeter data. The laboratory dip of the sediment within the core is measured by the goniometer. The subsurface dip as recorded by the dipmeter is returned to the laboratory orientation by removing the well deviation. If the dipmeter survey is accurate the laboratory dip as calculated from the dipmeter should correlate with the dip measured in the core.

Sedimentology

Sedimentary structures can be used to determine the nature of depositional sequences both in terms of the individual bedding structures and in the geometry of sand bodies. Although the goniometer allows the study of sediments from all environments, fluvial and aeolian depositional environments provide excellent examples of its application for reservoir geology.

Applications in fluvial systems

Determination of the orientation of bedforms within fluvial channel sandstone bodies enables the geometry of sandstone reservoirs to be established. This is important in a fluvial channel sequence where the overbank environment may be dominated by mudstones and siltstones with low reservoir potential. The optimum drilling program would aim to drill along the length of the channel sandstone body.

Using the electromagnetic goniometer enables accurate information to be gained about the orientation of sedimentary structures. This data can be plotted as a tadpole depth-plot with structure type (cross-bedding, bedding planes, erosion surfaces) individually identified by colour or by symbols. The data can be further sorted and plotted using the report generation software.

A dip profile, measured by goniometer, of a fluvial channel sequence is shown in Figure. 4. The sequence represents a series of stacked, cross-bedded, channel sandstone bodies separated by laminated shales and siltstones. Cross-beds, bedding planes and erosion surfaces can be clearly identified by the tadpole plot. Using the report generation software the data can be selectively plotted as stereonet plots, rose diagrams and histograms to highlight or illustrate features of interest. In the example, above a rose diagram of all bedding features shows a wide scatter of data with no clear indication of sand body geometry (Figure 5). However, by plotting cross-bedding data for each channel sequence in turn, for example Unit 1 (Figure 6), a more precise channel trend can be established. Using this software a correction can also be made to remove structural dip, determined by plotting a histogram of bedding planes for the unit, resulting in palaeocurrent plots for channel sandstone bodies giving sand body trends which can be entered into the geological model.

The format of the tadpole plots is also flexible, downhole dipmeter data can be plotted alongside the dip data measured from the core. The coloured tadpoles enables a comparison to be made between the dipmeter and identifiable features in the core, thus interpretations can be made about sedimentary features in the uncored intervals.

Applications in Aeolian systems

Reservoir anisotropy is an important feature in aeolian deposits whereby some aeolian dune types form sandstone bodies parallel to the palaeowind direction (seif dunes) and others are perpendicular to the palaeowinds (barchan and transverse dunes). These are the most common aeolian bedforms found in Rotliegend sequences in the North Sea area and were deposited by northeast trade winds in a northwestern European Permian desert (Glennie, 1972).

Barchan dunes commonly form isolated sand bodies and are characterized by a single slip face dominantly perpendicular to the main transport direction, although with a mean dip azimuth angular deviation of 54° (Ahlbrandt and Fryberger, 1980). Barchans may coalesce to form transverse dune ridges which form elongate sand bodies also perpendicular to the main palaeowind direction. In contrast, seif or longitudinal dunes form sand bodies parallel to the main palaeowind direction. They are characterized by two slip-faces, one either side of the sand ridge, although the seif dune may be slightly sinuous with slip-faces developed on alternate sides.

The results of a typical goniometer study of an aeolian sequence is shown in Figure 7. Measurement of the dune foresets results in two clear fields of dip orientation. Barchan and transverse dunes form a cluster of data which dip downwind, in contrast the seif dunes have slip-faces almost parallel to the main wind direction.

Thus in a detailed sedimentological study of aeolian sequences, incorporating a goniometer analysis of bedding orientation, dune type and wind direction can be established resulting in important information being gained about sand body continuity, orientation and therefore reservoir anisotropy.

CONCLUSIONS

The Electromagnetic Goniometer is easy to use and produces quick, precise and accurate data measurements. The integration of the goniometer with the report generating software enables clear, flexible and accurate presentation of the results.

The EMG has applications in the study of both structural geology and sedimentology in reservoir analysis and allows the factors affecting reservoir anisotropy to be more clearly understood.

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REFERENCES

AHLBRANDT, T.S. and FRYBERGER, S.G. (1980). Eolian deposits in the Nebraska Sand Hills. "U.S. Geol. Survey Professional Paper", **1120A**, pp. 1-24.

GARRETT, C.H., SHARER, P. AND HALSEY, J. (1988). Natural fractures and electromagnetic goniometry. "The Informer" Core Laboratories Publ. Iriving, Texas.

GLENNIE, K.W. (1972). Permian Rotliegendes of northwest Europe interpretated in light of modern desert sedimentation studies. "Am. Assoc. Petrol. Geol." **56**, pp. 1048-1071.

DAVIDSON, I. AND HAZSELDINE, R.S. (1983). Orienting conventional cores for geological purposes: a review of methods "Jour. Petrol. Geol." **7** pp. 461-466.

MURRAY, Jr. G.H. (1968). Quantitative Fracture Study - Sanish Pool, McKenzie County, North Dakota "Am. Assoc. Petrol. Geol.", **52**, pp 57-65.

NORMAN, D.K. AND GARRETT, C.H. (1988). Advances in fractured reservoir characterisation. "Pet. Soc. Can. Inst. Mins." Paper No. **88**-39-111.

STAPP, W.L (1977). The geology of fractured Austin and Buda Formations in the subsurface of south Texas. "Transactions, Gulf Coast Association of Geological Societies", **27**, pp. 208-229.

WILKINSON, W.M. (1953). Fracturing in Spraberry Reservoir, west Texas. "Am. Assoc. Petrol. Geol". **33** pp. 250-256

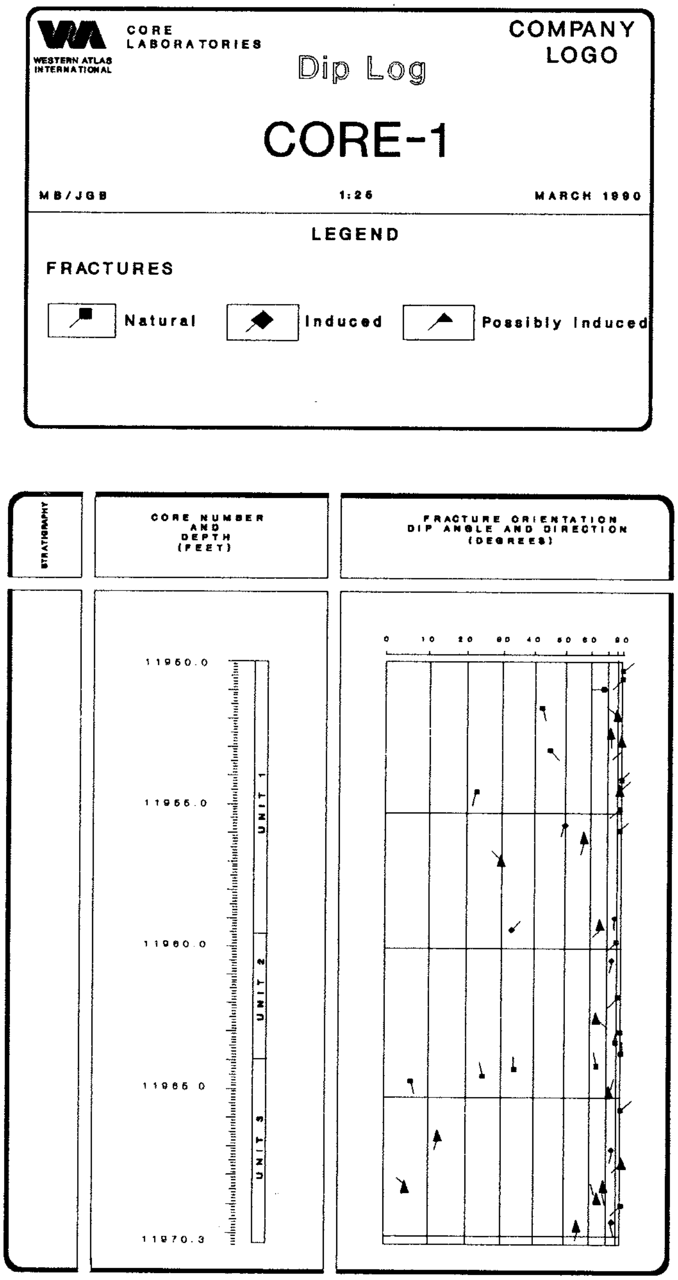


Figure 1.
Example Of Fracture Dip Log Plot

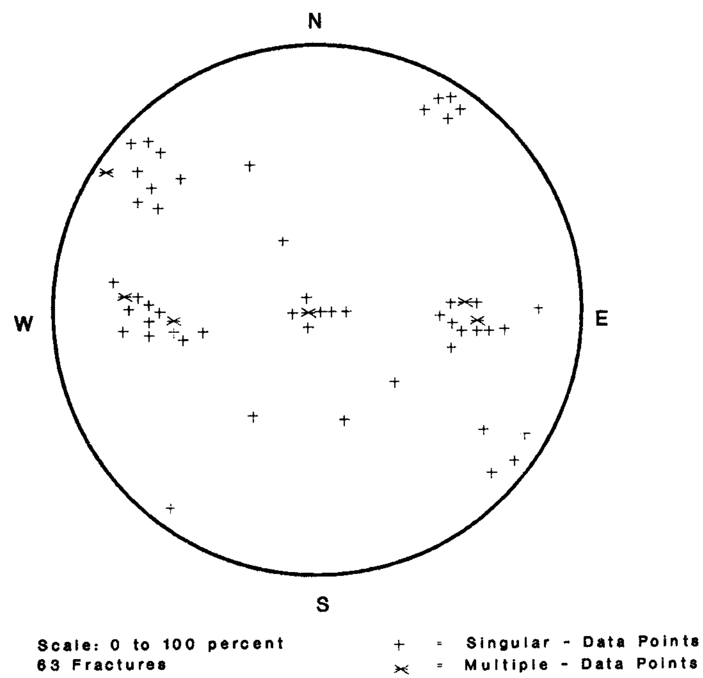


Figure 2a.
Poles To Fractures For Whole Cored Interval

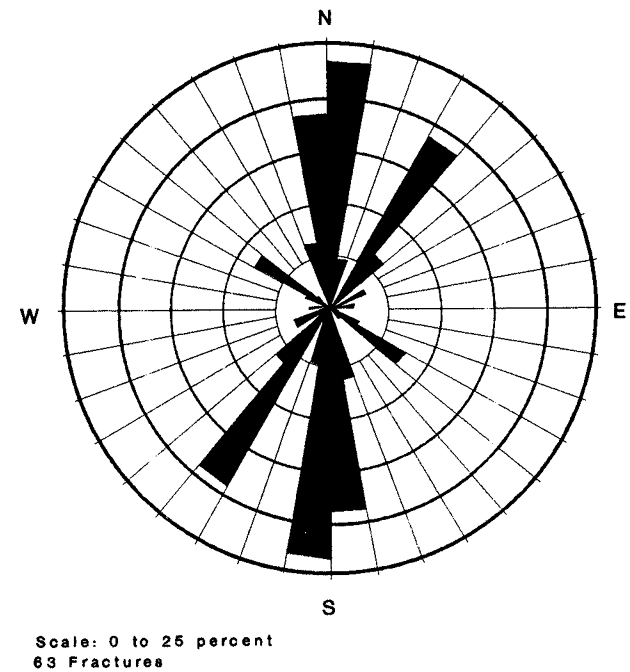
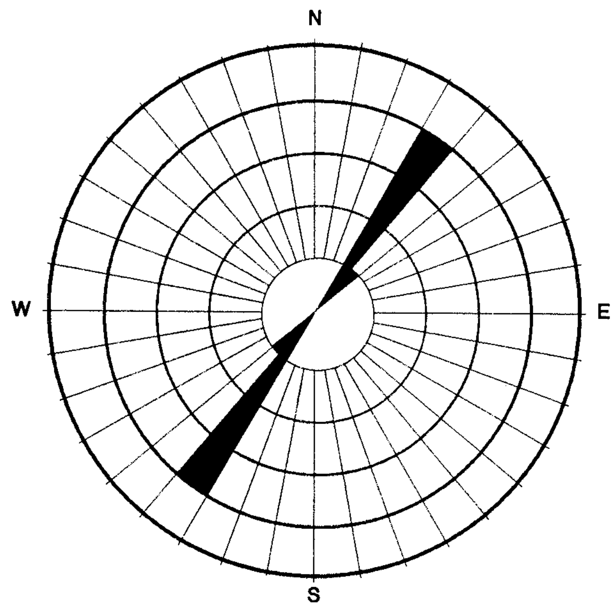
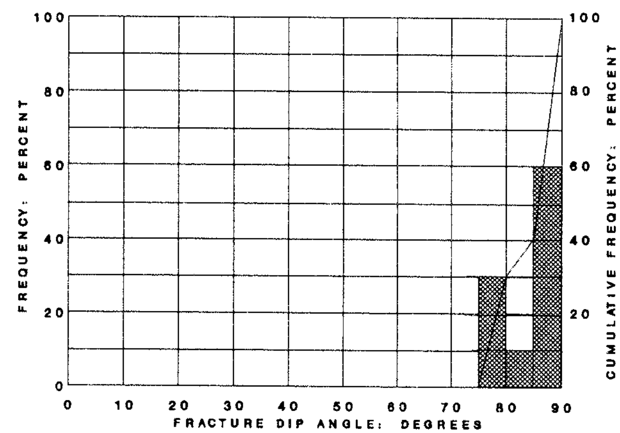


Figure 2b.
Percentage Distribution Of Fracture Strikes For Whole Cored Interval



Scale: 0 to 100 percent
10 Fractures

Figure 2c.
Percentage Distribution Of Fracture Strikes
For Oil Stained Fractures



10 Fractures

Figure 2d.
Fracture Dip Angle Histogram
For Oil Stained Fractures

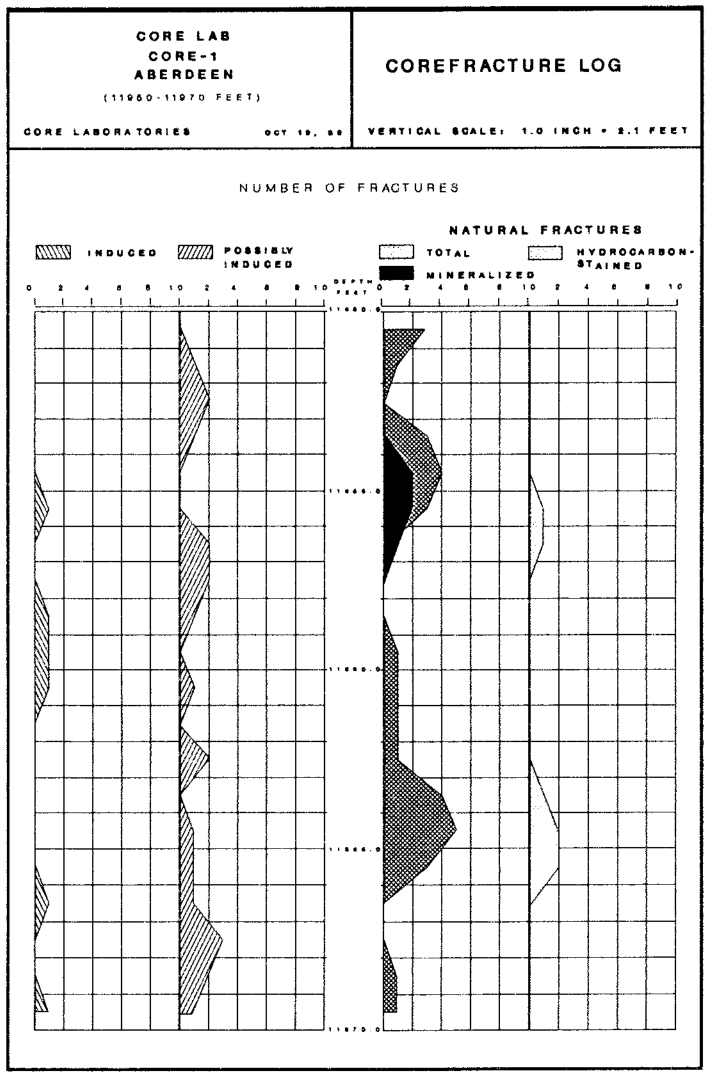


Figure 3.
Example Of Corefracture Log Plot

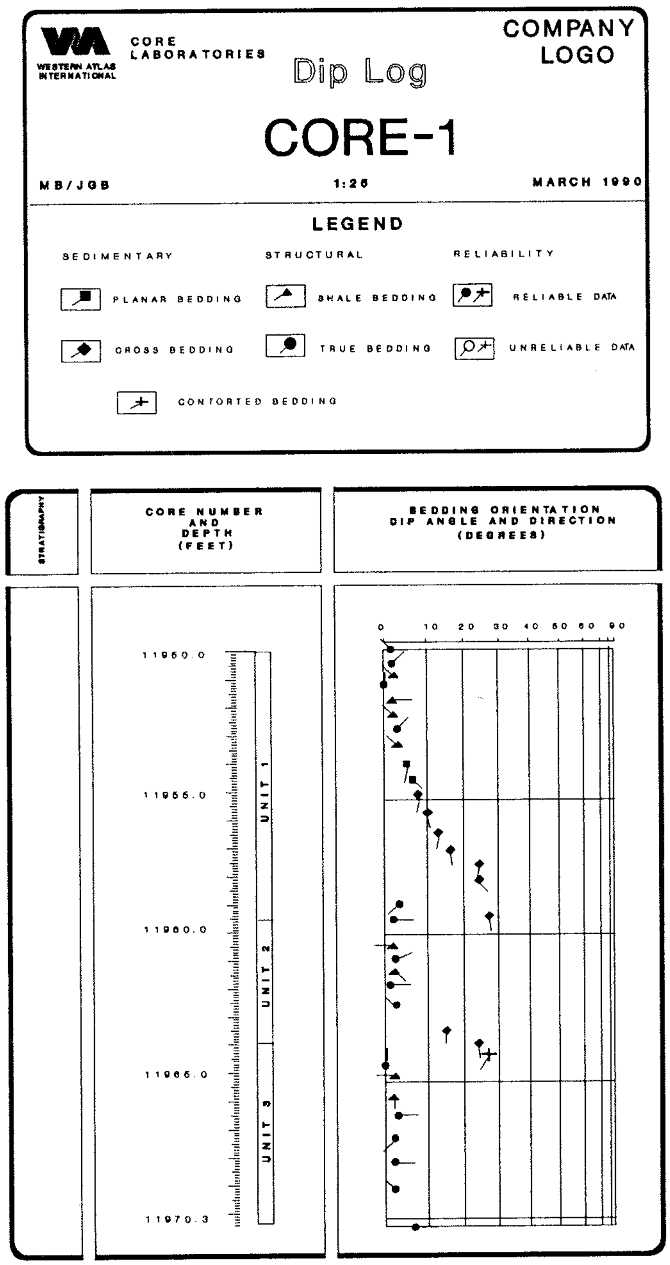
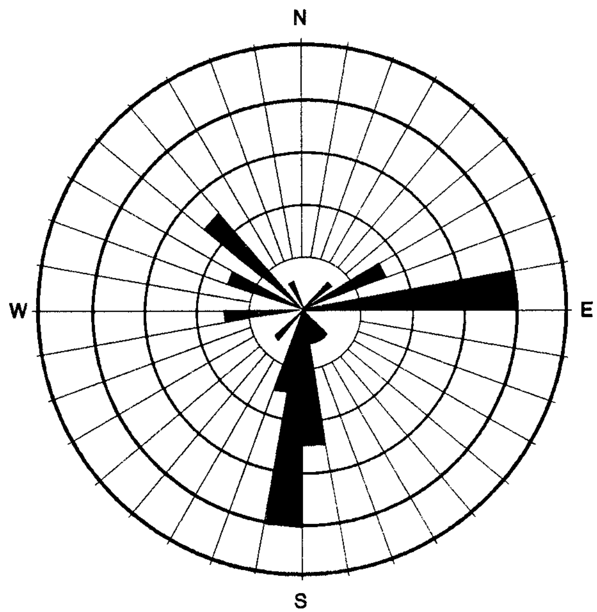
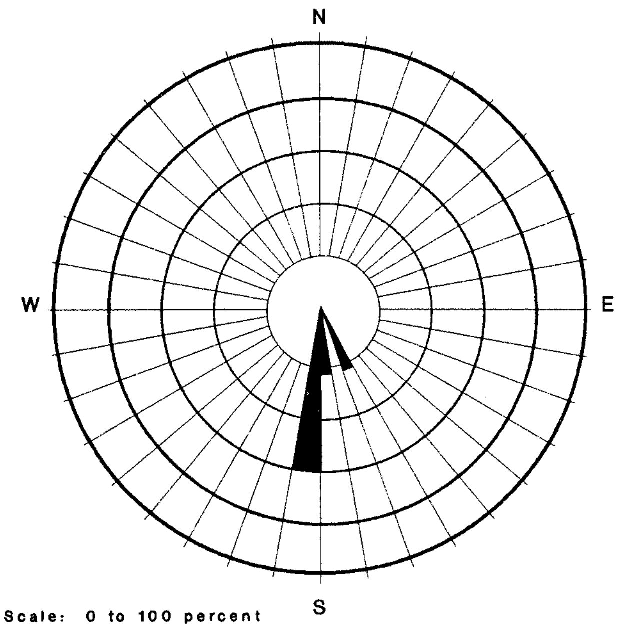


Figure 4.
Dip Log Of A Fluvial Sequence Using
The Electromagnetic Goniometer



Scale: 0 to 20 percent
31 Bedding Structures

Figure 5.
Percentage Distribution Of All Bedding Dip Azimuths In Units 1-3



Scale: 0 to 100 percent
9 Cross-beds

Figure 6.
Percentage Distribution Of Cross-bed Dip Azimuths In Unit 1 Channel Sandstone

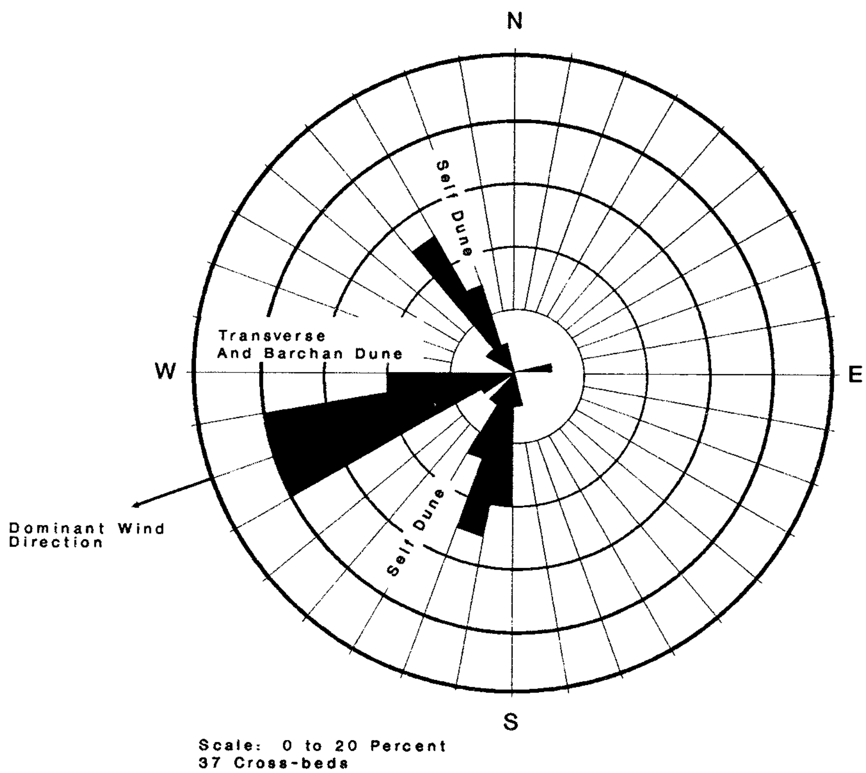


Figure 7.
Percentage Distribution Of Cross-Bedding Dip Azimuth
Identifying Seif And Barchan/Transverse Dunes