USE OF CT SCANNING IN THE INVESTIGATION OF DAMAGE TO UNCONSOLIDATED CORES

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ABSTRACT

The use of Computed Tomography (CT) scanners has proven to be a valuable tool in the evaluation of damage to unconsolidated cores. When examining sleeved cores to determine slabbing angle, undamaged sites for future plug and whole core analysis, sample heterogeneity and depositional features, CT scanning proves invaluable by providing nondestructive internal inspection capability.

The core material recovered from these unconsolidated friable formations typically undergoes a series of damaging alterations between in situ conditions and the laboratory. Studies have shown that improper handling techniques in the lab can often do as much damage to the core as the coring, wellsite handling and transportation phases. In the process of investigating the fragility of these sands and evaluating which processes are generally responsible for their damage, CT scans aid in greatly reducing such damage in subsequent cores by revealing not only the magnitude of the damage but also the implied cause in many cases. Examples are provided to demonstrate the effect of several types of core damage from both unavoidable sources such as pressure and temperature changes associated with bringing the core to the surface to the more catastrophic events resulting from physical shock. Invasion profiles and other useful drilling information can also be gleaned from this technique.

INTRODUCTION

In attempting to understand the nature of unconsolidated reservoirs encountered in the Gulf of Mexico, a renewed effort has been undertaken in the past few years to obtain cores from these sands. The advent of rigid inner barrel liners such as Aluminum, PVC plastic or fiberglass has resulted in improved preservation of the physical integrity of unconsolidated cores while new bit and catcher designs have produced high recovery percentages with low mud invasion damage.

However, subsequent inspection of these recovered cores has shown there is still considerable damage being done during coring, handling and transportation. Computed Tomography (CT) scanning has allowed investigation of the extent of this damage and recognition of areas where future alteration might be reduced. Evaluation of the core is also enhanced by using the ability of the CT scanner to look inside the opaque inner core barrel sleeve and determine proper orientation for slabbing, depositional features, whole core sample intervals and homogeneity of samples selected for analysis.

CT SCAN MEASUREMENT AND THEORY

X-Ray Tomography (CT scanning), originally developed in the medical sector, has found wide applications in the petroleum industry. CT scanning technology provides the capability of nondestructive visualization and analysis of the internal structure of core materials.

CT images are created by measuring the attenuation of a collimated X-ray beam after passing through a given substance. The sample attenuates the X-ray beam in an exponential manner such that:

$$I=Ioe^{-ux}$$

where Io and I represent the intensity of the X-ray beam before and after passing through the substance, x is the pathlength and u is defined as the linear attenuation coefficient. The attenuation coefficient u for that material is a function of the atomic number and bulk density of the material and the energy of the probing X-rays.(ref. 1)

To create a slice or cross-sectional image, the X-ray attenuation is measured for a multitude of different angles. A cross sectional reconstructed image is generated (figure 1) which represents the X-ray attenuation in specific volume elements or voxels of the material scanned. A surview or preview image is created (figure 2) by holding the position of the source and detectors constant and translating the sample with respect to the plane containing the source and detectors.(ref. 2) Examples of both of these scans will be presented.

USE OF THE CT SCANNER TO AID IN CORE INSPECTION AND ANALYSIS

SAND SHALE LAMINATIONS

Evidence of bedding planes and other depositional features are sometimes visible from CT scans. A surview scan (figure 3) indicates this interval to be a finely laminated series of sands and shales. Remember that the density difference of the sand and shale material provides contrasting CT attenuation. Similar interpretative models can be made for almost any two substances with differing X-Ray absorption characteristics.

ORIENTATION OF CORES FOR PROPER SLABBING ANGLE

Recovered conventional cores are usually slabbed longitudinally at an orientation which will reveal the maximum dip angle whether caused by deviation of the wellbore or natural tilting of the cored beds. This slab face is important not only in the study of depositional features, but also in the later plugging of the core to insure that the plug samples are taken parallel to the bedding. Since the cores usually arrive at the lab in an opaque inner barrel of PVC plastic or fiberglass, the direction of maximum dip must be determined by either opening the tubes for visual inspection or by CT scanning. This surview (figure 4) of a section of core from a deviated well shows laminated beds which are highly dipping. By examining a cross-sectional slice through the interval (figure 5), the laminations can be oriented properly for slabbing.

INTERNAL BEDDING FEATURES

Occasionally the CT scan can reveal subtle differences in bedding features in addition to the normally evident structural relief. In this example, the surview (figure 6) apparent dip of the formation beds in the small section of the core near the top is quite steep, however the breaks across the core are horizontal, suggesting that the sand and shale beds have very little structural dip. The apparent dip in this upper small sand interval is due to cross bedding in the formation and not structural dip. A slice (figure 7) through the crossbedded section reveals numerous light and dark stripes indicating cross beds in the core.

MISSING SECTION AND SAMPLE SELECTION

CT scanning of the core prior to slabbing not only aids in orientation and bedding recognition, but has the obvious advantage of screening sections of the recovered material for continuity and future analysis sites. Such information aids greatly in the selection of whole core sample intervals and determination of overall recovery. This surview scan (figure 8) shows a dark area in the upper portion of the core. A slice taken through the interval (figure 9) confirms that no core is present here and only a small amount of drilling mud remains, as evidenced by the brightness of the scan.

INCLUSIONS

The selection of samples for certain types of analysis requires that they be representative of the majority of the formation and free of any unusual mineral inclusions. Some type of nondestructive internal inspection is very useful in selection of those samples. A slice scan (figure 10) through a section of core being considered for special core analysis work reveals a number of bright spots apparent in the core. Further analysis of the interval revealed these to be shell remains imbedded in the core. Not only is this information important stratigraphically, but such inclusions can cause errors in laboratory measurements and misapplication of results if they are prevalent but undetected. If mineral inclusions and selective cementation are common throughout the core, the decision to make some measurements with whole core sections to average in the effect of this heterogeneity may be necessary to accurately represent the reservoir.

EXAMPLES OF DAMAGE AND HYPOTHESES OF CAUSE

The importance of the CT scan technique in the inspection and analysis is enhanced by its value as a damage assessment tool. Determination of the magnitude and cause of damage to this fragile material is often the first step in prevention or reduction of future alteration. A number of examples of damaged core with accompanying hypotheses of cause are presented. Positive confirmation of the exact cause of the damage mechanism (or combination of mechanisms) was attempted for each example shown, but was not always possible due to the inability to duplicate closely the downhole coring process.

CORE SEPARATED AT SHALE LAMINATIONS DURING CORING

The most frequent alteration of the core is mechanical separation with accompanying mud invasion. This longitudinal or surview scan (figure 11) of a core section typifies the separation of a laminated sand-shale sequence at the shale boundaries. Inspection of the slabbed core from these sections usually confirms that the core indeed separated at a sand shale interface rather than within the shale itself. Separations of this type are more common in thinly bedded sands and shales rather than in thicker, more structurally stable shale beds. Invasion of barite weighted drilling mud into the cracks (shown here as the bright lines across the core) suggests that this separation occurred downhole during the coring operation. Prevention of this type of damage is very difficult due to the fact that the material is so fragile.

DIAGONAL FRACTURE

Cases of mechanical damage are often seen when inspecting recovered cores. In this series of scans a shock induced fracture is shown in the core. The surview scan (figure 12) identifies a fracture running diagonally across the center portion of the section. Slice views at points A-1 and B-1 were taken to ascertain if the apparent surface crack ran through the core. Slice A-1 (figure 13) taken below the disturbed area shows a homogeneous section of sand with very little damage evident except on the fringe of the core. However, slice B-1 (figure 14) reveals that the fracture indeed traverses the core. The mud invasion pattern shown by the partial filling of the crack with mud indicates that the damage occurred at or very near the surface. Subsequent inspection of the slabbed core revealed that the fracture was indeed caused by the coring and was not a natural fracture or fault. The diagonal nature of the fracture indicates a slump failure possibly caused by the weight of the core and was triggered by rough treatment of the core during surfacing or while in the vertical position on the rig floor.

CORE SPIN

There are a number of mechanical shocks and torque stresses applied to the core as it is being cut. These sometimes cause the core not only to break but also to rotate in the inner barrel. A surview scan (figure 15) of this core interval shows apparent bedding planes dipping from left to right across the upper half of the section. However, note that below the sharp bright line about midway down the section, the apparent dip reverses, indicating a change in orientation of the core inside the barrel. The rounding of corners of the core material just above and below the break, probably due to some erosion of sand as the core turned also suggests spin as opposed to some natural event. A slice taken through the break area (figure 16) shows mud invasion deep into the core. Inspection of the slabbed core confirmed this diagnosis and ruled out the possibility of an unconformity here.

RUBBLE

If the core barrel is not circulated clean just off bottom before commencing the coring process, it is possible to leave an accumulation of cuttings, shale slough, and drilling mud in the core barrel. In some cases, this rubble can jam the barrel preventing the core from entering. This surview scan (figure 17) identifies the contents of a section of core to be primarily rubble as evidenced by the mixture of large clasts and fill material. The sand clasts are surrounded by drilling mud further indicating non-competent core material. However, the material could be useful for stratigraphic and petrographic analysis in the event that it can be correctly depth correlated.

PLUGGING DAMAGE

In order to obtain parameters for reservoir properties from a core, plug samples are generally taken for cleaning and quantitative analyses. It is imperative that these plug samples reflect the reservoir as accurately as possible, both in representation of the reservoir character and in quantitative results. Taking plugs in unconsolidated cores is difficult at best and sometimes results in serious damage to the plug sample and the remaining core. An end view scan (figure 18) of a core plug taken from a section of laminated sand reveals two fractures in the plug across its face. Note that a side view of this sample (figure 19) shows the fractures traverse the entire length of the plug. Although these fractures may be closed up by the addition of simulated overburden pressure, the resultant analyses may be inaccurate and should not be used for precise quantitative comparisons.

A second plug example shows damage not only along the plug lengthwise (figure 20) but also partially across the core as well (figure 21). This combination of fractures make the plug unsuitable for any analyses involving flow characteristics.

MUD INVASION

The invasion of mud filtrate and especially mud solids into cores represents a common and often serious problem in the subsequent analysis of the core. The use of the CT scan is an invaluable aid in detecting the presence and location of such damage. This slice view (figure 22) of a core shows the bright signature of barite weighted mud invading deeply into the core. A profile of CT numbers is shown across the slice. Since the CT number is directly related to material density, and assuming a fairly homogeneous local sand density, the mud invasion is shown graphically. Closer inspection of these damaged areas revealed both mud filtrate and, more seriously, mud solids have invaded in some cases. These mud particles are difficult to clean from the core and will cause inaccuracies in subsequent core analysis work. The best cure in this case is obviously prevention of the invasion if possible by the use of face discharge coring bits and low fluid loss mud systems. Lost circulation material can be added in some cases to aid in this effort.

CONCENTRIC FRACTURES

One of the more common occurrences of damage to sections of clean, massive unconsolidated cores is that of concentric fracturing or separation inside the inner barrel. This deterioration is thought to be a result of freezing, transportation shock, torque applied while coring or a combination of all these factors. Very little evidence of radial fractures has been found at the rig site by visually inspecting tube ends of the three feet sections of recovered material. Close inspection of mud invasion and fluorescence patterns show that in most cases, the separation point coincides with the depth of mud invasion (figure 23). Since the mud filtrate is water and is replacing mostly hydrocarbons in the invaded zone, it provides a cement to hold the sand together as it is frozen, whereas the oil or gas saturated portion of the core does not freeze as completely or at the same rate. In core sections which were originally water wet in the formation, the concentric separation tends to be less severe or not present. However, some samples have been observed to exhibit this type of failure having never been frozen, suggesting that torque on the sample while it was being cored followed by transport shock may have caused the damage. Again these samples were oil saturated in situ and invaded by fresh water drilling mud.

PREVENTION OF DAMAGE TO UNCONSOLIDATED CORES

The fragile nature of unconsolidated formations makes them difficult to core and even more difficult to analyze and preserve without significant damage to the recovered material. Once the decision is made to attempt to core an unconsolidated reservoir, a number of precautions can be made to improve the success of the project. These preparations should begin early in the life of the well in determining compatible mud systems, well deviation, hole size and bottom hole assemblies which will increase the chance of good core recovery. Care must be exercised as well in wellsite handling, transportation, laboratory techniques used while slabbing and sample taking, and finally in the analysis procedures themselves.

SUMMARY

The CT scanner has proven to be invaluable in providing a means of internal inspection for cores. The practical uses now are aiding in understanding what happens to unconsolidated cores, where the damage occurs and how extensive it may be. In the previous examples a number of practical interpretive methods have been demonstrated as well as the illumination of the most common occurrences of damage to unconsolidated sands during coring and handling. By recognizing the extent and most probable cause of these damage mechanisms, steps can be initiated to prevent or limit their extent in future core plans. Recent software enhancements and instrument design improvements have enabled the industry to make further advances in core analysis. The next logical step is prevention or minimization of such damage through revised coring and handling procedures. Following this path will lead to better cores with improved reliability of analysis results which is the goal we are pursuing.

ACKNOWLEDGEMENTS

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TOMOGRAPHIC (SLICE) MODE

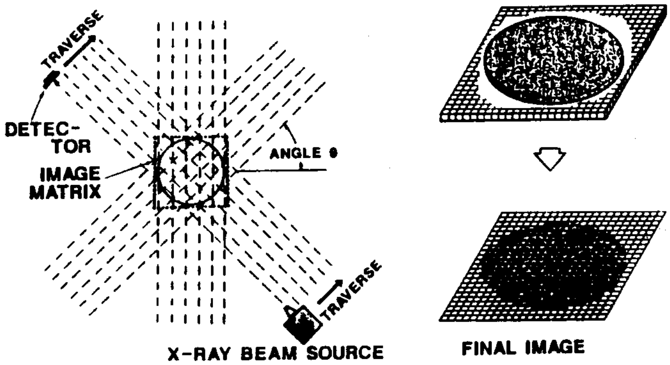

Figure 1. To create a cross-sectional image, the X-ray attenuation is measured for different angles.

SURVIEW MODE

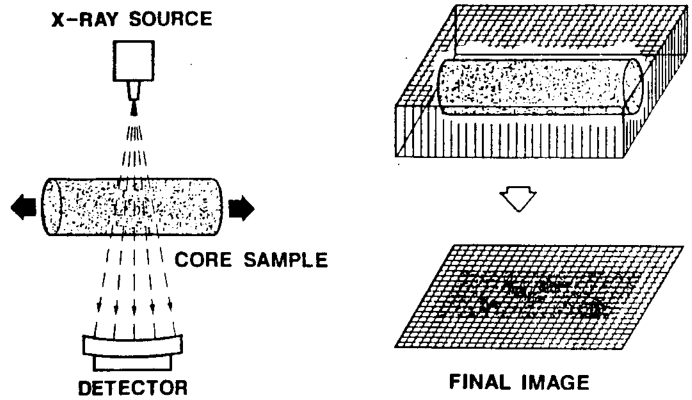

Figure 2. A surview or preview image is created by holding the position of the source and detectors constant.

Figure 3. A surview scan indicates this interval to be a finely laminated series of sands and shales.

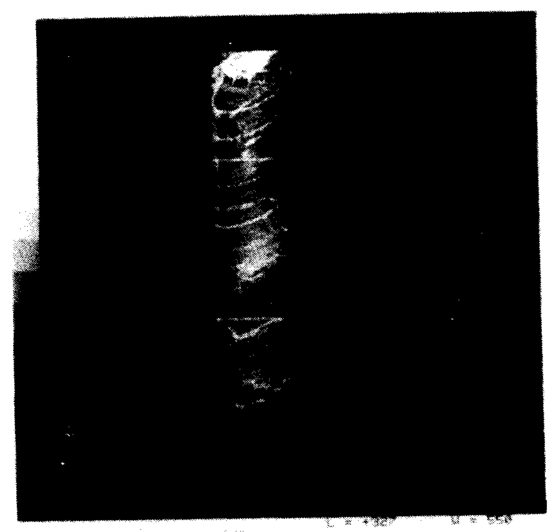

Figure 4. This surview of a section of core from a deviated well shows laminated beds which are highly dipping.

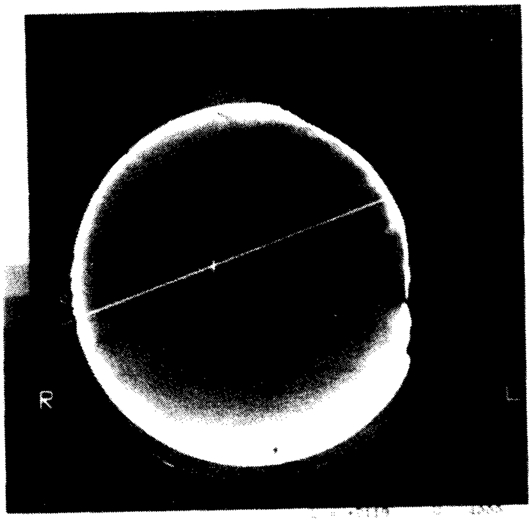

Figure 5. By examining a cross-sectional slice through the interval, the laminations can be oriented properly for slabbing.

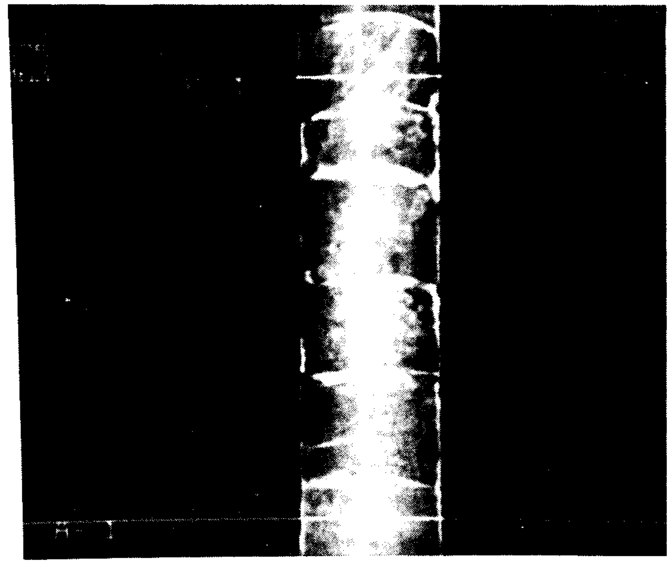

Figure 6. The apparent dip of the formation beds near the top is quite steep, however, the horizontal breaks across the the core suggest little structural dip.

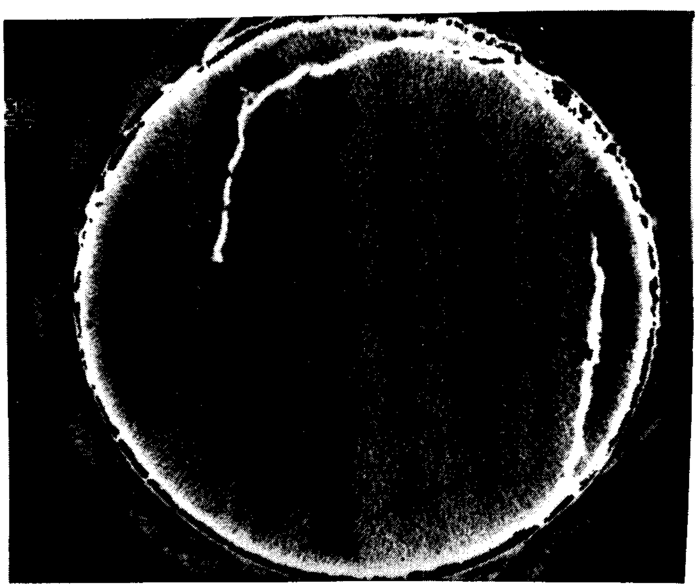

Figure 7. A slice through section reveals numerous light and dark stripes indicating cross beds in the core.

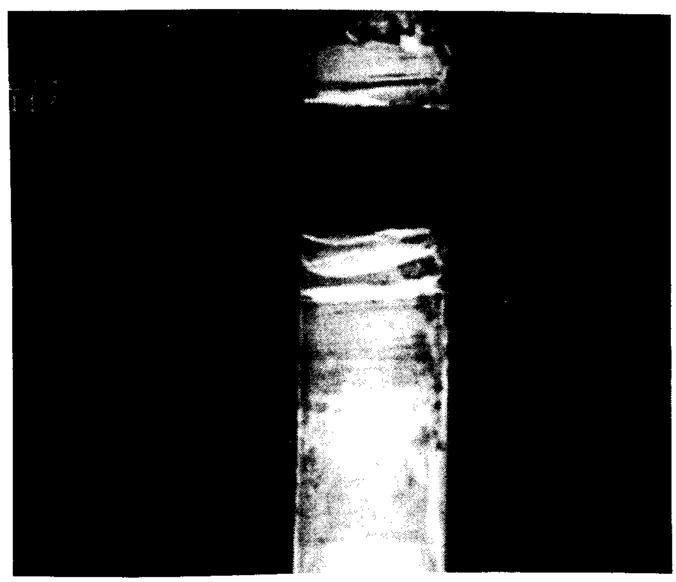

Figure 8. This surview shows a dark area in the upper portion of the core.

Figure 9. A slice through the dark interval confirms no core is present and only a small amount of drilling mud remains.

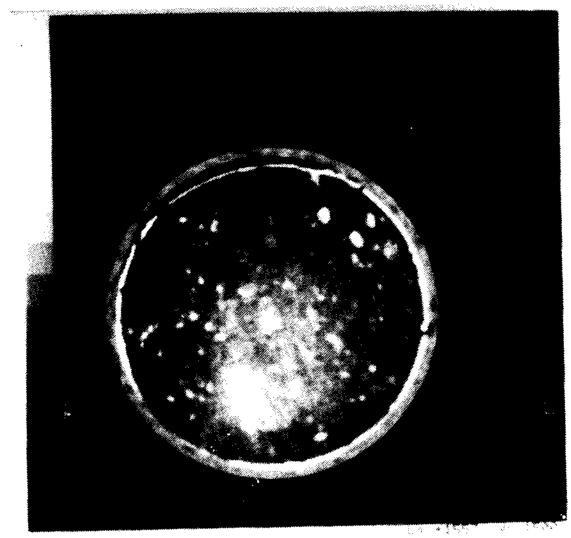

Figure 10. A slice scan through an area for special core analysis reveals shell remains imbedded in the core.

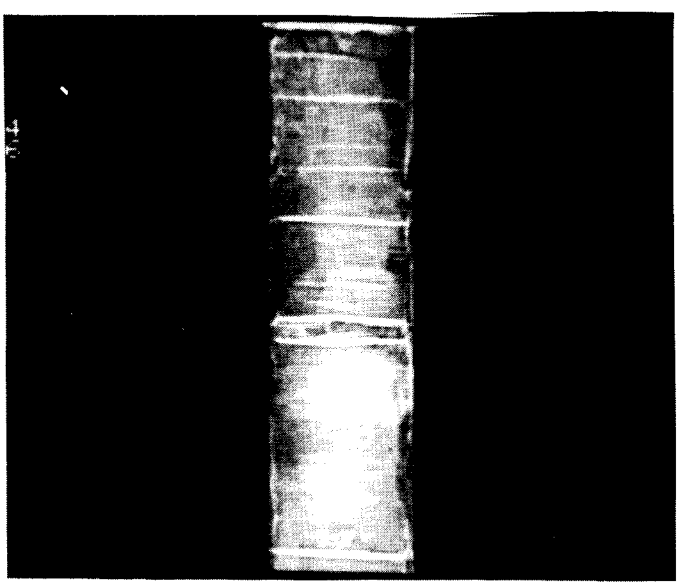

Figure 11. This surview scan typifies the the separation of a laminated sand-shale sequence at the shale boundaries.

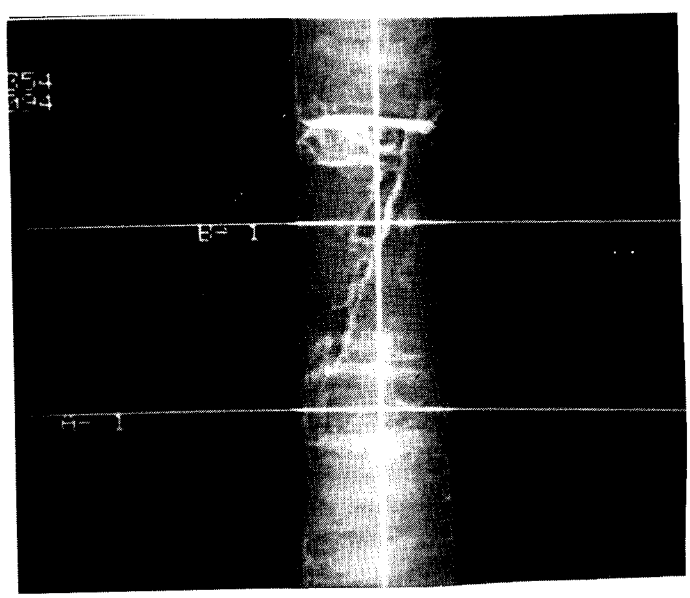

Figure 12. The surview scan identifies a diagonal fracture across the center portion of the section.

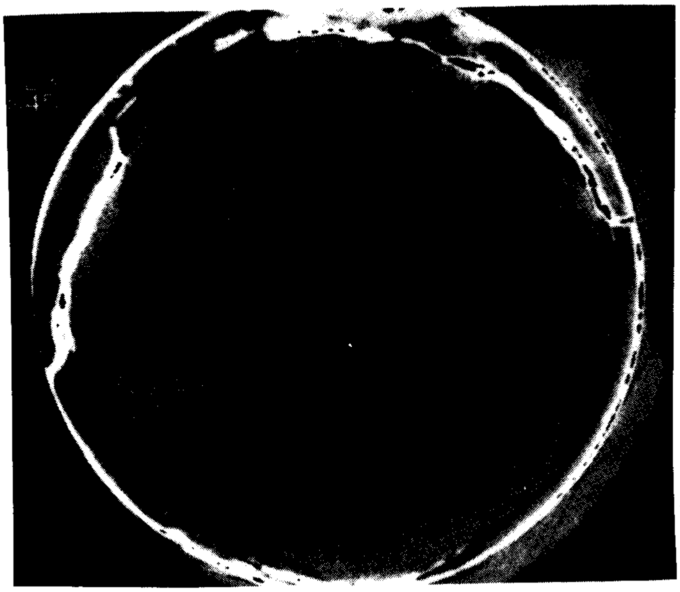

Figure 13. Slice A-1 taken below the disturbed area shows a homogeneous section of sand with little damage except on the fringe of the core.

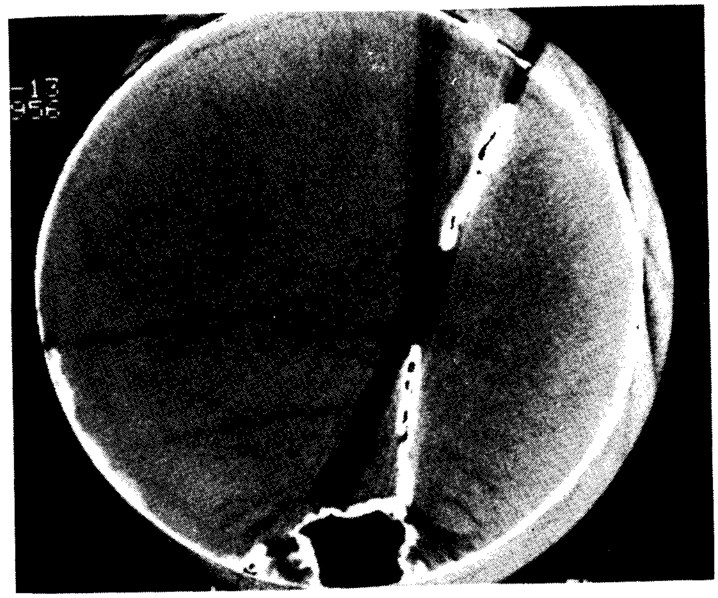

Figure 14. Slice B-1 reveals that the fracture tranverses the core.

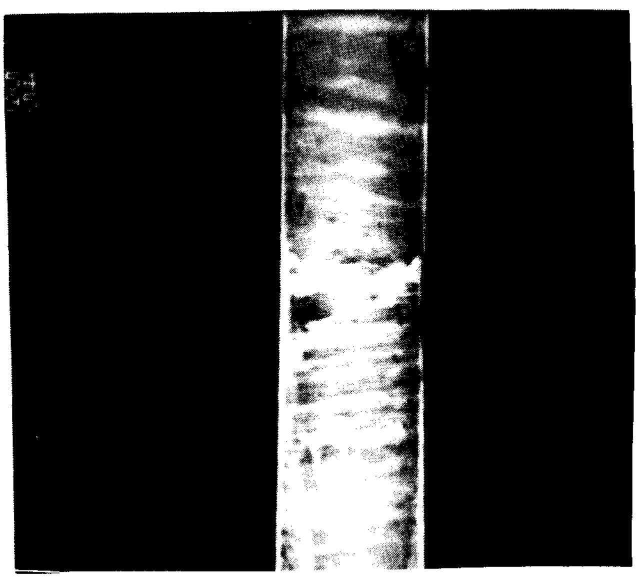

Figure 15. A surview scan of this core interval shows a sharp bright line indicating a change in orientation of the core inside the barrel.

Figure 16. A slice taken through the break area shows mud invasion deep into the core.

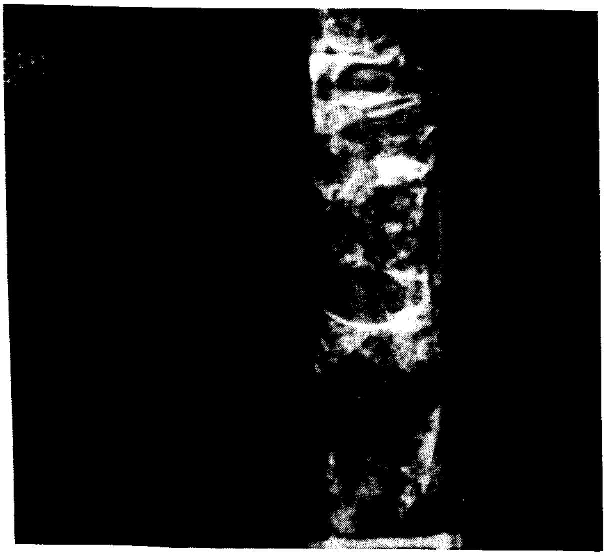

Figure 17. This surview scan identifies the contents of a section of core to be primarily rubble.

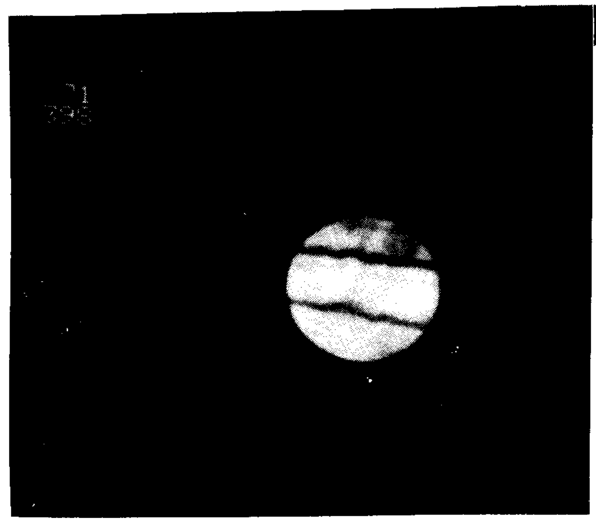

Figure 18. An end view scan of a core plug taken from a section of laminated sand reveals two fractures in the plug.

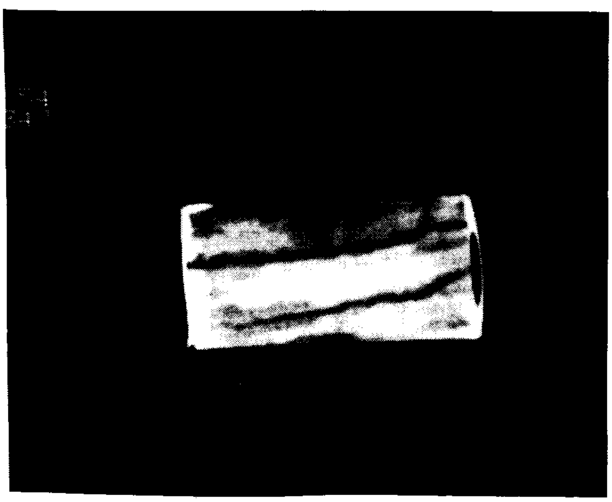

Figure 19. A side view of the sample in figure 18 shows fractures traverse the entire length of the plug.

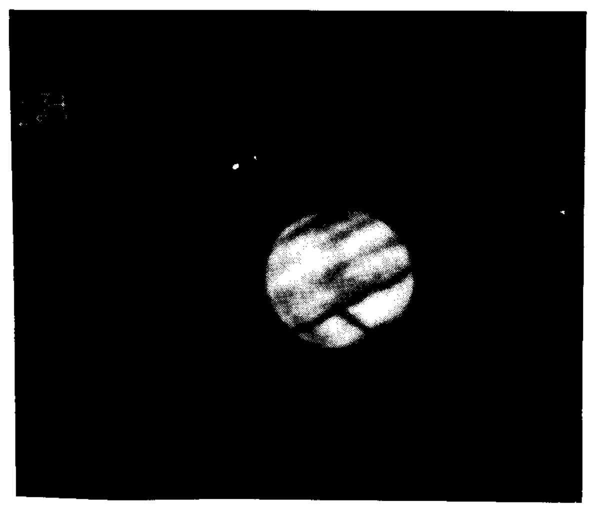

Figure 20. An end view scan of a core plug taken from a section of laminated sand reveals fractures in the plug.

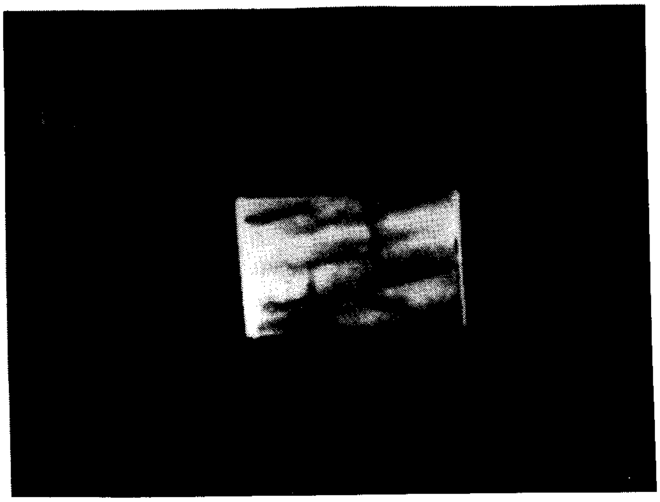

Figure 21. A plug example shows damage along the plug lengthwise and partially across the core.

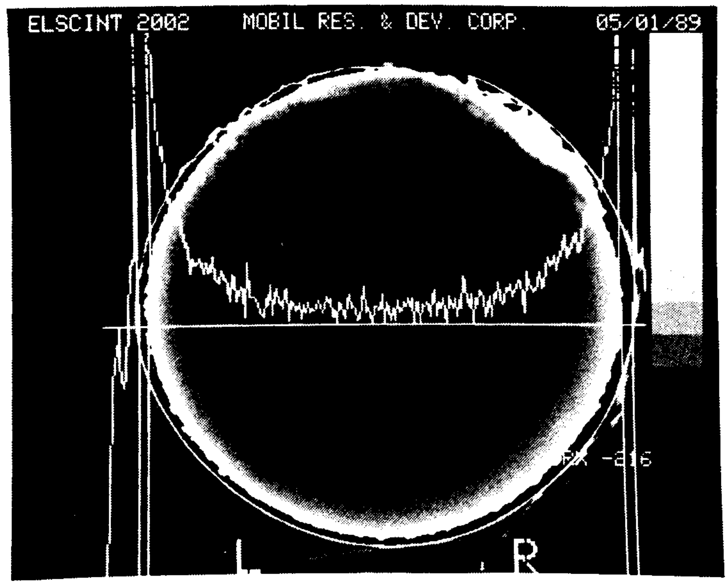

Figure 22. This slice view shows the bright signature of barite mud invading deeply into the core and a profile of CT numbers across the slice.

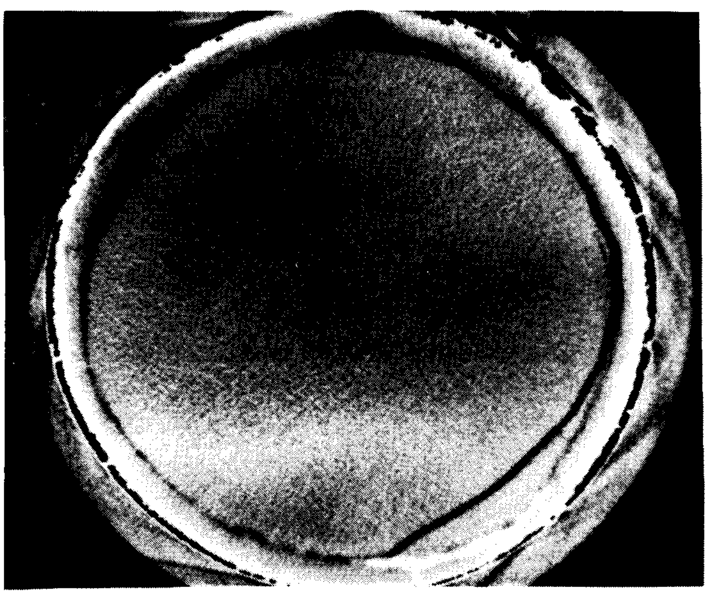

Figure 23. Close inspection of mud invasion and fluorescence patterns show that the separation point in concentric fracturing coincides with the depth of mud invasion.