AD-1706
MASTER

BERC/RI-77/10

**A STUDY TO DETERMINE THE FEASIBILITY OF
OBTAINING TRUE SAMPLES OF OIL AND GAS RESERVOIRS
FINAL REPORT**

By

Maurer Engineering, Incorporated
Prepared for ERDA Under Contract No. EY-76-C-02-0035

Date Published—October 1977

Bartlesville Energy Research Center
United States Department of Energy
Bartlesville, Oklahoma

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TECHNICAL INFORMATION CENTER
UNITED STATES DEPARTMENT OF ENERGY

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

This report has been reproduced directly from the best available copy.

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy \$12.50
Microfiche \$3.00

**A STUDY TO DETERMINE THE FEASIBILITY
OF OBTAINING TRUE SAMPLES
OF OIL AND GAS RESERVOIRS
FINAL REPORT**

By

Charles E. Ward
A. Richard Sinclair
Maurer Engineering, Incorporated
10301 NW Freeway, Suite 202
Houston, Texas 77092

Prepared for the Energy Research and Development
Administration Under Contract No. EY-76-C-02-0035
as Report BERC-0035-11

C. Ray Williams, *Technical Project Officer*
Bartlesville Energy Research Center
United States Department of Energy
P.O. Box 1398
Bartlesville, Oklahoma 74003

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Date Submitted—December 1976

Date Published—October 1977

UNITED STATES DEPARTMENT OF ENERGY
TECHNICAL INFORMATION CENTER

RET
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Foreword

The work described in the following pages was performed by Maurer Engineering, Inc. under a contract with the Energy Research and Development Administration (ERDA) and was sanctioned by personnel at the Bartlesville Energy Research Center (BERC) in Bartlesville, Oklahoma. The contract resulted from an unsolicited proposal submitted by Maurer on Aug. 4, 1975, which proposed to determine if it is feasible to recover, retrieve, and test an unaltered core sample while maintaining reservoir conditions on the sample. The contract was 1 year in duration with work beginning on Dec. 1, 1975.

Many personnel at BERC are proficient in tertiary oil recovery and massive hydraulic fracturing for stimulating low-permeability gas wells. They realized that the ability to obtain an unaltered reservoir sample would be a significant contribution. Enormous investments are usually necessary to perform tertiary or stimulation operations, and accurate information on important reservoir parameters would assist in making decisions for such investments. As a result, BERC personnel were hopeful that a tool could be built that would evaluate the actual reservoir contents before, and after, a flood front and could provide accurate water-saturation values in low-permeability gas reservoirs.

The results of the study indicate that it is not economically feasible to obtain an unaltered true fluid core under reservoir conditions but that improvements can be made in existing pressure core barrels that should make them operate more reliably. The results also indicate that mud invasion and flushing of the core might be reduced, or eliminated, if a coring device such as the Phase I system could be successfully built and tested. It is likely that ERDA will build and test the Phase I system as described in the final report.

C. Ray Williams
Technical Project Officer
Bartlesville Energy Research Center

SUMMARY

Current formation evaluation techniques do not provide information of the accuracy desirable for making sound, economic decisions. The ERDA Fossil Energy Division funded this study to analyze the problem and identify feasible alternatives for solutions.

The study concludes that a feasible solution is possible which would provide up to about 90% information accuracy under many operating conditions. This accuracy would be well within the economic range for most oil and gas operations.

The study also concludes that there is potential feasibility for the development of systems to approach 100% information accuracy under many operating situations. However, the cost of such a system is far beyond those considered practical within the economics of the competitive oil and gas industry. The justification of such a system has been likened to that of a "moon shot" approach and would take several years of development before true feasibility and probability of success could be assessed.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

After completion of the assigned tasks and assessment of the technology accumulated, the following conclusions have been reached:

- 1) A practical and improved system capable of approaching 90% accuracy in the determination of true fluid saturations appears to be feasible.
- 2) The best first-stage approach is a fairly uncomplicated pressure core barrel.
- 3) It appears to be feasible to build an ultra sophisticated system to achieve information accuracies approaching 100% if given "unlimited" resources.
- 4) One concept considered feasible under the "moon shot" approach is based on a highly complicated pressure core barrel system.
- 5) Another highly sophisticated system which appears to be feasible involves examination of the core at the bottom of the hole using various logging techniques.
- 6) The major problem which must be overcome regardless of the techniques involved is that of cutting the core without disturbing the true fluid content.
- 7) Additional studies are required in order to increase the probability of success of any true fluid coring approach.

Areas requiring additional study include:

- a) Evaluation of the influence of proposed and other bit designs on fluid invasion,
- b) Evaluate drilling fluid additives to improve non-invading properties.

Recommendations

If true fluid coring is to be pursued, the following short-term programs should be initiated:

- 1) The design and manufacture of a prototype pressure coring system similar to the Phase 1 concept outlined in this report.
- 2) An evaluation of bit design influences on fluid invasion with the objective of developing the most ideal bit design.
- 3) A study to identify drilling fluid additives improving non-invading characteristics. This study should probably be done in conjunction with the bit design evaluation.
- 4) A study to identify the most suitable composition for the non-invading, non-freezing gel proposed in Phase 1 of this study.

A long-range program aimed at the more sophisticated solution to the true fluid coring problem would be the development of a downhole "core logging" procedure to determine if this approach can in fact achieve the desired data accuracy.

Other advanced systems technologies are basically extensions of Phase 1 concepts and definition of future programs will be more appropriate following development and testing of the Phase 1 system.

ACKNOWLEDGEMENT

We wish to express our thanks to the Fossil Fuels Division of ERDA for the financial support of this project. Our special appreciation goes to Mr. Ray Williams (ERDA, Bartlesville) for his interest and contributions to the project.

The following industry personnel also made valuable contributions:

Skip Bilhartz	Atlantic Richfield Co.
Harold Bridwell	Rucker Hycalog
Bob Griffin	Terra Tek, Inc.
Ralph Jenkins	Core Laboratories
Dare Keelan	Core Laboratories
Steve Pontious	Shell Oil
David Rowley	Christensen, Inc.
Dick Walker	Lamar University
Lindsay Yell	Loomis Hydraulic Testing Co.

A STUDY TO DETERMINE THE FEASIBILITY
OF OBTAINING TRUE SAMPLES OF OIL OR GAS RESERVOIRS

<u>Chapter</u>	<u>Title</u>	<u>Page</u>
	Summary.	i
	Conclusions and Recommendations.	ii
	Acknowledgment	iv
	Table of Contents.	v
I.	Introduction of Coring	1
	Review of Present Problems.	3
	Objectives of the Study	5
II.	History of Coring.	6
III.	Applications and Uses of Core Data	17
IV.	Core Handling and Preservation	37
	Conventional Cores.	38
	Pressure Cores.	43
V.	Present Coring Technology.	62
VI.	Limitations of Present Coring Methods.	86
VII.	Specifications for a True Fluid Coring System.	105
VIII.	Concepts for Improvement of Present Technology	110
	Core Cutting.	112
	Core Transportation	133
	Core Analysis	140
IX.	Feasibility of a True Fluid Coring System.	144
X.	Phase 1 System	146
XI.	Phase 2 System	150
	Appendix A--Conventional and Special Core Analysis	155
	Appendix B--Patents.	317
	Appendix C--Literature Search on Coring Equipment.	319

I. INTRODUCTION

Review of Present Problems
Objectives of the Study

INTRODUCTION

In early drilling, the people involved in the business of exploration wondered what types of rock or lithology would be the best for producing oil. From this innate desire to know what was downhole, the drillers studied, smelled and tasted drill cuttings and chips in an attempt to characterize the rocks or formations. In order to logically extend their knowledge, it became very important to examine the rocks which actually contained oil.

The search for oil was then, as it is now, a very risky business and there was a definite need for better information so that each drilling attempt might have a better chance of success. As much information as possible on each drilling site was required and someone, perhaps inadvertently, hit upon the idea of using a type of coring device to recover part of the downhole formation. When early oilwell drilling operations began in Pennsylvania during the 1870's, several patents had already been filed on core drills. The science of core drilling was just beginning.

Early drillers and geologists cut cores primarily to provide geologic correlations. Coring overcame some of the objections to unreliable techniques of cuttings examination. Although early analysis techniques were crude, they did provide much useful information to geologists, engineers, drillers and the designers of drilling equipment.

As additional information was obtained from cores, more and more questions arose. As analysis techniques improved, more exact information about the reservoirs was discovered and today, a wide range of tests give factual, interpretive and evaluative information about strata being drilled.

Review of Present Problems

The continued growth in demand for petroleum resources coupled with declining reserves has resulted in increased pressure on reservoir engineers to improve the reliability of their reserve estimates and to evaluate efficiency of recovery techniques. Tertiary recovery systems are extremely expensive and, therefore, accuracy of residual oil saturation estimates is important to risk analysis. Although various logging techniques have been improved significantly in the past few years, the results are still only an indirect measurement of formation properties and the accuracy of interpretation is limited by assumed formation factors. A true fluid coring system would have appreciable application in development of both new and old reservoirs as shown in Table 1.

TABLE 1
APPLICATIONS OF TRUE FLUID CORE ANALYSIS DATA

Parameter Measured	Application
<u>NEW RESERVOIRS</u> Initial fluid saturations Porosity Formation resistivity factors Acoustic velocity	Improved reserve estimates and better evaluation of logs on later wells
Relative permeability Relative wettability Flow tests	Planning for future secondary and tertiary recovery
<u>OLD RESERVOIRS</u> Present fluid saturations Porosity	Evaluation of secondary and tertiary recovery economics
Relative permeability Relative wettability Flow tests	Selection and planning of recovery programs

Several major oil companies have sponsored R&D projects aimed at the accurate determination of fluid saturations in oil and gas reservoirs. All of the major efforts have included taking a core sample of the formation and techniques have centered on controlling the properties of the drilling fluid while coring as a means of reducing or totally eliminating alterations of true fluid saturation. These approaches are extremely costly and in general have not been successful. In addition, they do not prevent changes in the fluid content resulting from reduction in the confining pressure as the core is brought to the earth's surface.

Other techniques have attempted to recover the core while maintaining a constant pressure environment. This method has eliminated one source for error; pressure reduction, but does not adequately prevent flushing during the coring operation.

A simple combination of special drilling fluids and a pressure core barrel does not provide the total solution, but may suggest a concept for more sophisticated systems capable of capturing "true fluid" cores.

Objectives of the Study

This program was undertaken to assess the requirements, to define the problems, and to evaluate the feasibility of various alternative solutions.

The work was divided into five main tasks.

- Task 1 Review and evaluate existing pressure coring capabilities.
- Task 2 Examine and evaluate alternative concepts for obtaining uncontaminated cores.
- Task 3 Examine and evaluate alternative concepts for transporting uncontaminated cores to the surface test facilities while maintaining reservoir temperature and pressure.
- Task 4 Examine alternative concepts for evaluating reservoir properties by conducting core analysis at reservoir temperatures and pressures.
- Task 5 Assuming a positive response to the question of feasibility, make recommendations regarding the development of an improved coring system.

The following report summarizes the findings and evaluations resulting from the work on this program.

II. HISTORY OF CORING

3,000 B.C.

Double Core Barrels

Pressure Core Barrels

Special Coring Fluids

References

HISTORY OF CORING

3000 B.C.

Stone quarries used by the Egyptians as early as 3000 B.C. as a source of building materials for the great pyramids provide the first known record of the practical use of holes bored in rock. Solid rods were rotated in the rock, probably with quartz sand or other hard minerals added as cutting abrasives. At some point in time, hollow tubes were used in order to reduce the total amount of rock to be removed (Figure 1).¹ Rock cores resulted from the use of the hollow tubes. Holes drilled as deep as 20 feet using this technique have been found!

Figure 1
Hollow Rod and Abrasive "Corer"

This relatively simple and inexpensive technique has been used throughout history. A very similar approach to cutting rock is still used in stone quarries today where large blocks of stone are sawn by the use of long steel cables drawn through a slot in the rock with sand added as an abrasive.

Coring techniques apparently changed very little until rotary drilling machines were developed and came into common usage. About this time coring bits were manufactured by cutting a saw tooth pattern on the bottom end of the drilling tube (Figure 2).²

Figure 2
Single Tube Sawtooth Corer

The core was captured inside the tube by one of several methods. One technique was to bounce the tube against the bottom of the hole bending the saw tooth fingers in, thus retaining the core. Another technique was to pour sand and gravel down the tube where it would wedge between the core and the inside the core tube.

In 1863, a French engineer, R. Leschot, received a patent on a rotary drilling machine and a hollow coring bit set with diamonds (Figure 3).³

Figure 3
Handset Diamond Core Bit

Leschot's diamond set core bit constituted a major improvement in coring capabilities. The bit was manufactured by peening or brazing large industrial quality diamonds in holes drilled into a soft metal bit crown.

Double Tube Core-Barrels

The Leschot patent was later purchased by a group of investors and in 1892 M. C. Bullock, an important member of the group, received a patent for the first double tube core barrel (Figure 4).⁴

Figure 4
Bullock Double Tube Core Barrel

The inner tube permitted longer cores to be cut and recovered, since the core was protected from the drilling fluid flow through the barrel and was confined inside a tube much closer to the core diameter itself. A tapered spring-type "core-catcher" was located inside the lower end of the inner tube. This spring gripped the core and held it inside the barrel for removal from the hole. Core-catchers of a similar type are still used in core barrels today.

In 1908, following the earlier introduction of roller cutter bits, McLoughlin and Wynn applied for a patent on a roller-type coring bit. Rights to this patent was later purchased by Howard Hughes (Figure 5).⁵

Figure 5
McLoughlin and Wynn Roller Core Bit

By the early 1920's, the double-tube barrel had been improved to permit the inner barrel to rotate on a bearing. Thus, during the coring operation, the inner barrel could remain stationary while the outer barrel was rotated. This feature reduced damage and breakage of core and as a result, longer, better cores were then possible.

Today, almost all petroleum related coring is done using diamond core bits (Figure 6) and similar double-tube coring systems (Figure 7). These barrels are readily available in sizes suitable for use in all common hole sizes and are available with a number of special purpose attachments or auxiliary systems to improve the type and amount of

information determined from cores as shown in Table 1 below:

TABLE 1

SPECIAL PURPOSE CORING SERVICES

SERVICE	APPLICATION
Oriented Coring	Permits studies of directional properties of the formation cored.
Wireline Core Barrel	Primary application in mining and offshore sediments studies requiring continuous coring where tripping the pipe to remove cores is inconvenient.
Plastic Inner Tube Liner	Simplified handling of medium to soft cores.
Rubber Sleeve Core Barrel	Permits recovery of soft, unconsolidated cores not recoverable with conventional core barrels.
Pressure Core Barrel	Recovers core at bottomhole pressure for study of formation in undisturbed state.
Sidewall Coring *	Permits taking samples after a formation has been drilled by running equipment on a wireline.

* Not a rotary coring technique.

Figure 7
Modern Double Tube Core Barrel
(Courtesy American Coldset Corp.)

Figure 6
Typical Modern Diamond Core Bits
(Courtesy of Christensen, Inc.)

Pressure Core Barrels

As reservoir engineering and core analysis technologies improved, it became apparent that true reservoir fluid information is not obtained from conventional cores. As the hydrostatic head is reduced on the core during the trip out of the hole, oil and gases in the core will bleed out of the rock pores. In 1940, Sewell obtained a patent for a "Pressure Coring Device" (Figure 8).⁶ With this special core barrel device, once the core was cut it was withdrawn into an intermediate tube, the lower end of which was sealed off by a ball valve. A special valve arrangement also closed off the top of the inner barrel, thus sealing the core under bottom hole pressure. In the early 1960's the Sewell system was revived and modified by Humble Oil. About the same time Christensen Diamond Products Company, on contract from Shell Oil, designed and built a barrel similar in principle. The Humble barrel was later licensed to Loomis Hydraulic Testing Co., who still markets the system today.

Special Coring Fluids

The introduction of pressure core-barrels improved the reliability of fluid measurements in cores. However, it has been discovered that the true fluid content in cores is drastically modified by the flushing action of the coring fluid during the cutting operation. A number of attempts have been made to develop special coring fluids which would not invade or alter formation fluid volumes in the core.

Special oil base drilling fluids have been used with some success in certain limestone reservoirs. One research program attempted to seal the core surfaces as it was cut by using a latex rubber material suspended in the drilling fluid. This approach was totally unsuccessful in limestones and only marginally successful in sandstones. Other non-wetting, non-contaminating fluids have been evaluated with similar success.

In some cases, much improved information has been obtained by using a special fluid in combination with a pressure core barrel. In general, however, the technique is much too unwieldy and too expensive for practical application.

REFERENCES

1. Brantley, J. E., History of Oil Well Drilling, Gulf Publishing Co., Houston, Texas, 1971, p. 100.
2. Ibid, pp. 1110-1111.
3. Leschot, USP 39,235.
4. Brantley, J. E., Op. Cit.
5. Brantley, J. E., Op Cit., pp. 1072-1073.
6. Sewell, USP 2,216,962

III. APPLICATIONS AND USES OF CORE DATA

Specific Information Provided by Coring
Interpretive Data
Evaluation of Reservoir Parameters

General Tests
Special Tests
References

APPLICATIONS AND USES OF CORE DATA

Specific Information Provided By Coring

The main reason for cutting cores (preserving and examining them in a virgin state, if possible) is to know exactly what amount and type of fluid is present in the formation of interest. Also, cores provide cross correlation and calibration of logging techniques in certain areas and reservoirs. Other reasons for coring formations are that a much better estimate of reservoir quantity and potential can be made and a prediction of the field or well's performance can be stated.

The data that can be measured precisely on a core is the depth, permeability, and porosity. These measurements are considered to be an approximation of the reservoir at the depth where the sample was obtained. This depth is, of course, measured by the length of drill pipe in the hole (Figure 1).

Figure 1
Depth Measured By Pipe

Each conventional core brought back to the surface is probably contaminated by drilling fluids and filtrate; but after cleaning, air or nitrogen can be flowed through the core or a plug of the core to measure core permeability (Figure 2).

$$\text{PERMEABILITY (K)} = \frac{Q\mu L}{A \Delta p} \text{ (darcies)}$$

Figure 2.
Permeability

Permeability is the measure of the resistance of a fluid to flow through a porous media and is measured in darcies or millidarcies. A higher permeability has a lower resistance to flow and often allows a higher recovery rate.

A porous media is made up of many small sand grains, compacted media, or other sedimentary rock. Porosity is defined as the percentage of the total volume of the rock that is pore volume (Figure 3). Each of the different types of rock, such as sandstone, limestone, dolomites, etc. have different porosities. For example, sandstone can be thought of as having many small sand grains cemented together leaving pore spaces between the grains. Generally, sand and sandstones have a porosity of between 10 and 40 percent. Limestone and dolomite have a lower average porosity of 5 to 25 percent, but may have large vugs (cavities) or fractures that potentially can accommodate and store large quantities of oil and gas.

$$\text{Porosity} = \frac{\text{Pore Volume}}{\text{Total Volume}} \times 100$$

Figure 3

Porosity

The size of the pores largely determines what proportion of the space can be filled with oil or gas, while the nature of their interconnection determines the percent of oil that is recoverable. Pore size variation ranges from molecular size to cavern size.

With both permeability and porosity, large variations will be found even in the same reservoir or formation due to the natural deposition processes which produce heterogeneous rocks.

By collecting cores over a known interval and measuring permeability and porosity versus depth, the information shown in Table 1 can be calculated:

TABLE 1

Information Calculated From Porosity And Permeability

Position Of Permeable Zone
Position of barriers to vertical flow
Magnitude of permeability (average permeability over an interval)
Magnitude of porosity (average porosity over an interval)
Variation of permeability with depth
Permeability distribution
Pore structure interconnection
Presence or absence of oil if uncontaminated and preserved

Interpretive Data

Core analysis data interpretation permits predictions of the distribution of fluids and the type of production to be expected from a particular reservoir. Fluid contacts, whether they be gas-oil or oil-water, have important inferences during completion and production operations. Proper location of the perforated interval is often decided from cores. The type of production expected determines perforated interval, tubing size and surface equipment requirements. Some of interpretive data obtained from core analysis are shown in Table 2:

TABLE 2

Production Information Provided By Cores

Type of fluid production
Transition zone definitions
Fluid contact position
Zones of potential water or gas coning
Depleted zone production
Gas production possibilities
Condensate production possibilities

When discussing the above parameters, the first three can be lumped together. The exact position of an oil-water contact can sometimes be found by an abrupt change in the saturations of the fluids, although filtrate invasion usually obscures interpretation of the available information. Also, alternating stringers of high and low permeability sands near the contact make the finding of fluid-to-fluid contacts difficult.

Dirty sands are likely to have non-uniform pore size distributions and will have a large transition zone from oil to water. If a low gravity oil is found, then the problem of water production can be aggravated by the oil's high viscosity; hence, lower mobility.

Certain other information¹ from cores allow some general rules of thumb to be established for certain types of reservoirs. These rules permit interpretation of core properties based on: changes in water and oil saturations; magnitude of water and oil saturations;

FLUID
CONTACT

- Oil Saturation = 70%
- Water Saturation = 30%
- Oil Saturation = 20%
- Water Saturation = 80%

Figure 4

Change In Saturation Fluid Indicates Fluid Contact

The magnitude of the total water saturation helps to interpret the ability of a formation to produce. Prior history of the particular reservoir is sometimes essential to make a correct assessment of the situation. A ratio of oil and water saturation indicates the type of fluid production to be expected. In California, for example, the residual oil-water ratios are found to be 0.05 to 0.35 to 1.0. The critical limit for this ratio varies with the particular area in question.

A gas-water ratio is another criterion that is useful in either gas or oil zones since it tells something about gas cap expansion or oil shrinkage.

Water or gas coning can be estimated by measurement of vertical core permeability and proximity of the producing formation to a water contact (Figure 4). The thickness of the productive interval is important to minimize coning problems. Also, withdrawal rate or drawdown influences the magnitude of coning. Shale breaks or barriers help

to prevent coning from having a significant effect. The absolute magnitude of permeability is not as important as the ratio of the horizontal to vertical permeability which is usually estimated quite closely from analysis of the recovered cores (Figure 5).

Figure 5
Water cone beneath a partially penetrating well in a bottom water drive reservoir

Gas producing formations are easier to find from cores because of the more abrupt transition of gas to oil or gas to water. Fluid-to-fluid transitions are more subtle and spread out. When a contact is not intersected by the core, the interpretation as to gas or water production can be made on the basis of total relative water saturation. Generally, gas saturations increase with depth while water saturations tend to decrease. In some cases, shallow high-porosity, dirty sands may show total water saturations of over 80% and still produce gas while deep, low-porosity limestone may show water saturations below 50% and be water producers.

A gas condensate formation presents an interpretive problem similar to a gas reservoir, but light-colored liquid hydrocarbons may be present in amounts ranging from a trace to about 5% of the pore space. At intermediate depths, oil saturations above 2% may indicate an oil rim around a condensate reservoir. One complication is the

retrograde condensation which presents unusual interpretive complications if cores were not taken in pressure core barrels. Below 10,000 ft, with oil saturations of about 3 to 8%, the reservoir is near the critical region where the distinction between gas and liquid phase diminishes.

Evaluation of Reservoir Parameters

Cores and core data are used to make overall evaluations which are estimates of a semiquantitative nature. These are mainly estimated production rates, reserves in place and recoverable reserves. The rate of production is estimated from permeability data of the cores. The controlling factor is the total millidarcy-foot capacity of the section exposed to production. Usually it is communicated as the productivity index or barrels of oil per day per psi pressure drop.

The water intake rate is needed when planning a water injection or water flood program. Other information cores will provide are: zones of highest intake, number of injection wells required and wellhead pressure required. The estimates are based on the injectivity index or barrels of water injected per day/per psi pressure differential. There are two cases to consider: one, injection into a depleted zone and the other injection into a reservoir at equilibrium pressure.

Core samples of an oil-bearing formation provide the only means for direct measurement of many important properties of the formation. Knowledge of the core properties is important in developing well completion techniques and methods. Subsequent workover operations, field development and operating practices are also guided by crucial core information.

Specific applications of interpreted core analysis may require composite informations from many cores in a reservoir or related area. Also, the core analysis may not be used solely as a basis for complex decisions, but in conjunction with all available information from other formation evaluation methods. A summary of the principal applications and uses of core analysis is given in Table 3.

For exploration wells, the zones that are productive in related reservoirs are cored to test for permeability, porosity and oil saturation. If oil is found, an estimate of commerciality is made to decide on whether the well can be completed.

Figure 6
Exploration Operation

TABLE 3

Area of Interest	Specific Applications
Exploration Wells	<p>Evaluate productive possibilities of edge wells, field extension and wildcats</p> <p>Determine subsurface structural and stratigraphic conditions</p>
Field Development	<p>Determine optimum spacing</p> <p>Determine new locations</p> <p>Define field limits</p> <p>Find capacity of field tankage and pumpage</p> <p>Define fluid contacts in field</p> <p>Determine structural and stratigraphic correlations</p> <p>Establish a cross check on well-logging methods</p> <p>Select water intake wells</p> <p>Select optimum completion intervals</p>
Well Completion and Workover Operations	<p>Select drill stem test intervals</p> <p>Interpret drill stem test information</p> <p>Select sequence of completion of multiple zones</p> <p>Determine packer and plug seats</p> <p>Determine perforation depths</p> <p>Determine hydraulic fracturing and acidizing requirements.</p> <p>Evaluate completion</p> <p>Determine recompletion intervals</p>
Well and Reservoir Evaluation	<p>Find the net pay</p> <p>Estimate initial production and pressure drawdown</p> <p>Estimate water intake rate and injection pressure</p> <p>Estimate zone depletion schedule</p> <p>Estimate probable recovery</p> <p>Find oil or gas in place</p> <p>Help in unitization operations</p> <p>Help in reservoir studies</p> <p>Help plan pressure maintenance</p> <p>Help plan secondary recovery operations</p> <p>Provide information on future uses of the reservoir</p>

Correlation of core data from the various wells in a field is important for developing a thorough understanding of the size and characteristics of that specific reservoir.

The analysis of cores provides specific information necessary for properly completing every zone of interest in a well.

Figure 7
Formation Fracture Treatment

General Core Tests and Analyses

In modern day core analysis tests, each series of cores will be analyzed and the interpretations made in a formal report. The depth over which the cores are taken will be plotted on a depth chart (coregraph). Any corresponding well logs at this depth will be compared to the coregraph. The important data included in the report are shown in Table 4:

TABLE 4
Data Included On Core Analysis Report

The cored or analyzed interval
The number of permeable and productive feet in the interval
The capacity of the productive interval
The averages of the core analysis data measurements
The calculated, approximate and preliminary values of original stock tank oil in place in an oil productive interval
Estimate of recoverable oil by both solution gas drive and water drive in units per acre/foot
Net pay thickness
Connate water content
Reserves in place

Special Tests and Analysis

Under certain conditions special tests will be run on cores to provide even more detailed information on rock properties. Specifically measured data on fluid distribution and multiphase flow characteristics of the reservoir rock are essential to detailed reservoir studies. Some of the tests are performed on preserved cores, but they also can be used on fresh cores if available. A brief listing and description of these tests are as follows:

1. Capillary Pressure Curve

Figure 8
Capillary Pressure Curve

Air is used as a non-wetting phase to enter large pores at low pressure head and smaller ones at higher pressure. Figure 8 shows the typical curves for six different permeability cores. Results of this test show the irreducible minimum water saturation.

2. Oil-Waterflow Data

These tests measure relative permeability effects (or interference) of the flow of oil and water. Now, fresh cores give best results but old cores can be given a restored saturation of oil and water and flow data measured.

3. Residual Oil Data

A sample is saturated with brine, then restored to reservoir oil and water saturations. Permeability to oil is measured and the sample is then flooded with brine until only water is produced. Permeability to brine is then measured and the residual oil content calculated.

4. Waterflood Susceptibility Tests

These tests are water/oil relative permeability measurements that predict the effectiveness of an artificially introduced water drive on natural water drive. The results of the test are shown in Fig. 9 where the water cut and water input is related to the amount of oil recovered.

Figure 9
Waterflood Evaluation Curves

5. Gas-Oil Relative Permeability Data

These tests are needed for gas drive, gas injection, expanding gas cap or gravity drainage production. One method of calculation for gas-oil permeability was developed by Welge². Although not a simple calculation, computers can easily solve and plot the gas-oil permeability curves when given all required input information. A typical gas-oil relative permeability curve is shown in Fig. 10.

Figure 10
Relative Permeability Curves

6. Water Permeability Data

Fresh water damage or blockage can be measured when swelling clays are present in the core.

7. Electric Resistivity Measurement

A formation resistivity factor and ratio are measured from the cores. This information is used to refine electrical log calculations. After core and logs are calibrated, other wells that were not cored can be correlated very accurately with the wells and formations that were cored.

References

1. Elmdahl, B. A., "Core Analysis of Wilcox Sands," World Oil, 134 (June, 1952), ppg. 181-190.
2. Welge, H. J., "A Simplified Method for Computing Oil Recovery by Gas or Water Drive," AIME Trans. 195 (1952), p. 91.

IV. CORE HANDLING AND PRESERVATION

Conventional Cores

Cleaning

Preserving

Pressure Cores

Handling of Frozen Pressure Cores

Laboratory Analytical Techniques

Values to be Measured on Unflushed
Pressure-maintained Cores

Advantages to be Gained if Pressure and
Temperature are Maintained on the Unflushed
Core

Problems Related to Transfer and Laboratory
Analysis

References

CORE HANDLING AND PRESERVATION

Conventional Cores

Practices for handling and preserving conventional cores vary considerably, and are depended upon oil company policies, type of core being analyzed, type of analysis planned and the length of time from removal until the analysis will be performed. However, most practices are based on variations of American Petroleum Institute procedures: ¹

"2.113 Cleaning the Core

It is recommended that the core be wiped to remove soft mud cake and excess mud as soon as possible following its removal from the core barrel. The excess mud should be wiped off with a damp - not wet nor dry - rag. Preferably, the rag should be dampened in drilling fluid and wrung out as often as necessary to prevent its becoming too wet. Core samples to be sent to the laboratory should never be washed with water or any other liquid after removal from the barrel. Depending upon the firmness of the core, there may be a question whether the mud cake should be removed either by wiping with a rag or scraping with a knife. If field examination is required, it may be necessary to scrape part of the core in order to make the examination. Emphasis must be placed on never washing the mud from the core. In any event, the wiping, examination, and sampling procedure following removal from the core barrel should take a minimum of time. The time a core is exposed to the drilling fluid and the atmosphere will affect the subsequent core analysis.

Even a few minutes exposure of cores, depending upon atmospheric conditions, can cause the loss of both water and light hydrocarbon fractions. Tests have shown that as little as 1/2 hour exposure to the atmosphere can result in 10 to 25 percent loss in water content. If the core is accidentally washed with water, allowed to remain in the core barrel, or let stand before sealing in a container, then a notation of the washing, the number of hours in the core barrel, or the length of exposure time before sealing in the container should be made."

The preservation of the core is an attempt to maintain it as nearly as possible in the same condition as existed upon its removal from the core barrel until it is ready for analysis. An additional objective of preservation is to prevent breakage of the core during shipment and storage. Hard and consolidated cores may be durable enough not to require special precautions and support. However, special care should be taken to give adequate support to cores which are soft or poorly consolidated. The use of glass jars, easily deformable plastics, paper cartons, and other non-rigid containers should be avoided if core samples are to be shipped or will be subjected to other rough handling. As previously stated, there are a number of acceptable practices for preserving cores during transportation and storage. These methods are clearly described in API RP 40:²

"2.131 Sealing in Air-tight Cans

Core samples selected for analysis, particularly when saturation determinations are critical, may be sealed in metal cans. This is an efficient, rapid method. Cores may be canned directly or sealed in cans after a preliminary wrapping using aluminum foil, or polyethylene or other suitable plastic. There should be a minimum of space between the core sample and the can, particularly if no preliminary wrap is used. If the core is friable, some provision to prevent its movement in the can during shipping should be made. The use of paper, wax paper, cardboard, or materials which may absorb moisture or oil from the core should be avoided. If the entire core is shipped to the laboratory following the selection and canning of samples for fluid-saturation tests, the canned samples - each properly labeled for depth - may be replaced in the position from which they were removed from the core. The core should be properly logged on its arrival at the laboratory. Normally, it is recommended that cores not be canned with any fluid surrounding the core. The sealed container should not be subjected to large temperature fluctuations, if possible, in order to minimize evaporation and condensation of core fluids in the container.

2.132 Sealing in Air-tight Steel, Aluminum, or Plastic Tubes

Using suitable couplings, caps, or O-ring seals the entire core may be preserved for analysis by placing it in steel, aluminum, or plastic tubes. A close-fitting tube is desirable. Normally, no fluids should be used in packaging the cores although the cores may be pre-wrapped in plastic or metal foil. Large variations in temperature during storage and shipment should be avoided.

2.133 Sealing in Plastic Bags

Core samples which are sealed in plastic bags should have a minimum of air space between the core and the bag wall. Any excess bag can be folded against the core wall and taped in place to assure a tight fit. Excess air may be withdrawn by suction. Care must be taken in adjusting the bag so that sharp points on the core do not puncture the bag. In some cases, more than one layer of plastic bag or sheeting may be used for wrapping cores. Cores sealed in plastic bags may be packed in boxes with suitable packing to prevent their being broken in shipment, or they may be canned or placed in metal or plastic tubes. The same precautions must be observed for cores sealed in plastic bags as for those sealed in cans, so far as exposure to extremes of temperature is concerned.

2.134 Freezing in Dry Ice (U.S. Patent No. 2,617,296)

Cores which are preserved by freezing should be frozen very rapidly by application of dry ice. Slow freezing may result in the migration of fluids within the core structure or breakage of the core. Cores are commonly frozen when the core-analysis laboratories are local. Preservation by freezing of cores for extended storage requires refrigeration or continuous repacking with dry ice. If it is necessary to allow the core to warm to room temperature before testing, the condensation of moisture from the atmosphere onto the core surface must be prevented. Slow thawing of the core will cause some redistribution of the fluids within the core matrix.

Freezing will affect properties of cores flushed with fresh water more than those flushed with saline mud filtrate. These effects will decrease with liquid saturation.

2.135 Wrapping in Metal Foil and Plastic Tape

Cores should be wrapped with metal foil and plastic tape only if they are consolidated enough to withstand shipment and will be analyzed in a few hours. Care must be taken that the foil is not punctured by sharp points of the core. To preclude this, cores are often double or triple-wrapped. Effective wrapping with metal foil is best accomplished by lapping the edges along the length of the core as well as on the ends and folding once or twice, finally pressing the folded edges down against the core. The use of a self-sealing vinyl tape has been substituted for plastic, after foil wrapping. Foil wrapping prevents the adhesive on the tape from absorbing oil from the core.

2.136 Plastic Coatings

Plastic coatings have been used where cores are not to be tested within a few hours and need to be transported over distances which may involve rough handling. The cores should be scraped reasonably free of mud cake, dipped in the molten plastic, tagged, and shipped in this condition. One procedure used for dipping cores in molten plastic requires a thermostatically controlled melting pot to hold the plastic in a barely melted condition. The core to be coated is grasped by tongs or by the thumb and forefinger at one end submerged about two-third of its length in the molten plastic, immediately removed, and allowed to cool and set for a few seconds. It is then grasped by the coated end and dipped, allowing the second plastic layer to overlap the initial one.

A dip such as that just described should leave a plastic layer about 1/16 in. thick, completely surrounding and sealing the core with no air space between, yet not penetrating the core beyond one sand grain depth. If transportation over long distances is anticipated or if cementation of the core is not good, it may be advisable to repeat the dipping process, thereby building up the thickness of the coating. This can be continued to achieve any reasonable thickness desired. However, for normal physical protection, the initial dip coat is satisfactory. Very poorly consolidated cores may be wrapped in foil before dipping.

Plastic used for coating cores must have certain properties, as follows:

- a. It must be dimensionally stable over long period of time.
- b. It must not react with oil or water.
- c. It must not contain oleic acid, oil, solvent, or any other liquid which may be exuded when set.
- d. It must be impermeable to gases, oils, and water when set.
- e. It must have a low melting point, preferably below 200 F. maximum.
- f. It must have a fairly low viscosity when melted. The viscosity should be similar to that of an average oil paint such that it will pour readily or drip slowly from a small opening, yet will not quickly penetrate capillary openings.
- g. When removed from heat and exposed to normal air temperatures, it should dry and set tack-free within 5 to 15 sec.
- h. When set, it should be tough but pliable, slightly elastic, but with good tensile strength; and not melt at temperatures below 180 F."

Pressure Cores

The most commonly used procedure for preserving pressure cores is by freezing with dry ice.^{3,4} On cores taken with the Loomis pressure barrel, it is first necessary to remove the drilling fluid entrapped between the inner barrel and the outer barrel prior to freezing. If this is not done, the drilling fluid will become frozen, locking the inner barrel inside so that it cannot be properly removed.

To accomplish proper flushing, a back-pressure regulator is attached to a port in the ball valve housing and a high-pressure positive displacement pump is attached to the flushing head at the top of the inner barrel. A material such as gelled varsol is then carefully pumped into the annular space between the inner and outer barrels maintaining the desired bottom-hole pressure during the process. The gelled material is slowly forced through the barrel until all of the drilling fluids have been displaced. The core barrel is then placed into an insulated container and carefully frozen with dry ice.

The freezing procedure requires approximately one hour. Once this has been accomplished, the pressure maintenance is disconnected and the outer tube removed from around the inner barrel. Standard pipe cutters are then used to section the 10 ft. inner barrel into easily handled lengths and the core is broken at each cut. Since prolonged exposure of the core to materials such as nitrogen, hydrogen and oxygen can significantly alter formation wettabilities, the cores should be quickly capped and wrapped with aluminum foil or plastic as quickly as possible, replaced in insulated containers and covered with dry ice. Cores preserved in this manner can be transported and stored for several months before thawing and analysis without apparent damage.

In 1947, Wisenbaker proposed the process of preserving cores by freezing with dry ice.⁵ His studies of over 80 samples from 4 different wells showed that no appreciable porosity change was caused by quick freezing samples fully or partially saturated with water. No appreciable change in permeability was noticed for samples with 10% or more gas saturation. Samples fully saturated with water but with a permeability of more than 10 millidarcys also showed no substantial change. Samples fully saturated with water and with permeability of less than 10 millidarcys showed some change in permeability. Fresh core samples adjacent to those analyzed at the well were frozen and analyzed at times ranging from 20 hours to 30 days after freezing with no appreciable change in permeability, porosity, oil or water saturation attributable to quick freezing.

In 1953, Kelton⁶ reported on a study conducted to verify Wisenbaker's findings. Eighty-six pairs of samples from the Gulf Coast, West Texas and the Mid-Continent area were analyzed. The data was then grouped with that obtained by Wisenbaker with the resulting total of 177 sample pairs from 10 different wells. The results of this study are shown in Table 1:

TABLE 1

— A Comparison of Permeability and Porosity Averages of Samples Frozen at Well-Site vs Corresponding Averages for Adjacent Samples Not Frozen

Permeability Range, or Well Designation	Number of Sample Pairs	Average Permeability, md			Average Porosity, Per Cent		
		Frozen Samples	Unfrozen Samples	% Diff.	Frozen Samples	Unfrozen Samples	% Diff.
0-10 md	49	3.23	3.14	2.9	15.3	14.7	4.1
10-100 md	17	30.0	28.6	4.9	18.0	18.3	-1.6
100-1,000 md	15	356	339	8.0	19.2	19.3	-0.1
1,000-3,040 md	5	2,396	2,390	0.3	21.1	21.4	-1.4
Well A	12	125	111	12.6	26.5	24.1	10.0
Well B	22	175	167	4.6	17.5	17.2	1.7
Well C	20	22.7	22.3	1.8	18.2	17.8	2.2
Well D	37	24.9	26.0	-4.2	19.5	19.1	2.1
Total	177	Weighted Averages		2.7			2.5

The final conclusions of Kelton's study was the same as previously found: that for all practical purposes, any changes in permeability, porosity and fluid saturation of oil well cores brought about by quick freezing are negligible.

Handling of Frozen Pressure Cores

The following steps are required to prepare frozen cores for analysis:⁷

- (1) Core removal from metal pressure barrel
 - (a) The sleeve containing the frozen core is cut into 3-4 ft. lengths in the field.
 - (b) After arrival at the laboratory, two grooves are milled down the axial length of the sleeve and on opposite sides of the core while maintaining the core in a frozen state. See Figures 1, 2, 3 & 4. The groove is deepened until only paper thin metal remains. The barrel is cooled with liquid nitrogen during the milling operation. Problems are encountered here with freezing damage to the milling equipment.
 - (c) The final sleeve removal occurs in the laboratory by wedging a tool in the milled groove of the sleeve and twisting or tapping. See Figure 5.
- (2) Mud removal from sample circumference after core is out of the metal pressure barrel but still frozen.

Figure 1 - Milling Frozen Core.

Figure 2
Milling Off Metal Sheath Around Frozen Core

Figure 3
Side View of Milling Off Sheath of Frozen Core

Figure 4
Close Up of Milling Operation

- (a) Frozen mud adheres to the core surface and is difficult to remove. A similar difficulty exists with both water base and polymer muds.
- (b) The mud must be rasped off or a chipping process must be used. The core must be isolated from the atmosphere to prevent moisture condensation on the surface. This can be accomplished if the core is worked on in a deep chest surrounded by CO_2 vapor. See Figures 6, 7 and 8.

Figure 5

Wedging Off Sheath from Frozen Core.

Figure 6
Cooling Core for Final Cleaning.

Figure 7
Rasping Off Frozen Mud From Core

Figure 8
Scraping Frozen Core

- (3) Trimming and drilling of core samples after mud removal.
- (a) Samples are cut into 4" to 8" right cylinders while frozen. This yields full diameter samples normally used in subsequent tests. Samples must be sawed while frozen. If necessary, the trimming process can be stopped while the core is refrozen, or liquid nitrogen can be directed to the cutting surface. See Figure 9.
 - (b) Plugs (1" or 1½") can be drilled from the frozen core using liquid nitrogen as the bit lubricant.
- (4) Exclusion of core from oxygen and nitrogen is a problem only if core wettability changes are to be avoided. The shipment of the core in the metal barrel, and subsequent storage in dry ice, minimizes this problem. It is also minimized during surface mud removal in the deep chest with the core in the CO₂ vapors.
- (5) The expansion of fluids within pore space that is one hundred percent liquid saturated can be a problem in certain formations. This saturation condition occurs when cores are from virgin formations at initial pressure conditions, or when taken from within a water flooded zone maintained at initial pressure. Fluid expansion in these cases may increase the measurable pore (storage) volume of the rock, and volume of the rock, and in unconsolidated formations result in changes in bulk volume as well. Where gas saturation is present to furnish volume into which the fluids can expand, no alteration in measured properties is likely to occur.

Figure 9
Liquid Nitrogen Being Used to Cool Cores During
Trimming Process.

Laboratory Analytical Techniques (Dependent on Data Required)

- (1) The frozen full diameter sample is measured for length, diameter and weight and is placed in an air tight container. A quick (15 second) vacuum is applied to remove air surrounding the sample within the container.
- (2) The sample is then allowed to thaw overnight. Gas evolves during the thawing process and expands. The gas is trapped, and its volume is measured.

- (3) Composition of the evolved gas can be determined by chromatograph.
- (4) Heat is applied to the core container to vaporize the oil and water - which are recovered in a calibrated receiving tube attached to the underside of the container. The receiving tube is submerged in liquid nitrogen, or a suitable coolant, to condense the vaporized fluids. See Figure 10.
 - (a) 450°F and vacuum application is used in some processes. This effectively cleans and dries the core if oil gravity is 35° API or above.
 - (b) 250°F and no vacuum will remove all water and some oil. The core must be weighted, oil extracted by an independent process, and the core re-weighted to find the additional oil removed during this subsequent cleaning.
- (5) After the core is cleaned and dried, the pore volume is determined using one of several suitable techniques. Porosity (pore volume divided by bulk volume) is then computed.
- (6) Permeability is determined on the clean, dry core.

Values To Be Measured On Unflushed, Pressure-maintained Cores

Porosity, permeability, and oil, gas and water saturations are the principal measurements that would be made on unflushed, pressure-maintained cores. Of these measurements, the oil, gas and water saturation measurements would be the most important

Figure 10
Collecting and Analyzing Apparatus For
Core Examination

since they would represent values that cannot be determined otherwise. Adequately accurate permeability and porosity values can be obtained from conventionally cut cores in most cases. Where a formation is unconsolidated, such as many in California, the analysis of pressure-maintained cores may yield more accurate porosity values.

It must be emphasized that the volume of oil determined to be present in unflushed, pressure-maintained cores would be the best possible evaluation of oil reserves, both for new reservoirs and for reservoirs at flood-out. The volume of gas produced from such cores and a compositional analysis of the gas would also be important and would be an early indicator of the quality of the oil, the gas-oil ratio, and the bubble point, or perhaps the dew-point if one exists.

Advantages To Be Gained If Pressure And Temperature Are Maintained On The Unflushed Core

It has been observed that certain laboratory tests sensitive to the surface kinetics or "wettability" of the rock-fluid systems are sensitive to temperature. ^{8,9,10,11,12,13,14}. Relative permeability and sometime capillary pressure tests are examples of such tests. There are no known studies of the effects of temperature reduction on the wettability of pressure maintained cores. This would perhaps be futile because of the probability of altering the wettability of the system during coring which already has been recognized. It cannot be accepted a priori that an unflushed, pressure maintained core, if kept isolated from air, would undergo a permanent wettability change upon temperature reduction. It may be possible that certain salts or waxes would precipitate which would not go back into solution upon returning the core to reservoir temperature. This could

have an effect on the surface kinetics and thus the relative positions of the oil and water phases.

Problems Related To Transfer And Laboratory Analysis Of Pressure And Temperature Maintained Cores

The transfer and analysis of cores while maintaining reservoir pressure and temperature will constitute a large subclass of problems. It will be assumed here that since no flushing has taken place, that there will be no contamination of the core and no need for core cleaning. The cores will have to be shaped into right cylinders for mounting in appropriate laboratory instruments. Both horizontally and vertically oriented samples would be necessary because of the vector nature of some properties. Exclusion of air or any other material from the core samples while transferring, shaping, or mounting samples for tests would be required. No loss of pore fluid should be allowed during these processes. The procedure of freezing the samples during transferring and preparation in the case of pressure only maintenance, of course, cannot be employed in the temperature and pressure maintenance case.

Since such ideal formation samples have never been within reach of the core analyst and reservoir engineer, little thought has previously gone into solution of the above mentioned problems. It is believed, however, that presented with high probability of eminent availability of the cores, suitable solutions to the problems of analysis would be forthcoming.

REFERENCES

1. API RP 40, "API Recommended Practice For Core Analysis Procedure," American Petroleum Institute, Dallas, Texas, First Ed., August, 1960, p. 6.
2. Ibid, pp. 7 & 9.
3. Yell, Lindsay, Loomis Hydraulic Testing Co., Interview, February 3, 1976.
4. Walker, Dick, Lamar University, Interview, January 26, 1976.
5. Wisenbaker, J. D. "Quick Freezing Of Cores," Oil & Gas Journal, Jan. 25, 1947, pp. 275-281.
6. Kelton, F. C., "Effect of Quick-Freezing vs Saturation of Oil Well Cores," Journal of Petroleum Technology, January, 1953, pp. 21-22.
7. Jenkins, Ralph, "Handling Frozen Pressure Cores," A special report prepared for ERDA Project E(34-1)-0035, Core Laboratories, Dallas, Texas.
8. Bobek, J. E., Mattax, C.C., and Denekas, M.O., "Reservoir Rock Wettability-Its Significance and Evaluation," Journal of Petroleum Technology, (1958), No. 213,213.
9. McCaffery, F.G., "The Measurement of Interfacial Tensions and Contact Angles at High Temperature and Pressure," Journal of Canadian Petroleum Technology (1972) 11, No. 3,26.
10. Colpitts, G.P, and Hunter, D.E., "Laboratory Displacement of Oil by Water Under Simulated Reservoir Conditions," Journal of Canadian Petroleum Technology, 1964, 3, No. 2,66.

11. Odeh, A.S. and Cook, E.L., "Discussion - Effect of Temperature on Waterflooding," Journal Canadian Petroleum Technology, 1965, 4, No. 4, 242.
12. Edmondson, T.A., "Effect of Temperature on Waterflooding," Journal of Canadian Petroleum Technology, 1965, 4, No. 4, 236.
13. Davidson, L.B., "The Effect of Temperature on the Relative Permeability Ratio of Different Fluid Pairs in Two Phase Systems," Journal of Petroleum Technology, 1969, No. 8, 1037.
14. Poston, S.W., Ysrael, S., Hossain, A.K.M.S., Montgomery, E.F., and Ramey, H.J., Jr., "The Effect of Temperature on Relative Permeability of Unconsolidated Sands," Society of Petroleum Engineers Journal, 1970, 10, No. 2, 171.

V. PRESENT CORING TECHNOLOGY

Introduction

Double Tube Core Barrels

Oriented Coring

Wireline Core Barrels

Rubber Sleeve Core Barrels

Pressure Core Barrels

 Loomis Pressure Barrels

 Shell/Christensen System

References

PRESENT CORING TECHNOLOGY

Introduction

The analysis of cores taken in hydrocarbon and minerals source rocks has become a standard source of data for evaluation of production potentials. To meet the specific needs of the drilling industry, a number of companies have become expert at coring and have developed variety equipment and services for industry.

In addition to providing coring equipment for a wide range of hole sizes and depth of operation, these service companies have developed a number of specialized coring systems. The most commonly used systems are shown in Table 1:

TABLE 1 MOST COMMONLY USED CORING SYSTEMS
Conventional Double-tube Barrel Wireline Barrel Rubber Sleeve Barrel Pressure Barrel

While each of these coring systems have been designed to meet specific requirements, they all have similar components necessary to the task (Figure 1). The bit is located at the lower end of the system and is connected to the bottom of the drill string through an outer tube which acts as the torque and load-bearing member. Most coring systems have an inner core receiving tube which is attached at the top to the outer tube through a swivel assembly so that the inner tube remains stationary while the outer tube rotates.

Figure 1
Essentials Of A Coring System

The lower end of the inner tube is normally located in the throat of the core bit and contains a core grasping device to hold the core during the trip out of the hole. (Figure 2).

One of the most sophisticated coring systems available in the petroleum industry is the rubber sleeve core barrel (RSCB) which was developed to permit recovery of very soft unconsolidated formations which could not be captured using the conventional double-tube coring system.

Figure 2
Core Catcher

The pressure core barrel is of greatest significance to this study because these barrels are designed to deliver the core to the surface under bottomhole pressure. This and the other coring systems are discussed in greater detail below.

Double Tube Core Barrels

The conventional double tube core barrel is used for most oilfield coring requirements (Figure 3). The wide variety of available barrels and sizes of barrels are shown in Table 2:

TABLE 2
TYPES OF CORE BARRELS

Core Barrel Size & Type	Outer Tube OD inches	Outer Tube X-Sectional Area, Sq. in.	Core Dia. in.
AMERICAN COLDSET CORPORATION			
Standard Core Barrels			
3-5/8" x 1-7/8" x 40'	3-5/8	3.83	1-7/8
4-1/8" x 2-1/8" x 60'	4-1/8	5.07	2-1/8
4-1/2" x 2-3/8" x 60'	4-1/2	5.58	2-3/8
5" x 2-7/8" x 60'	5	7.07	2-7/8"
5-3/4" x 3-3/8" x 60'	5-3/4	8.25	3-3/8
6-7/8" x 4-1/4" x 60'	6-7/8	10.01	4-1/4
Maritime Core Barrels			
6-1/4" x 4" x 60'	6-1/4	16.49	3
4-3/4" x 2-3/8" x 60'	4-3/4	5.58	2-3/8
CHRISTENSEN DIAMOND PRODUCTS COMPANY			
3-1/2 x 1-3/4 Slim Hole	3-1/2	3.7	1-3/4
4-1/8 x 2-1/8 250 P Series	4-1/8	5.1	2-1/8
4-1/2 x 2-1/8 Marine Series	4-1/2	7.6	2-1/8
4-3/4 x 2-5/8 250 P Series	4-3/4	6.7	2-5/8
5-3/4 x 3-1/2 250 P Series	5-3/4	9.2	3-1/2
6-1/4 x 4 250 P Series	6-1/4	10.1	4
6-1/4 x 3 Marine Series	6-1/4	16.5	3
6-3/4 x 4 250 P Series	6-3/4	13.1	4
8 x 5-1/4 250 P Series	8	15.8	5-1/4
RUCKER-HYCALOG			
4-1/2" x 2-3/8" x 60'	4-1/2	5.22	2-3/8
5-3/4" x 3-1/2" x 60'	5-3/4	8.25	3-1/2
6-7/8" x 4-3/8" x 60'	6-7/8	11.16	4-3/8
6-7/8" x 3-1/2" x 60'	6-7/8	19.40	3-1/2
7" HW	7	20.76	3-1/2
6-1/2" HW	6-1/2	15.46	3-1/2
4-3/4" HW	4-3/4	10.65	1-7/8
4-1/8" HW	4-1/8	6.29	1-7/8

PART NAME	
COMPLETE BARREL (less tools & core head)	
1. SAFETY JOINT ASSEMBLY	
A. Safety Joint Pin	
B. Spring (3 required)	
C. Plunger (3 required)	
D. Friction Ring	
E. "O" Ring	
F. Safety Joint Box	
G. "O" Ring	
2. SWIVEL ASSEMBLY	
A. Cartridge Cap	
B. Shims	
C. Bearing Retainer	
D. Thrust Bearing	
E. Cartridge Plug	
F. Inner Tube Plug	
G. 1" Steel Ball	
H. Pressure Relief Plug	
3. OUTER TUBE SUB **	
4. OUTER TUBE (30 ft. with sub.—2 required)	
5. THREAD PROTECTOR (upper)	
6. THREAD PROTECTOR (lower)	
7. INNER TUBE (30 ft.—2 required)	
8. THREAD PROTECTOR (upper)	
9. THREAD PROTECTOR (lower)	
10. INNER TUBE SHOE (complete)	
A. Inner Tube Shoe (upper half)	
B. Inner Tube Shoe (lower half)	
11. CORE CATCHER (standard)	

Figure 3 - Double Tube Core Barrel
(Courtesy Christensen
Diamond Products Company).

It should be noted that most oilfield coring applications are performed using diamond core bits. Therefore, virtually all coring systems are manufactured and marketed by companies who also market diamond bits. The design of basic double tube coring systems is predicated by several factors. The equipment must be strong enough to withstand the forces applied during coring operations. It should also be reliable, have long, low cost operating life and be simple to maintain. In order to achieve these goals, it has been necessary to utilize very simple, uncomplicated design parameters with the result that there is very little difference between core barrels available from the various manufacturers.

A number of more sophisticated modifications are available for special coring requirements. For example, when coring very soft formations, such as offshore sediments, it can be beneficial to use a plastic liner (Figure 4) inside of the inner tube. Once the core is brought to the surface, the plastic tube is removed in one section, thus facilitating the handling of the very soft core. Once removed from the inner tube, the core containing plastic sleeve can be cut into manageable lengths and capped for transportation without further disruption of the core.

Any standard core barrel can be adapted for use with the plastic liner by providing a liner retaining lip in the inner tube shoe and providing core catching means for the slightly reduced core diameter necessitated by the small internal diameter of the plastic liner.

Figure 5

Reference Marks Scratched On Core

Wireline Core Barrels

Wireline Coring Systems provide added utility to the conventional double tube systems in situations where continuous coring over long intervals is desired (Figure 8). The inner barrel is detachably mounted in the outer barrel and can be retrieved to the surface through the inside of the drill pipe on a wireline. The obvious advantage of such a technique is that the drill string does not have to be removed from the hole in order to dump the core. In order to accomplish wireline removal from the inner barrel, the largest diameter of the inner barrel system must be smaller than the minimum diameter in the drill string. This means that under normal circumstances, the core diameter will be quite small compared to conventional systems in the same size hole. Wireline cores generally provide only marginally adequate samples for proper formation evaluation. The small core size relative to hole size also means that considerably more rock must be removed by the bit, thereby leading to slower penetration rates and

Figure 4
Plastic Liner in Inner Barrel

Oriented Coring

The most sophisticated addition to the conventional coring system is probably the core orientation system. This system is used when it is important to determine directional properties of the formation being cored.² Reference scribe marks (Figure 5) are scratched into the surface of the core as it enters the inner tube (Figure 6). Above the core barrel in a non-magnetic drill collar is a multi-shot magnetic survey instrument which is rigidly attached to the top of the inner tube by a connecting rod (Figure 7). The survey instrument records the directional position of the scribe marks periodically during the coring operation. These periodic data points are later correlated with the proper depth position on the core. Core orientation, as well as most other available modifications to the standard coring system, add cost and complication to normal coring operations. They are, therefore, seldom used except for absolutely necessary situations.

Figure 8
Wireline Coring
System

increased bit costs.

The wireline coring system finds primary application in the mining industry, where minimum string wall thickness and small drill pipe annulus clearance permits maximum core diameter, and in offshore sediments coring where pulling the drill string is either impractical or very costly.

Figure 6
Scribing Knife At Lower End
Of Inner Barrel

Figure 7
Core Orientation System

Rubber Sleeve Core Barrels

The rubber sleeve core barrel is another fairly complicated special purpose tool. Developed by Jersey Production Research Co.³, this system permits the recovery of very soft, unconsolidated formations, conglomerates or badly fractured rock, which cannot be recovered using conventional coring systems (Figure 10). The basic improvement of the RSCB is the rubber sleeve itself, which is stripped onto the core immediately after it is cut, thus preserving its exact position in the formation. Once operation is begun, the top of the rubber sleeve is held in a fixed relative position with the formation so that even voids and lost core can be accounted for exactly. The rubber sleeve provides a protective seal around the core, thus reducing contamination from exposure to the drilling fluid. Additional design features isolate the flowing drilling fluid away from the core during the coring operation.

Figure 10
Unconsolidated Core In Rubber Sleeve

During the trip into the hole and preparation for coring, the splined two-foot slip joint is locked in an open position (Fig. 11a). When ready to begin actual coring operations, a plug is dropped from the surface through the drill pipe to unlatch a ratchet tube (Fig. 11b). From this moment until completion of the coring operation, the top of the rubber sleeve (which is attached to the bottom of the ratchet tube) will be held in its fixed position relative to the formation being cut. As the bit is rotated, cutting the core, the outer tube moves downwardly with bit load being applied by hydraulic pressure of the flowing fluid passing through a jet nozzle section. The rubber tube is stripped off of a carrying sleeve onto the core as the carrying sleeve advances downward with the outer tube and bit. After each two-foot interval of core is cut, the drill string is lowered, closing the two-foot spline and advancing the upper ratchet system on the ratchet tube as it is held in its fixed position by a second ratchet in the outer tube section (Figure 11c). Since the top of the rubber sleeve is supported by this ratchet tube, the weight of the sleeve and core are suspended by the tube and not the core itself. This prevents core collapse, crushing and jamming that occurs when attempting to core similar formations with a conventional barrel.⁴

The rubber sleeve core barrel provides the only present means of coring and recovering these unconsolidated types of formations. However, because of its complicated sequence of operation and cost of the rubber sleeve itself, the technique finds limited application. Typical rental costs are on the order of \$50 to \$100 per foot. Several features of the RSCB, such as the spline, spline locking mechanism and the hydraulic force for opening the spline joint appear to have potential application in an improved pressure coring system.

(a)

(b)

(c)

Figure 11
Rubber Sleeve Core Barrel

Pressure Core Barrels

The concept of bringing cores to the surface under pressure is not new. In 1938, Sewell⁵ suggested a core barrel with a cylinder valve in the lower end of the outer tube (Figure 12). In 1941,⁶ and 1944,⁷ Sewell recommended improvements to his original idea. In 1944, Auld⁸ suggested a wire line version of a pressure barrel (Figure 13) with a flapper valve. There is no evidence indicating that any of these systems saw field application until the late 1950's. The Sewell patents were originally assigned to Standard Oil of New Jersey and may have restricted application of the pressure concept. However, in the late 1950's, Humble Oil Co., a subsidiary of Standard Oil of New Jersey, designed and built a field operational tool based on concepts of Sewell.

Figure 12
Sewell Pressure Core Barrel
(USP 2,216,962)

Figure 13
Wireline Pressure
Core Barrel

(USP 2,347,726)

The Humble system saw field application within the Humble organization until the mid 1960's when marketing rights were licensed to Loomis Hydraulic Testing Co., Inc. Loomis has made the system available for commercial use, but the lack of technical personnel, a total lack of experience in coring and the apparent absence of financial incentive from industry, has resulted in no new developments being made on the original Humble system. It is used today in essentially the same form as the original design of the late 1950's.

Loomis Pressure Barrel

Specifications of the Loomis barrel (Figure 14) include a core diameter of 2-5/8 inches and a length of 10 ft. Maximum working pressure for the system is 4,800 psi. The barrel has a maximum outside diameter of 6 inches and is, therefore, restricted to a minimum hole size of 7-7/8 inches under most drilling conditions.⁹

Figure 14
Loomis Pressure Core Barrel

In operation, the Loomis sytem is lowered to the bottom of the hole and the core is cut in a generally conventional manner. After the core is cut and broken off, the bit is held several feet above the hole bottom. A ball is dropped through the drill pipe from the surface to unlatch the spline mechanism allowing the outer tube to fall under its own weight. After the ball valve passes over the end of the inner tube, a gear arrangement on the ball valve engages a corresponding rack in the ball valve housing and the ball is rotated to a sealed position. The upper end of the inner tube has a sealing surface with two O-rings that shoulders and seals in the upper barrel seal ring of the outer tube (Figure 15). As the outer tube reaches the extent of its travel, a valve in the inner tube head is opened from the pressure maintenance system located above. Drilling fluid fills the opening from the inner tube to the gas accumulator chamber which is separated from the mud by a sliding seal piston. An inert gas, such as nitrogen, was placed in the accumulator prior to the coring operation and pressure is maintained at a pre-set value by a pressure regulator. The pre-set pressure was calculated to be the same as the bottom hole pressure.

After the closing operation, the barrel is tripped out of the hole in the conventional manner, the bit is removed and the barrel head and outer tube down to the upper pressure barrel seal is removed. A back pressure regulator is attached to a port in the ball valve housing at the lower end of the barrel. A high pressure positive displacement pump is attached to a port in the flushing head at the top of the inner barrel. Gelled Varsol is then pumped through under pressure to displace the drilling mud left between the inner tube and the outer tube after the coring operation. This drilling fluid must be removed so that the barrel can be disassembled and inner barrel removed

Figure 15
Loomis Barrel In Sealed Position

after the core has been frozen. When the drilling fluid has been displaced satisfactorily, the barrel is placed into an insulated container and the core frozen, using dry ice. When frozen, the outer tube is removed and the inner tube is cut into manageable length sections with a standard pipe cutter and the core is broken off at each joint. Each of the sections is then placed into a marked insulated container with dry ice for transportation and storage at the lab.

In the 10 year period prior to 1975, the Loomis system apparently saw an average usage of about 8 cores per year. As a result of several tertiary recovery project evaluations, 10 to 15 pressure cores were taken during 1975 and to date approximately 30 pressure cores have been taken during 1976. With the exception of a recent carefully controlled program by Atlantic Richfield (18 of 19 cores recovered at the surface under pressure), previous applications of the Loomis system have been only marginally successful with an average of only about 50% of the cores cut being recovered at the surface under pressure.

Shell/Christensen System

In 1964, Shell Development Co. contracted Christensen Diamond Products Co. to design and build a pressure core barrel for a specific program which they had planned. The specifications selected by Shell included a hole size of 5-1/2 inches and core length of 5 feet. The final design resulted in a core diameter of 1-3/4 inches, a maximum working pressure of 5000 psi and a nominal outer barrel diameter of 4-3/4 inches (maximum OD 5-1/4 inches).

There was no public information concerning the Humble design at that time and, therefore, the Sewell patent provided the basic reference. On this basis and also the fact

that principal project engineers for Christensen at the time (Rowley and Bridwell) were both former Jersey Production Research employees, it is no surprise that the Christensen design was basically the same as the Humble design (Figure 16).

Figure 16
Shell/Christensen Pressure Core Barrel

The operation of the barrel is nearly identical. The barrel is lowered into the hole and core cut in a near conventional manner. After the core is broken off, the bit is held several feet off bottom. A ball is dropped through the drill pipe from the surface to unlatch the spline mechanism and the outer tube falls under its own weight. Should there be an indication that the outer tube had not fallen or was not opening properly, provision was made to apply hydraulic force by pumping the drilling fluid through a set of nozzles. After the outer tube had moved downward a few inches, the upper shoulder of a sliding intermediate sleeve contacted a ring held in the outer tube by shear pins. Continued movement by the outer tube carried the intermediate tube downward until the ball valve located at the lower end of the intermediate tube had passed over the end of the inner tube. At this point, shear pins holding the slip ring sheared and further travel of the intermediate tube permitted. The continued downward movement of the outer tube brought a set of gears into contact with teeth on the ball valve rotating the ball closed to the sealed position. At about the same time, a lever was tripped at the top of the inner barrel closing a plug valve and, thus, sealing the inner tube completely. Another valve was subsequently opened providing communication between the inner barrel and the gas pressure loaded equalization system. Pressure in the accumulator system had been pre-set at a value 50 to 100 pounds higher than calculated bottom-hole pressure. After the sealing sequence, the barrel was tripped to the surface in the conventional manner.

At the surface, the system was disassembled and the inner tube and pressure system were removed from the barrel. The analysis of all core on the project was handled by Shell Development in their own lab and, therefore, they chose not

to freeze the core. To insure that pressure was maintained on the system until time for analysis, a larger pressure maintenance system replaced the coring pressure system for transportation to the lab. The inner barrel systems were easily manageable without further breakdown because of their small size.

On the completion of the initial program lasting about two years, Shell stored their pressure core barrel and it has not been used since. Shell desired to take pressure cores during 1975 and it was decided to use the Loomis system instead of rebuilding their own system after storage of more than 8 years. Another deciding factor in the decision was that the Shell Development project engineer on the previous pressure coring program had since retired, leaving no one who was completely familiar with the Shell/Christensen system.

It can be seen from the previous discussion that a wide variety of coring equipment is available to meet exploration requirements. However, even though pressure coring systems are available they do not meet the requirements defined as the objectives of this true fluid coring project.

REFERENCES

1. Drilling Manual, International Association of Drilling Contractors, Houston, Texas, Jan., 1975, p. AS-2.
2. Rowley, D. S., Burke, C. A., Manuel, T., "Oriented Cores In 1964," Paper presented at Michigan Basin Geological Society, Michigan State University, April 24, 1964, 17 pgs.
3. Hildebrandt and Bridwell, USP 2,927,776.
4. Christensen Diamond Products Co. Catalog (SD-668)
5. Sewell, USP 2,216,962.
6. Sewell, USP 2,238,609
7. Sewell, USP 2,343,805
8. Auld, etal, USP 2,347,726
9. Loomis Hydraulic Testing Co., Advertisement, Oil & Gas Journal, March 1, 1971, p

VI. LIMITATIONS OF PRESENT CORING METHODS

Flushing

Pressure Reduction Bleed-off

Reliability

Core Size

Core Handling

References

LIMITATIONS OF PRESENT CORING METHODS

Previous sections of this report have discussed the current technology for obtaining true samples of oil and gas formations. The most sophisticated of these techniques do, in fact, provide more accurate answers than those obtained by conventional day-to-day coring techniques. However, technology in present use still has serious limitations and does not achieve the desired capability of determining true unaltered ratios of formation fluids in the reservoir pore space. These limitations include: flushing of the core during the cutting operation, bleed-off during the trip out of the hole, reliability and effectiveness of coring equipment, and core handling requirements. Each of these factors is discussed in the section that follows along with the relative significance regarding the feasibility of obtaining true unaltered formation samples.

Flushing

Laboratory studies by Young and others before him clearly demonstrated the invasion of filtrates into formation during drilling and coring operations.¹ Jenks was concerned with flushing during coring operations and attempted to determine specifically those factors that influenced the amount of flushing. He found that oil, including residual oil which is not mobil under normal water flooding pressure, can become mobil and be stripped from the rock close to the working bit under conditions frequently encountered in normal coring operations.² In most coring operations, there is no provision for isolation of the core from the drilling fluid in the throat of the core bit. In fact, as shown in Figure 1, the core must act as one side of the fluid flow channel. It is impossible to prevent some fluid invasion in flushing as long as this condition exists.

Figure 1

Core Acting As One Side Of Flow Channel

Jenks also found that the amount of flushing is increased by increased over-balance pressure in the borehole as shown in Table 1. Tables 2 and 3 show that larger cores result in reduced stripping as does shorter time exposure (faster drilling rate). Later drilling studies have confirmed these finds.

Early in the development of rotary coring techniques, this problem of flushing was recognized and many concepts were proposed for its elimination. In 1932, Johnston received a patent covering the concept of placing a heavy molten metal in the bottom of the hole to isolate the core from the drilling fluids, thus preventing flushing (Figure 2).³ By selecting a low melting point material, such as Woods' metal, lowering the mud temperature at the end of the coring operation would result in "freezing" of the molten metal, thus sealing the lower end of the inner tube. In 1941, Mounce suggested a similar technique whereby mercury or other heavy water insoluble fluid would be used (Figure 3). There is no known record of these concepts being placed into actual practice.

TABLE 1

CORRELATION OF OVERBALANCE, DEPTH OF
INVASION AND OIL-STRIPPING

(0.6-inch Berea Sandstone Core, Mud B, 150 lbs WOB)

Borehole Pressure (psi)	Depth of Invasion (in.)	Reduction in Residual Oil (%)
100	0.10	19
200	0.20	26
350	0.27	54
500	0.33	48

TABLE 2

EFFECT OF BIT DIAMETER ON
OIL-STRIPPING(Berea Sandstone — Mud B — 200 psi Overbalance —
150 lbs WOB)

Bit Type	Reduction in Residual Oil (%)
0.6-inch (flat-face)	25
0.6-inch (round-face)	26
1.5-inch	17

TABLE 3

EFFECT OF DRILLING RATE ON OIL-
STRIPPING

(0.6-inch-Diameter Berea Sandstone Cores)

Borehole Pressure (psi)	Weight on Bit (lbs)	Coring Time (min)	Penetration Rate (in./min)	Reduction in Residual Oil (%)
100	150	2.47	1.23	19
100	100	5.37	0.56	24
200	150	2.13	1.42	26
200	100	6.51	0.46	35
350	300	1.15	2.63	44
350	150	2.48	1.18	54

Figure 2
Use Of Molten Metal To Isolate Core
(USP 2,146,263)

Figure 3
Use of Mercury to Isolate Core
(USP2,264,445)

Later, in 1951, Smith suggested cutting small cores without fluid circulation (Figure 4).⁵ Other concepts similar to this are known to have been tried. However, the small, short core obtained in this manner is generally not satisfactory for most reservoir studies.

Figure 4

"Dry Drilling" Small Cores
(USP 2,541,785)

As work continued in an effort to eliminate flushing of the core, Cochren, in 1958, suggested filling the inner tube with a viscous fluid which would be expelled as the core was cut in such a way as to lubricate a pilot core bit (Figure 5).⁶ The normal circulating fluid would be by-passed through a reaming core head above so that the core would never be exposed to the conventional drilling fluid. The preferential viscous fluid was an asphalt, but thermal setting plastic or even a chemically setting material would be alternatives. In 1959, Williams suggested a similar approach except without allowance for lubrication of the pilot bit (Figure 6)⁷ and Bridwell,⁸ in 1962, suggested another similar system (Figure 7). There is no evidence that these techniques were tried or were successful.

Figure 5
Use of Viscous Fluid To Isolate Core
And Lubricate Pilot Bit
(USP 2,862,691)

Figure 6
Use Of Noninvading Fluid To Isolate Core
(USP 2,880,969)

Figure 7
Isolation Of Core With Nonimbibing Fluid
(USP 3,064,742)

In 1963, Hildebrandt suggested a coring bit where the drilling fluid was isolated from the lower end of the inner tube by a sleeve and was discharged through the face of the core head tangentially (Figure 8).⁹ This bit design has been used for a number of years in conjunction with the rubber sleeve core barrel. The use of tangential fluid discharge apparently results in substantially reduced washing away of soft, unconsolidated cores. While tangential discharge in itself does not appear to be particularly important to the reduction of fluid flushing, the concept that controlled bit shape and fluid discharge may achieve this objective does have significance to our study.

Figure 8
Tangential Discharge Core Bit
(USP 3,095,935)

It appears that the techniques described above were either unsuccessful or impractical for normal coring operations. As a result, Jersey Production Research Co. undertook a project in the early 60's to develop a non-flushing drilling fluid to be utilized during the coring operation. This project lasted about 5 years and was finally abandoned as unsuccessful.

We have been unsuccessful in our attempts to gain access to the records of this project (these records are now property of Exxon Production Research). Correspondence from EPR management cite as their reasoning, "Our engineers feel that they have a good understanding of the fluid invasion process. They are confident that a practical TFC (True Fluid Coring) system cannot be developed if emphasis is primarily on controlling mud properties."¹⁰ Discussions with technical personnel involved in the original project indicate that the quoted statement is, in general, true.

Theoretical analysis and analog modeling studies indicate that under normal coring techniques, it is likely that the core is flushed as much as several inches ahead of the bit face, as shown in Figure 9. Further study will be required in order to verify concepts of controlled bit design and low filter loss drilling fluids for the reduction of invasion and flushing.

Figure 9
Flushing Ahead Of Core Bit

Any new true fluid coring system design which does not utilize totally noninvading circulating fluid must include a feature which isolates the core from fluid invasion.

Pressure Reduction Bleed-Off

Under most new reservoir conditions and even under many depleted reservoir conditions, some of the hydrocarbon constituents normally in a gas phase at surface pressures will still be liquified under bottom hole pressures. The reduction of hydrostatic pressure during the trip out of the hole would result in these gasses coming out of solution and moving through the pore space of the core, carrying some of the liquid phases along. At the surface, even a core cut without invasion or flushing would not be representative of true formation saturation because of this fluid movement. The use of sealed barrels without pressure maintenance but trapping of all constituents is a potential solution. However, an effective reliable pressure coring system will probably be required in most cases. In the opinion of most industry personnel, there is not a great need, at this time, for maintaining formation temperature as well as pressure.

Reliability of Pressure Coring Systems

The lack of reliability is a major limitation in the successful application of presently available pressure coring systems. The Loomis system is based on the system licensed from Humble Oil and remains virtually unchanged from the original design of the early 1950's. Several design features of existing systems are sources of operational problems and should be redesigned in any new pressure coring system.

The ball valve appears to be the best solution for sealing the lower end of the inner tube. However, the complicated use of levers and gears to actuate the ball valve are a source of problems (Figure 10). When the outer

tube is unlatched and falls to retract the inner barrel through the ball valve and, subsequently, to close the ball valve, there is a moment of sharp impact when the gears are engaged. This frequently results in damaged teeth and failure of the ball valve to close properly and seal. In the Loomis system, the upper end of the inner tube is closed by an O-ring sleeve shouldering inside the upper barrel seal. Both of the sealing surfaces and the O-rings are exposed to the drilling fluid flow during the coring operation. Some erosion can occur and foreign material, such as loss-circulation materials, can cake and build up around the O-ring surfaces, leading to problems in proper sealing when desired.

Figure 10
Gear Operated Ball Valve

On occasion, when core has been broken off, it has extended below the bottom of the inner tube and when the inner tube was retracted through the ball valve this extended core prevented closure of the valve (Figure 11). Care should be taken in the new design to provide for adequate clearance to insure proper operation of the ball valve.

Figure 11
Ball Valve Blocked By Core

The other pressure coring system presently in existence was designed for Shell Development Co. by Christensen Diamond Products in 1964. The design work was carried out without the benefit of detailed knowledge of the then proprietary Humble barrel design. Several design features are certainly improvements over the Humble system, however, in general the Shell/Christensen design is considerably more complicated. The same problems and limitations of gears operating the ball valve are present. In addition, several other shear pin rings and valve levers are a source of continual damage and failure.

Mud Displacement

When the Loomis barrel is brought to the surface and disassembled for further handling, it is necessary to use a time-consuming technique in order to remove the drilling mud from the space between the inner tube and the outer tube. The present operating technique requires that a pressure regulating system be attached near the ball valve and gelled Varsol pumped, under pressure, into the annular space to remove this drilling fluid (Figure 12). If this drilling fluid is not removed prior to freezing the core, disassembly of the outer tube and removal of the inner barrel for handling is impossible. An improved system should either eliminate the necessity for this flushing operation or should at least reduce the volume of entrapped drilling fluid to reduce the time involved in its completion.

Figure 12
Displacement Of Drilling Fluid Under Pressure

Once the core is frozen and the inner barrel removed and transported to the laboratory for evaluation, there is a problem in extracting the core from the metal tube. Present practice involves placing the frozen core in an endmill and carefully milling a longitudinal groove in the metal sleeve at 2 points diametrically opposed. Liquid nitrogen must be

used as the coolant for the endmill and it is also necessary to do the operation quickly before the core can begin to thaw. While Core Lab indicates that the operation is not difficult, it does represent an additional step in the analysis technique that should be eliminated, if possible.

Figure 13
Shell/Christensen Sealed Inner Barrel

The use of a sliding intermediate sleeve with attached ball valve housing simplifies the problem of drilling fluid in the annular space between the inner and outer barrel since the volume is quite small. However, in order to achieve this feature, it was necessary to reduce the overall diameter of the ball valve itself (Figure 13). Since the inner tube containing the core must pass through the ball valve, the smaller diameter therefore required a much smaller and undesirable core size. It is considered very important that core size should not be less than 2-1/2 inches in diameter and any new system should be designed around this parameter.

Core Size

To meet specific program requirements at the time, the Shell/Christensen pressure barrel design was based on a very short 5 foot core length. This simplifies transportation and handling, but significantly increases time and costs when it is necessary to core an entire formation of any thickness. While it poses no problem to increase the overall barrel length and thus the core length, this is a factor that must be considered in any new design.

The Shell/Christensen system was limited to a 1-3/4 inch core diameter. This is considered to be inadequate and most experts agree that the minimum diameter should be at least 2-1/2 inches.

Although much longer and larger diameter cores are very desirable, these benefits are gained only with significant increase in handling problems and decrease in system reliability, to say nothing of the physical limitations imposed by hole size and depth requirements of the drilling operation itself.

Core Handling

While satisfactory procedures seem to have been developed for handling the core from the freezing stage through preparation for final analysis, it is desirable to eliminate as many steps as possible. As discussed earlier, the core is locked inside the inner tube by freezing as a result of the drilling fluid entrapped in the annular space between the core in the inside of the inner tube (Figure 14). Once the inner tube is removed by the machining operation, it must be then placed inside a deepfreeze where the remaining

layer of frozen mud must be manually chipped and scraped from the core surface (Figure 15). Even if this procedure can be completed quickly and easily, it does represent a period of time when the core is exposed to an uncontrolled atmosphere and, if at all possible, this procedure should be avoided.

Figure 14

Core "Locked" in Inner Tube By Frozen Mud Layer

With the exception of flushing ahead of the bit all of the limitations to present true fluid coring systems discussed above can be eliminated through understanding and careful design of a new system. The flushing problem is obviously very difficult and additional work will be necessary to find a satisfactory solution. This is extremely important to the success of a true fluid program since no pressure core system, regardless of reliability and simplicity, will be of any benefit if the core is altered before entering the barrel.

Figure 15
Frozen Mud Being Chipped From Core

REFERENCES

1. Young, F. S., Jr., "Dynamic Filtration During Microbit Drilling," Petroleum Transactions, Society of Petroleum Engineers, Sept., 1967, pp. 1209-1224.
2. Jenks, L. H., Huppler, J.D., Morrow, N.R., and Salalhiel, R. A., "Fluid Flow Within A Porous Medium Near A Diamond Bit," Reprint, The Journal of Canadian Petroleum Technology, Oct.-Dec., 1968, pp. 1-7.
3. Johnston, USP 2,146,263
4. Mounce, USP 2,264,445
5. Smith, USP 2,541,785
6. Cochren USP 2,862,691
7. Williams, USP 2,880,969
8. Bridwell, USP 3,064,742
9. Hildebrandt, USP 3,095,935
10. Welch, L.W., Jr., President, Exxon Production Research Co., Correspondence, Feb., 17, 1976.

VII. SPECIFICATIONS FOR A TRUE FLUID CORING SYSTEM

Core Barrel Size

Core Diameter

Core Length

Pressure

Temperature

Coring Fluid

Monitoring

VII. SPECIFICATIONS FOR A TRUE FLUID CORING SYSTEM

In addition to the capability of taking unaltered cores, any true fluid coring system must be capable of operation under typical field conditions. Design requirements, based on evaluation of typical coring situations and discussions with industry personnel are summarized in Table 1.

TABLE 1
SUMMARY OF CORING SYSTEM
DESIGN SPECIFICATIONS

Parameter	Requirements
Core Barrel Diameter	6-1/4 inch nominal O.D.
Core Diameter	2-1/2 inch minimum
Core Length	10 ft. minimum 20 ft. maximum
Pressure Capability	5,000 psi minimum 10,000 psi maximum
Temperature Capability	275°F maximum
Coring Fluid	minimum modification to normal drilling fluid
Monitoring	capable of signalling specific system failures

Core Barrel Size

Most applications for a true fluid coring system will occur in holes of 7-7/8 inches or larger. The core barrel should therefore be designed with a 6-1/4 inch nominal outside diameter. In order to achieve maximum core size

it would be possible to mount the lower ball valve in a sub at the lower end of the outer tube. It is an acceptable practice to use a larger diameter (up to 7-7/8 inches diameter) for such a sub located at the bottom of the barrel, provided the length is kept to about 18 inches or less.

Core Diameter

In order to minimize influences of fluid invasion and to provide adequate sample for analysis, it is desirable to obtain as large diameter of core as possible. The maximum size of core is limited by the outer tube size; however, it is felt that in no case should the core be less than 2-1/2 inches in diameter.

Core Length

A primary application for a true fluid coring system would be the evaluation of formations prior to tertiary recovery programs. In such applications, it is considered extremely important to be able to study the entire producing interval in order to evaluate differences in fluid saturations with depth. This would often require continuous coring of 1 to 2 hundred feet at a time. It is, therefore, necessary that as long a core be obtained on each run as is practical. Any new system should be capable of minimum core lengths of 10 feet with 20 ft. capability being even more desirable.

There are some applications where transporting core to the laboratory for analysis while maintaining sealed-in pressure (and without freezing). In these cases, it may be desirable to cut very short cores (e.g. 5 ft.) to simplify handling problems. It should be noted that almost any system capable of handling longer cores can be modified to take short cores as well.

Pressure

It is thought that any true fluid coring system should be designed to seal in a minimum of 5,000 psi. This would permit operation in normally pressured reservoirs to a depth of about 11,000 ft. Although operation at higher pressures is not a typical requirement, if possible any new true fluid coring system should be capable of up to 10,000 psi.

Reservoir gases remain in solution until pressure is reduced to the "bubble point" pressure. If the 10,000 psi requirement cannot be reasonably incorporated into the pressure coring system, an alternate technique could be used. The pressure inside the sealed barrel could be allowed to reduce gradually during the trip out of the hole by releasing flow into a catch chamber through a pressure relief valve. The pressure reduction would cease and be maintained constant at a pressure slightly above the bubble point, thus preventing the gases from evolving and altering the true fluid content of the core.

Temperature

High bottom hole temperatures are not anticipated for most true fluid coring application. Therefore, no great emphasis should be placed on achieving temperature capabilities in excess of normal elastomer limits of about 275 to 300°F.

Coring Fluid

Although not absolutely necessary, it is desirable that any true fluid coring system be able to achieve satisfactory results with little or no modification to the conventional drilling fluids being used.

Monitoring

Any highly advanced designed true fluid sampling system should be equipped with sensors and a telemetry system. This system should be capable of recognizing specific failures in the operation of the equipment and provide a signal to the surface to permit corrective actions to be taken.

VIII. CONCEPTS FOR IMPROVEMENT OF PRESENT TECHNOLOGY

Cutting

Eliminating Invsion

Sealing

Reliability

Core Transportation

Up and Out of the Hole

Down the Road

Core Analysis

CONCEPTS FOR IMPROVEMENT OF PRESENT TECHNOLOGY

Many ideas have been proposed for methods of obtaining true fluid cores. Most of these ideas were discarded without attempt at application because they were technically impractical. Other concepts failed because adequate technology for success did not exist at the time or because the concept of a totally integrated coring system was not developed. Some reasonable ideas were not tested or evaluated simply because of inadequate funding.

During this study, hundreds of ideas relating to true fluid cores have been evaluated. These many ideas have ranged from detailed design considerations for a small portion of a coring tool all the way to a very broad concept for an entire system. In the following chapter, these many concepts have been organized into several logical categories to reduce confusion and to simplify evaluation. These major categories are summarized in Table 1 and are discussed individually in greater detail below:

TABLE 1
CATEGORIES OF TRUE FLUID CORING CONCEPTS

Category	Problem Addressed
Cutting	Cutting speed; rock damage
Invasion	Elimination of fluid alteration
Sealing	Maintenance of bottom hole pressure; core diameter
Reliability	Simplified handling; improved reliability
Transportation	Pressure and temperature maintenance; reduction of disturbance
Analysis	Reduced complexity; improved accuracy

Cutting

Many different methods of cutting cores quickly and without damage to rock properties are being considered. One idea is to use the Subterrene Corer being developed by Los Alamos Scientific Laboratories (Figure 1). Although this system which melts the rock can achieve high penetration rates, the concept is not considered feasible for several reasons. A tremendous amount of energy must be supplied from the surface in order to melt the rock. Even more importantly, it is felt that the high temperature operation of the system would immediately destroy true fluid ratios in the core obtained.

Figure 1
LASL Subterrene Corer

The concept of firing bullets into the bottom of the hole, such as the Sandia Tround system (Figure 2), offers the likelihood of attaining high penetration rates, possibly without the use of damaging fluid circulation. However, it is very likely that the core would be fractured and fluid saturations disturbed.

Figure 2
Sandia Tround Terra-Drill

Several techniques of single and multiple punch cores have been considered. In addition to the probable core damage, these techniques do not meet the requirement of desired core diameter and sample length.

Various methods of taking sidewall samples have been considered and the conventional punch core method was discarded for the same reasons as bottom hole punch coring. However, one concept does provide some very interesting possibilities. By lowering a small pressure coring system driven by a downhole mud or electric motor (Figure 3) on a wire line, it would be possible to alternately drill and take true fluid core samples. The curved tube opening from the

drill collar to the hole annulus would be plugged during the drilling operation. While this concept does not provide a core of adequate diameter and length to satisfy the generally desired true fluid sample requirement, it could be used for sampling in existing wells of depleted reservoirs without requiring new holes to be drilled. This could provide valuable information at a greatly reduced cost. The primary development problem of such a system is the necessity of coring out into the formation far enough to reach uninvaded, unaltered reservoir rock.

Figure 3
Sidewall Corer

Roller cone bits generally penetrate at rates exceeding those achieved by the typical diamond bit in most formations. Their use, however, is likely to be limited because of probable rock damage, problems of maintaining proper core gage and problems relating to prevention of fluid invasion.

The use of diamond coring bits on any new true fluid coring system seems to be the most logical approach. All of the justifications for using diamond bits in conventional coring techniques apply in this case also.

The idea of utilizing downhole motors, either mud driven or electric, to provide rotary power for a true fluid system, has good merit. Their use should be given strong consideration especially for any highly sophisticated coring system.

Eliminating Invasion

The most critical problem to be overcome in the development of a true fluid coring system is the elimination of drilling fluid invasion during the coring operation. Successful development of all of the other subsystems would be of little value if the core is altered when it enters the system. It is felt that additional study and testing will be necessary to develop the most promising of the concepts being considered.

The most obvious idea would be the development of a special drilling fluid which could replace conventional drilling fluids and which would not permit fluid invasion. Such a non-invading fluid must necessarily maintain all of the other characteristics of a conventional drilling fluid in order to be useful. In addition, the problem is aggravated by the necessity of maintaining a hydrostatic head (probably greater than reservoir pore pressure) sufficient to prevent blowout. Previous attempts at developing such a fluid have proved very costly and generally unsuccessful.

It is possible that a heavy liquid such as mercury could be spotted at the bottom of the hole to provide isolation of the formation being cored from conventional drilling fluid. It would still be necessary to maintain an undesirably high hydrostatic head to prevent blowouts and there is a definite possibility that fluid invasion would still occur by mud filtrate leakage into the hole wall around and past the heavy liquid.

One interesting concept would be to freeze the rock and fluids ahead of the coring bit, thus locking formation fluids in place. This would probably require the use of liquid nitrogen and a complicated system of insulated piping from the surface would be needed.

The use of an open hole packer to separate the reservoir rock from the normal drilling fluid looks very promising (Figure 4). The use of a packer would overcome the problem of excessive hydrostatic head since pressure below the packer could be adjusted to match formation pore pressures. The primary problems involved for this concept include the necessary circulation of a non-invading fluid to cool and clean the bit, and the complex equipment required to set and release the packer system itself. Open hole packers are routinely used in many drilling operations and the problems involved can probably be solved.

Figure 4
Open Hole Packer To Protect Reservoir

By using an "auger" type bit (Figure 5), it might be possible to drill below a packer without the use of an additional circulating fluid. Auger bits are used successfully on surface holes where the material being cut is unconsolidated, but it is doubtful that such a technique would work under bottomhole conditions and in hard rock formations.

Figure 5
Dry Drilling Auger Bit

The best non-contaminating fluids that could be used are the produced formation fluids. The main problem is how to withdraw sufficient fluid from the formation without causing alteration of the fluid saturation in the area being cored. It might be possible to use a formation fluid produced with special handling to prevent alteration from an adjoining

well. Handling of this fluid would be a problem and would not provide a universal solution (e.g. in a gas reservoir).

The most promising short-term solution to the problem of invasion includes the use of conventional drilling fluid but at a greatly reduced flow rate and a pilot-type coring bit (Figure 6). If the majority of the drilling fluid was by-passed above the coring system to provide adequate maintenance of hole conditions and only a minimum amount of fluid necessary to clean and cool the bit allowed to cross the bit face, the problem of dynamic filtration (i.e. invasion) would be greatly reduced.

Figure 6
Bit Design to Reduce Invasion

The pilot bit mentioned above should also include features to totally isolate the core from the circulating fluid by providing a rotating seal at the lower end of the inner tube system. It is thought that a replacable pilot bit extending ahead of the bit crown would further reduce the problem of fluid invasion.

If reduced fluid flow resulted in excessive bit wear caused by overheating, the bit could be cooled by circulation of a refrigerant inside the bit crown (Figure 7).

Figure 7
Refrigerant Cooled Bit

Sealing

After a true fluid core has been cut, it is necessary to seal the inner tube system in order to maintain bottom hole pressure during the trip out of the hole. While there is not a significant mechanical problem in sealing the lower end of the inner tube, the technique used is significant in that it controls the maximum core diameter that can be used.

The simplest method of closure and one which requires very little space in the open position is the flapper valve (Figure 8). The primary limitation with this concept is reliability of sealing. During the coring operation, with the valve in the open position, the sealing surfaces are exposed to rock cuttings and debris. It is felt that adequate positive closure and sealing would be difficult to achieve.

Figure 8

Flapper Valve

The Loomis coring system uses a ball valve. While careful design is necessary to obtain adequate core diameter, this approach appears to have the best reliability (Figure 9). The sealing surfaces are wiped clean by the rotating action of the valve and actual surfaces are never exposed to cuttings and debris. Previous problems with this sealing technique have generally not been related to sealing itself but have been more related to mechanical operations and closure of the valve.

Figure 9
Ball Valve Design Controls Core Diameter

Additional concepts worthy of consideration include use of quick-setting "epoxies" to plug the lower end of the inner tube. Other concepts such as cone shape spring leaf closures and other complicated systems do not appear to have the reliability and safety under high pressures that is considered necessary.

Improved Reliability and Ease of Handling

One possible step to improved reliability is the use of downhole instrumentation and controls to monitor and modify specific portions of the recovery operation. These improvements would reduce errors in functioning which cause failure to obtain a core sample, as well as provide better environmental control over the core such as maintaining downhole pressure and temperature around the core as it is raised to the surface.

Instrumentation and controls for the downhole environment could be electrical, mechanical, hydraulic, pneumatic or more probably a combination of these types of devices. All of the above equipment has specific advantages and disadvantages when applied to a well's hostile environment.

As a general design approach, the development of a highly reliable control system is the first criteria with accuracy and cost of a secondary importance. This is because the high costs of attempting to obtain this type of core make the cost of the unit less significant, but the need to obtain a core sample rapidly and reliably on each downhole trip of extreme importance. Accuracy is less important because the variability of strata over relatively short depths overshadows any small variations in the core's state.

There are two specific problem areas in core recovery where the use of downhole controls could be of help. The first is controlling the closing of the main ball valve on the core chamber. This would involve limiting the torque on the valve to prevent damage to it; monitoring the valve's face to insure it is clear before allowing the ball to actuate; and signalling to the surface when the valve is closed so the core can be brought to the surface. The second is maintaining the core at its downhole temperature and pressure while it is brought to the surface.

Three basic techniques can be used as a power source to close the ball valve. One technique previously used is to trip a heavy tube on the drill string and allow it to fall. A rack-and-pinion arrangement attached to the tube and valve rotates the valve's ball as the tube falls. This arrangement does allow control of the closing torque by varying the tube's weight, which is directly proportional to the torque. However, the impact load on the gears and their exposure to the down-hole fluids does frequently damage them, which prevents proper actuation.

As an alternative option, the use of a hydraulic or pneumatic actuator could be considered (Figure 10). Fluid powered equipment is ideally suited for a high force, low energy application where there are extreme space requirements. A hydraulic (liquid media) system would probably be more desirable than a pneumatic (gaseous media) system because the relatively incompressible liquid media would minimize impact loading from the jerking of the ball valve as it closes. However, the use of gas as a power source would be very desirable as discussed later.

Figure 10
Hydraulically Actuated Ball Valve

Hydraulic actuators would be used to close the ball valve. They could be vane type rotary actuators mounted on the side of the ball and direct coupled to its rotating shaft; or linear actuators mounted above the ball valve and connected to the ball's rotating shaft with a linkage. The rotary actuators would be most desirable because of their minimal moving parts and their direct coupling to the ball. Torque limiting of the closing would be accomplished by limiting the pressure difference across the actuators.

Because the actuation is a short term transient operation, the use of an accumulator for power storage would be very simple and reliable. A conventional hydraulic accumulator for this application consists of a pressure vessel, mounted on the core recovery system, partially full of hydraulic fluid. The remainder of the vessel is filled with compressed inert gas. A barrier consisting either of a sliding piston or a flexible rubber bladder is used to isolate the fluids. The gas stores the system energy and acts like a spring by keeping the hydraulic fluid at pressure.

One disadvantage to this concept is the pressure in the accumulator must be greater than the wellbore pressure, which for deep wells exceeds 10,000 psi. This requires high pressure accumulators and gas charging equipment which complicates the system. This can be prevented by dumping the hydraulic fluid into a second accumulator at a lower pressure than the first and thus isolating the system from the wellbore pressure. However, all hydraulic components must be capable of sustaining the pressure difference between the hydraulic system and the wellbore which would make them considerably more massive. Also, a second accumulator would have to be mounted in the system.

As an alternative, the opposite of an accumulator could be considered. This might consist of a vessel mounted on the

system and connecting it to the hydraulic control valve's low pressure side. The vessel would be sealed at atmospheric pressure and full of air. As the drill string is lowered downhole, a pressure difference will exist between the vessel and the wellbore. If the hydraulic control valve's pressure side is connected to the wellbore pressure, this pressure difference would be used to operate the system.

In this configuration, all components would be at the wellbore pressure, except the vessel and low pressure side of the hydraulic valve. Actual drilling mud could be used as the hydraulic fluid or with the use of a barrier, hydraulic oil could be used, with wellbore mud pressurizing the oil.

The actuators would be controlled by a hydraulic valve mounted on the core recovery system. The activation of the hydraulic valve to close the ball valve could be accomplished with conventional techniques such as dropping a ball down the drill pipe to trip the valve open or use a mud pulse technique to actuate the valve.

Also, a downhole sensor that detects when a piece of core has been broken off and is held in the inner recovery tube could be used to automatically activate the ball valve without any communication from the surface. This sensor could consist of a "feeler whisker" set at the upper end of the inner tube. When the core moves up the inner tube, it would bend the whisker. The end of the whisker would be connected to a hydraulic switch that senses the bending and activates the hydraulic valve. The switch could be mechanically, hydraulically, or electrically coupled to the actuator's valve. An all mechanical coupling would have potential problems of reliability as well as the difficulty of packaging it in a

downhole system. A hydraulic switch could have some problems of reliability, but it would be relatively easy to couple to the hydraulic valve with hydraulic tubing. An electrical switch could be made to actuate most reliably and would be quite easily coupled to the hydraulic valve; however, this would involve the added complexity of an electrical power source (batteries) downhole.

A third concept for closing the ball valve would be the use of an electrical motor for actuation. However, a motor and gear box with sufficient torque to actuate the ball valve would be very difficult to package for downhole operation.

All of the above valve closing concepts could be designed to not actuate if sensors detected a core or other obstructions in the ball valve. These sensors would consist of feeler whisker as discussed above. Also as discussed above, the sensor's switch could be either mechanical, hydraulic or electrical. If a falling tube is used for closing the valve, the switch could cause the retraction of shear pins that hold the tube. If hydraulic actuators are used, the switch could be tied to their hydraulic control valve as discussed; and for an electric drive, the switch could be connected to the motor's start switch.

For added reliability, the ball valve's face sensors, as well as a sensor that detects full rotation of the ball, could be tied to a surface communication system to let operators know the status of the recovery operations. A system such as a mud pulse, or mud siren, could be readily used for this application. Communication to the surface, especially when the ball valve is clogged, would enable the operators to take corrective action when it is necessary and would inform them if the action was successful.

Hydraulic systems could also be utilized to provide a positive opening force to insure relative movement between the outer tube and the inner tube (Figure 11). A similar technique could be used to provide hydraulic dampening (Figure 13) to reduce impact if outer barrel weight and/or other forces are used to provide relative movements. Another alternative is to use a simple set of fluid nozzles which use drilling fluid flow to provide hydraulic force to extend the outer tube (Figure 13).

Figure 11
Hydraulic Extension Of Outer Tube

Figure 12
Hydraulic Damping Of Outer Tube Movement

Figure 13
Fluid Nozzles Using Drilling Fluid
Energy To Extend Outer Tube

The use of a non-invading and non-freezing gel inside of the inner tube and displaced by the core as it enters would simplify handling of the core under present techniques of freezing (Figure 14). The use of such a gel would eliminate the time-consuming and undesirable operation of removal of frozen drilling fluids from the core surface prior to analysis.

Surface handling and preparation for transportation could be further improved by reducing the problems involved in flushing drilling fluid from between the outer tube and the sealed core system. For example, an attachment could be designed to permit flushing with the ball valve in an open position, thus reducing restriction of flushing fluid flow.

Handling of ten to twenty foot long cores at the surface is a significant problem. The present technique includes cutting the inner tube into short sections after the core is frozen. This inconvenient technique could be eliminated by designing an inner tube manufactured in short sections and designed for easy separation after the core has been frozen.

Figure 14
Non-Invading Gel In The Inner Tube

Core Transportation

The concepts of core transportation include all ideas that involve moving the core up the hole after it is cut and transporting the core to the lab for analysis.

The first part of this section discusses the considerations and concepts for "up and out of the hole." The second part of this section discusses moving the core "down the road."

Up and Out of the Hole

Cores are normally recovered after the drill pipe is pulled out of the hole and the core barrel is then removed from the end of the pipe. Other concepts have been presented such as the one by Auld shown in Figure 15, where a wireline tool recovers the core barrel to the surface. This concept is less desirable because it is only able to recover a small core. It does allow continued coring without pulling the drillpipe, which gives a definite time and cost advantage.

Another concept for lifting the core is to reverse circulate or "float" it out of the hole and drop in another coring cartridge so that coring can continue. This 1968 concept by Elenburg is illustrated in Figure 16. With a tool such as Elenburg's, coring would be considerably faster, but would probably suffer from the same problem as the wireline retrievable core; the core is too small. Also, with the complexity needed to encapsulate and trap the pressure in the core, an extremely complex tool would be required and reliability might suffer.

Figure 15
Wireline Retrivable Pressure Core Barrel
(USP 2,347,726)

Figure 16
Reverse Circulating Corer
(USP 3,419,092)

Another concept under consideration is to keep the core at reservoir temperature as well as pressure. This might preserve the formation wettability which has been shown to change during cooling - especially freezing the core. In general, the surface temperature and wellbore, as the core is withdrawn, is less than the sample's in situ temperature. Therefore, only sample heating will be considered. The most compact and easiest to control type of heaters for this application are electrical resistance. Exothermic chemical reaction type could be considered, but they require high pressure storage accumulators, as discussed above, as well as very accurate metering valves which would be difficult to make reliable. Resistance heaters of course do require the handling of electric power downhole and the packaging of batteries in the core recovery system. However, control of temperature would be quite straightforward with a simple instrument such as a bimetal switch.

The controlled temperature could be determined by measuring the downhole temperature and presetting the control before putting the system downhole. An alternative to eliminate the separate temperature measurements is to have the activation of the ball valve closure mechanism also "lock" the temperature control so it maintains the temperature it is at in the wellbore. This can be achieved by allowing the sensor to "float" at its null position until it is locked. At that point, it measures only deviation of temperature from the locked valve and applies heat to the sample until the deviation is nulled.

There are several reasons why the concept of temperature maintenance has been ignored to date. First, the cores would be extremely vibration sensitive and gravity segregation would become a major problem or at least a dominant consideration. Second, by using a simplified, finite element, heat transfer analysis as shown in Example 1, we see that the amount of heat required could be tremendous.

Example 1

Simplified Heat Loss From Core Barrel

For a 10,000 ft. reservoir, keep the core at reservoir temperature while it is brought up the hole.

Reservoir Temperature (T_R) is 300°F and the mud temperature (T_M) at the surface is 100°F .

Assumptions:

- 1) 10 increments for heat loss (1000 ft per increment)
- 2) 1 hr/increment or 10 hr total time to come up the hole.
- 3) Conductivity (k) of core barrel is $26\text{BTU/hr ft}^{\circ}\text{F}$
- 4) Core Barrel Length (L) = 30 ft
- 5) Outer and inner radii of core barrel are:
 $r_o = 3\text{ in.}$, $r_i = 1\text{ in.}$
- 6) Mud temperature changes linearly from bottom to surface.

Heat loss equation:

$$Q = \sum_{i=1}^{10} \frac{T_R - T_M}{\frac{\ln r_o/r_i}{2KL}}$$

By figuring the average temperature difference in each 1000 ft increment and summing, we find that the total heat loss would be:

$$Q = 3,236,913 \text{ BTU}$$

or

$$Q = 944 \text{ kw-hr}$$

The heat loss is equal to the amount of heat energy required to keep the core at a reservoir temperature of 300°F.

For the particular case shown in Example 1, the total amount of make-up heat would be about 3.2 million BTU, or 944 kw-hr. No battery system could possibly supply this amount and a large cable to a surface power supply would be required. The drilling mud could be used to heat the core if it were kept near reservoir temperature in a zone around the core barrel as it was brought to the surface. This would require a pressurized mud system to prevent boiling at the surface. Continuous circulation during the trip out would also be required.

The opposite approach could also be used; that is, freeze the core at the bottom of the hole and bring it up frozen. In this case, pressure retention would be less important. One immediate problem with this concept is that a tremendous refrigeration system would be required or alternately an insulated pipe to the surface could supply liquid nitrogen or solid carbon dioxide to freeze the core. A problem exists if the mud also freezes in the hole, the possibility of sticking the tool and pipe might exist.

Wellbore pressure could also be maintained on the core as it is removed from the hole. Conventional techniques are a pre-charged gas chamber and pre-set regulator valve. This provides a very reliable technique for pressure control. One possible improvement would be to use a small pressure chamber as a reference for control of the core tube pressure. When the ball valve is actuated, the reference chamber is isolated or "locked" to maintain the wellbore pressure.

The regulator valve would then sense the deviation of the sample tube and reference pressure and maintain the tube at the reference pressure. All of the above sensors and controls are mechanical or hydraulic. More sophisticated and compact equipment could be developed using electronic circuitry and transducers. However, the wellbore temperatures (often in the 300-550°F range) would require some form of cooling of the electronics in order to protect the circuits. Also, the extreme vibration loads from drilling would pose considerable reliability problems.

A concept using a system of spot coring, which means core a section, continue drilling and core another section, would reduce the problem of handling. Then all sections of the cores would be sealed and brought to the surface. This would add to the coring tool's complexity, but would allow small sections of core to be taken economically through a thick formation.

At the surface, the core might be more easily handled by a sectioned inner barrel whereby pressure is maintained on each section.

Down The Road

After the core is to the surface, it must be transported to the lab for analysis. One concept that should be considered is to bring the lab to the rig site. This would reduce core handling and improve the dependability of results. No special transport trucks would be needed, but a specially equipped mobil van would be needed on site.

Presently, in preparation for transport, the cores are frozen and chopped into lengths suitable for people to handle and keep frozen during transport. A better idea would be a sectioned core barrel which would come apart but still remain sealed. This would add some complexity but might give a better chance of always having some good sections on each coring run. This, coupled with a non-freezing gel built into the core barrel container, would greatly simplify the eventual analysis. Frozen mud around the cores continues to be a problem when the cores are finally retrieved from their pressure containers. Core damage would be avoided if no frozen mud had to be chipped off and preparation labor costs would be reduced.

If the cores are heated and handled hot, a short, convenient length is required. Also, vertical transport might be desired to minimize gravity segregation. Vibration in transit might be the biggest disadvantage because of its possible effects on the fluids, their positions and relative saturations in heterogeneous cores. With all of the other requirements of recovering heated cores mentioned previously, this concept will be tried only in a very expensive and sophisticated coring system.

A final concept to consider while transporting core sections is a standardized container with a built-in temperature controller which would maintain core temperature during transit and allow direct plug-in of power for change-over at the lab site. This would delete the need for special trucks or trucks with special chamber attached and would minimize handling as much as possible. This concept could be used to keep the cores frozen or at reservoir temperatures, whichever was most desirable.

Core Analysis

A concept which bears further study is that of analyzing the core at the bit as the core is taken. If it were possible to perform all or at least critical parts of the desired core analysis at the bit under bottom hole temperature and pressure conditions, the difficult task of sealing the core, transporting it to the surface under in-situ temperature and pressure conditions, transporting it under the same conditions to the analysis site, and then analyzing the core under pressure and temperature might be greatly simplified.

It is technically feasible to perform at least part of the tests on the core in the core barrel at the bottom of the hole as the core is cut. For example, core saturations

could be determined through a combination of nuclear, sonic and electrical sensors. Such an in-situ determination of saturations might eliminate the necessity of transporting the core to the surface under pressure and temperature. A conventional core barrel might be used to recover the core for geological examination and measurement of permeability under restored core conditions. Also eliminated might be the need for high pressure, high temperature core analysis laboratory equipment.

Two important trade-offs must be considered:

- 1) Is it technically and economically more advantageous to perform the required saturation or other analyses at the bottom of the hole?
- 2) Are results of such measurements sufficiently accurate to meet requirements?

Conventional wireline logging methods have been used for many decades to determine formation porosity and fluid saturations. These measurements are hampered, however, by the fact that these measurements must look from the hole out into the formation through mud, mud cake, mud filtrate and the invaded part of the formation in an attempt to make measurements which represent the true formation and its fluids. A logging system in which an unaltered sample of the rock is taken into a chamber with the proper type and configuration of sensors should be capable of providing accurate, reliable determinations of porosity and fluid saturations. Needless to say, the success of such a system is dependent on getting a true sample of the rock and its fluids. However, the same constraint is placed on the true

fluid coring system even if the sample were transported to a remote laboratory for analysis.

Such a system might appear similar to the one shown in Figure 17. Data could be transmitted to the surface in real time or could be recorded downhole for later study. Most likely, however, the core would be recovered for correlation studies and for other measurements (such as restored 3-phase relative permeability) which could not be performed downhole.

Figure 17
Logging While Coring Tool

If results of this approach were accurate enough to eliminate surface requirements for actual core, it could be crushed and flushed to the surface after analysis (Figure 18). This would permit continuous coring through the entire zone of interest.

Figure 18
Turbine Core Disintegrating Bit
(USP 2,975,849)

IX. FEASIBILITY OF A TRUE FLUID CORING SYSTEM

The objective of this entire study was to determine the feasibility of obtaining unaltered true fluid samples of oil and gas reservoirs. After having examined the problem and many alternative solutions, we have determined that there is virtually no probability of obtaining completely unaltered samples. Any technique within the bounds of a practical bore hole size must alter the reservoir slightly. However, there is an acute need for accurate fluid saturation in reservoir production planning. This need is so great that 100% accuracy is not absolutely necessary and a system which approaches true results would be acceptable. It is felt that there is a very good probability that a system can be developed which will give results much improved over present techniques which cause flushing of 50% to 100%. It is desirable to reduce flushing to less than 10%.

The present Loomis pressure coring system is believed to give results approaching this accuracy under certain field conditions when the system functions properly. The design concepts for a Phase I True Fluid Coring System which can routinely and reliably achieve results approaching 90% accuracy is thought to be not only feasible but also within the practical normal economics of drilling operations.

The development of a Phase I system will require several parallel effort programs requiring about 18 months from inception to field test of a prototype coring system. These parallel efforts include the design and manufacture of a prototype coring system, the laboratory evaluation of the influence of bit design on fluid invasion and the manufacture of an optimum bit design, and the evaluation of drilling fluid additives to reduce fluid invasion. No dramatically new technology

development is required to develop this system. The fact that such a system has not already been built can be attributed to the lack of unified effort and economic incentive to develop such an integrated system.

Several very sophisticated system concepts appear capable of reducing flushing to the 2% to 5% range. Development of such a system would only be possible under an "unlimited funding" approach with the evaluation of alternatives, development of new technology, and design and development of prototype for field testing requiring a minimum of five years. While this type of accuracy is not needed at present, future needs and increased concern over maximum energy production may require that a very sophisticated coring system be developed.

X. PHASE 1 SYSTEM

The Phase 1 True Fluid Coring System is thought to be feasible. It should be capable of significantly improved results over currently available systems. This system (Figure 1) would cut and recover a core maintained under bottomhole pressure but not temperature, and would rely on the freezing technique to permit handling and transportation of the core to the analysis laboratory without pressure maintenance. The system would have the alternative capability of being manufactured to take a very short (e.g. 5 feet) core which could be maintained under pressure at the surface for special applications such as the tight gas sands where freezing might be detrimental to accurate analysis. The design parameters considered essential to this Phase 1 system are described below:

- 1) The inner tube system would be sealed at both top and bottom by hydraulically actuated ball valves.
- 2) The bottom ball valve should be mounted in an outer tube sub to permit maximum core size.
- 3) There should be a sliding intermediate sleeve to provide a sealed chamber between the lower end of the inner tube and the ball valve sub in order to minimize the volume of trapped drilling fluid and reducing the total weight of the equipment to be handled at the surface.
- 4) There should be a by-pass or dump valve provision either in the barrel or located immediately above the barrel to permit by-passing most of the drilling fluid without circulating through the bit.

Figure 1

PHASE I PRESSURE CORING SYSTEM

- 5) The coring bit itself should be designed with a tapered crown to direct the influences of dynamic fluid invasion away from the core. The bit should also include a replacable pilot bit to provide further isolation of the core from the drilling fluid.
- 6) The bit should utilize tangential face discharge of the drilling fluid to provide optimum cleaning at low fluid velocities.
- 7) There should be a viscous, non-invading gel inside the inner tube to be displaced by the core as it enters the inner tube. This gel should not freeze when the core is frozen with dry ice.
- 8) There should be a provision for a sliding plug to retain the gel in the inner tube until coring has started.
- 9) There should be flow channels provided to allow the extruded gel to clean and cool the pilot of the coring head.
- 10) There should be a sleeve in the core bit with a rotating seal at the lower end of the inner tube to provide complete isolation of the core from the drilling fluid at that point.
- 11) There should be fluid nozzels attached to the outer tube to provide a positive force assisting extension of the spline and retraction of the inner tube through the ball valve.
- 12) There should be adequate clearance between the lower end of the inner tube and the ball valve to insure that the ball valve will not be blocked by a core.

protruding slightly below the bottom end of the inner tube.

- 13) It is desirable that the system be designed with sensors to detect and provide surface indication in the case of critical operational failure (e.g. a fluid flow restriction would indicate failure of the ball valve to close completely).
- 14) Provision should be made for removal of trapped drilling fluids by flushing at the surface through the opened ball valve without loss of bottom hole pressure.
- 15) The inner tube should be designed in short 2-5 ft. sections easily separated at the surface after the core has been frozen to facilitate handling.
- 16) Since the core will not be locked inside the inner tube by frozen mud, an alternative system should be considered to permit the core to be hydraulically removed from the inner barrel after freezing for sectioning and placement into sealed containers which are capable of temperature maintenance during transportation to the lab.

XI. PHASE 2 SYSTEM

A highly sophisticated true fluid coring system can be built if adequate time and funds are provided. The practical value or even the necessity for such a system is dependent on the outcome of field trials of a Phase 1 system. For example, a Phase 2 system may be necessary to overcome the problem of fluid invasion during the actual coring operation. On the other hand, if bit design, fluid by-passing, and other concepts in the Phase 1 system substantially eliminate this invasion problem, the necessity for a Phase 2 system is not as great.

Since an advanced true fluid coring system is envisioned essentially for the purpose of solving the invasion problem, any Phase 2 system must address this problem first. Several interesting alternative concepts have been proposed for handling the core and analysis. Regardless of the alternative taken, however, at least a portion of the system will be basically the same.

The basic system will include a core barrel run below a packer to isolate the reservoir rock from the conventional drilling fluid (Figure 1). A closed circulating system below the packer will utilize a special non-invading circulating fluid with the pressure of this fluid being balanced to match reservoir pore pressure, thus eliminating hydrostatic overpressures. The conventional fluid circulation above the packer will be maintained to condition the hole and to drive a mud motor providing hydraulic, mechanical and electrical power for operation of servo-controls and sensors in the coring system. Rotary power will be provided by the drill string from the surface or by a mud motor or an electrodrill (in which case, there would be direct communications with the surface and the need for downhole power generation would be eliminated).

Figure 1
Advanced Pressure Coring System

In one alternative, the core barrel would consist of a pressure coring system capable of maintaining pressure and temperature during the trip to the surface. Since the pressure and temperature conditions must be maintained at least through some point in the analysis cycle, it is probable there would be provision for on-site analysis in order to minimize the problems associated with maintaining pressure and temperature. The pressure coring system would very likely be an evolutionary design based on Phase I experiences.

With another alternative approach, logging sensors would measure reservoir properties as the core passes through the lower end of the inner tube. The coring system could be designed with or without pressure and temperature maintenance capabilities as required. With advances in logging techniques, this approach may supercede the other more normal coring schemes since accurate property measurement downhole would eliminate pressure maintenance and surface handling problems that greatly complicate the tools design.

Final Report

**A STUDY TO DETERMINE THE
FEASIBILITY OF OBTAINING TRUE
SAMPLES OF OIL AND GAS RESERVOIRS**

Appendix

by

**Charles E. Ward
A. Richard Sinclair
Maurer Engineering Incorporated**

for

**The Energy Research and Development Agency
Fossil Energy Division
Project No. EY-76-C-02-0035.*000
Report No. BERC-0035-11
Attention: Mr. Ray Williams**

**December, 1976
TR76-24**

Maurer Engineering Inc.

10301 NW FREEWAY · SUITE 202 · HOUSTON, TEXAS 77092 · (713) 683-8227

APPENDICES

APPENDIX A Conventional and Special Core Analysis

APPENDIX B Patents

APPENDIX C Literature Search

APPENDIX A

CONVENTIONAL AND SPECIAL CORE ANALYSIS PROCEDURES

- I. Introduction
- II. Pressure Core Analysis
 - A. Introduction
 - B. Retrieval and Transport
 - C. Laboratory Analysis
- III. Conventional Core Analysis
 - A. Conventional (Plug-Type) Core Analysis
 - 1. Summation of Fluids Method
 - 2. Dean Stark (Solvent Extraction) Method
 - B. Whole Core (Full-Diameter) Core Analysis
 - C. Side Wall Core Analysis
 - D. Supplemental Tests
- IV. Special Core Analysis
 - A. General Discussion
 - B. Sample Preservation, Packing and Shipping Procedures
 - C. Capillary Pressure Tests
 - D. Water Permeability
 - E. Formation Resistivity Measurements
 - F. Water Flood Tests
 - G. Relative Permeability
 - H. Overburden Permeability and Porosity
 - I. Residual Gas
 - J. Thermal Recovery Tests
 - K. Caprock Analysis
 - L. Rock Compressibility
 - M. Wettability Studies
 - N. Acoustic Velocity
 - O. Surface and Interfacial Tension
 - P. Sieve Analysis

- Q. Sample Preparation and Selection
- R. Petrographic Studies
- S. Determination of Hydratable Clay Content
- T. Pictures
- U. Production Research
- V. References

1. INTRODUCTION

An important need for current and future planning is to be able to determine directly the oil or gas in place in a reservoir. This need exists both for new reservoirs, for the purpose of accurately determining the reserves of a company or the nation, and for depleted or partially depleted reservoirs for the purpose of establishing the efficiency of production practices or for studying the feasibility of secondary or tertiary recovery procedures. Current industry practice is to determine porosity and water saturation and calculate the volume of hydrocarbon in place by the difference of the pore volume and water volume of a formation. This places an important accuracy requirement on both the porosity and water saturation values. Two methods that may be described as direct are in use to determine residual oil saturation at floodout conditions, the log-inject-log¹ method and the single well tracer² method. Both of these methods have important limitations.

In addition to the need to know the quantity of oil or gas existing in a reservoir at any state of depletion, it is important to know the positions in the rock pores occupied by oil and water. The energy existing on the interfaces of the fluids and rock, or the surface kinetics, greatly influences the relative position of the fluids or the state of wetting of a formation. These characteristics, working together with the pore geometry, viscous character and relative quantities of each fluid, control relative permeability, and the quantity of residual oil remaining in the formation at depletion. It would be very desirable to know the wetting of the formation and contained fluids to be able to predict the amount of oil that can be produced and also for engineering analysis of secondary and tertiary recovery systems. However,

the possibility of altering the surface kinetics or wettability of the reservoir is always present with currently available coring techniques.

The oil and gas industry does not yet have a coring tool that will recover unflushed and unaltered core. Filtrate from the drilling fluid flushes and replaces some or most of the native pore fluids from the formation as the core is being cut. As the core is brought to the surface, the gases dissolved in the residual formation fluid expand and drive out a varying portion of the liquids in the formation pores after the cutting process is completed.

Flushing is generally believed to occur to a depth sufficient to flush cores up to $3\frac{1}{2}$ inches in diameter across the complete face of the core. Larger diameter cores may have an unflushed portion at the center, (depending on permeability) but it cannot safely be assumed that the native fluids in the portion not flushed by drilling fluid filtrate are in their in-situ positions and quantity.³ In the majority of cases, where the permeability of the formation is greater than 1 to 5 md, the hydrocarbon saturations are reduced to residual values by filtrate when coring with water base mud. Flushing occurs slightly ahead of the coring bit except where low vertical permeability prevents it. Where vertical permeability is low, the cores may not be fully flushed to residual (minimum) hydrocarbon saturation values.

The liquids in the pores of core samples nearly always have some dissolved gas in them. As the confining pressure is reduced by bringing the core to the surface, a point is reached where the gas breaks out of solution. From that point on, the expanding gas drives liquid from the core until the relative permeability to gas is

100 percent. The mobile fluid phase, usually a combination of drilling fluid filtrate and native formation water, is expelled by the expanding gas. The residual liquid oil provides most of the solution gas, and the oil shrinks significantly as the gas is liberated. Small quantities of liquid oil may be displaced by the expanding gas. Similar alterations occur if oil or gas drilling fluids are used. A pressure retaining core barrel, ^{4,5,6,7,8} designed to permit taking cores up to 10 feet in length, is in use in the industry that retains the fluids in the core as they exist in the core barrel at the bottom of the hole, after the core is cut. The flushing has occurred but the additional alteration of the fluid saturation caused by pulling the core to the surface is avoided.

II. PRESSURE CORE ANALYSIS

A. Introduction

In the body of the report, a detailed analysis of the pressure core analysis has been presented to shed light on what additional steps need to be taken to provide a true fluid core. Pressure core analysis has been a giant improvement over the conventional cores because it provided much additional information and at the same time caused much more care and planning to go into the coring process.

In this section of the appendix, a summary of the additional requirements and tests on pressure cores will be presented. Much greater detail of the entire pressure coring process is presented in the text.

B. Retrieval and Transport

Pressure cores are presently retrieved by either a Loomis or Shell-Christensen apparatus - with Loomis being the only pressure core barrel now in use. This double barrel captures the core and a ball valve is closed which seals in the pressure as the core is retrieved to the surface. Reservoir formation pressure is maintained in the core; however, temperature is not controlled and will depend on mud temperature.

The pressurized core barrel is removed from the tool, cleaned and frozen to be ready to transport the core to the lab. After freezing, the core is sectioned and kept under frozen conditions as it is brought, usually by special truck, to a laboratory for analysis.

C. Laboratory Analysis

Much preliminary lab work is required before analysis can begin on the pressurized core. At the lab, the metal pressure barrel is removed, again under frozen conditions. Frozen mud is removed from the core by a laborious hand cleaning and shipping operation.

The cores are cut into 4" and 8" cylinders to yield full diameter specimens, and plugs (1" or 1-1/2") are drilled from part of the core. All of these cores are sectioned or cut under controlled, frozen conditions. They are now ready for complete analysis.

Laboratory analysis begins with a complete description of the section of core to be analyzed. The following steps show what is required to get a permeability measurement:

- (1) The frozen full diameter sample is measured for length, diameter and weight and is placed in an air tight container. A quick (15 second) vacuum is applied to remove air surrounding the sample within the container.
- (2) The sample is then allowed to thaw overnight. Gas evolves during the thawing process and expands. The gas is trapped, and its volume is measured.
- (3) Composition of the evolved gas is determined by chromatograph (when there is a need to know).
- (4) Heat is applied to the core container to vaporize the oil and water - which are recovered in a calibrated receiving tube attached to the underside of the container. The receiving tube is submerged in liquid nitrogen, or a suitable coolant, to condense the vaporized fluids. See Figure 8.
 - (a) 450°F and vacuum application is used in some processes. This effectively cleans and dries the core if oil gravity is 35° API or above.
 - (b) 250°F and no vacuum will remove all water and some oil. The core must be weighed, oil extracted by an independent process and the core re-weighed to find the additional oil removed during this subsequent cleaning.
- (5) After the core is cleaned and dried, the pore volume is determined using one of several suitable techniques. Porosity (pore volume divided by bulk volume) is then computed.

(6) Permeability is determined on the clean, dry core.

Along with permeability, porosity and oil, gas and water saturations are the principal measurements that are made on unflushed, pressure-maintained cores. Of these measurements, the oil, gas and water saturation measurements are the most important since they would represent values that cannot be determined otherwise. Adequately accurate permeability and porosity values can be obtained from conventionally cut cores in most cases. Where a formation is unconsolidated, such as many in California, the analysis of pressure-maintained cores may yield more accurate porosity values.

It must be emphasized that the volume of oil determined to be present in unflushed, pressure-maintained cores would be the best possible evaluation of oil reserves, both for new reservoirs and for reservoirs at flood-out. The volume of gas produced from such cores and a compositional analysis of the gas would also be important and would be an early indicator of the quality of the oil, the gas-oil ratio, and the bubble point, or perhaps the dew-point if one exists.

III. CONVENTIONAL CORE ANALYSIS

A. Conventional (Plug Type) Core Analysis

Conventional or plug analysis is the type most frequently employed. It involves the use of a relatively small sample of core to represent an interval of formation to be tested. It is used where the uniformity of the reservoir formation permits such a sample to accurately represent the interval.

- (1) Core sampling and preservation. Analytical data can be no better than the sample from which they are obtained. Thus, it is essential that the samples be properly preserved until the analysis can be performed. Prior to sampling the core, pertinent field and reservoir information, when available, should be obtained by the analyst to assist in maximum utilization of core data. This may include such items as structure of the field and position of cored well on the structure, evidence regarding type of drive, any known contacts, gravity and viscosity of produced oil, original gas-oil ratio, reservoir pressure and temperature, and chloride content of produced water. Mud data and coring conditions are recorded.

The frequency of sampling for conventional analysis is generally one sample per foot. Where the formations consist of laminated sand and shale, or shows other irregularities in lithology, more frequent sampling is desirable. About 200 to 300 grams of sample are ordinarily taken for analysis from the portion of each foot that appears to be most representative of the productive formation of that foot. For whole-core

analysis, the sample interval is determined by the lengths of the segments of full diameter core available. The lengths of these samples can vary from 3 inches to 24 inches, and generally average about 12 inches. All of the sidewall sample recovered is used in the analysis if the sample is suitable.

Proper sampling, handling, and preservation of the core by trained personnel are essential for obtaining good data. Immediately upon removal from the core barrel, the core should be wiped (not washed) free of drilling mud. The representative samples of core should be selected and immediately placed in sealed containers, or quick-frozen. A log and description of the lithology of the core and visual characteristics such as fractures or staining, is made in as much detail as is pertinent.

The technique of quick-freezing has been found suitable and convenient for preservation of fluid contents if cores are to be transported elsewhere for analysis. Other methods, including the use of jars, cans, plastic tubing, plastic bags and even sealing in plastic, may be employed with good results provided suitable precautions are taken against breakage, loss of fluids by evaporation or capillary action, and condensation in the container from low temperature in transit. The samples should not be immersed in oil, water, or drilling fluid if residual saturations are to

be determined. Variations from the usual methods of transporting cores may be desirable in some cases where certain specialized measurements are to be performed.

- (2) Basic measurements. The minimum basic measurements made on cores generally comprise the determination of porosity, permeability, and residual fluid saturations. In addition, various supplementary routine tests such as chloride content, oil gravity, vertical permeability, and the like, may be made as an aid to interpretation and evaluation.

POROSITY. Various techniques for measuring porosity are used by different laboratories. The methods are based on the determination of any two of the three quantities grain volume, void volume, and bulk volume. The grain volume and bulk sample volume may be determined either by gravimetric or volumetric methods. The void volume may be measured by extraction of gas or air content, by saturation with a liquid or by calculation from Boyle's law upon compression expansion of gas in the sample. Extraction may be accomplished by solvent extractors, solvent flushing in a holder, solvent flushing in a centrifuge, vacuum distillation, or by a patented gas-driven solvent technique employing any of several suitable hydrocarbon solvents. Care must be taken in drying the sample to insure complete drying, and at the same time to prevent dehydrations of clay minerals or similar materials.

In addition, another method is in common use which may be described as a summation of fluids method. This involves determination of the oil and water content, then adding to the sum of these the gas content determined by injection of mercury into an adjacent fresh (not extracted) sample.

The Boyle's law type of porosimeter is capable of accurate grain volume determinations, with errors within ± 2 percent, and with the particular advantage of normally using a much larger sample than the other techniques. The gas extraction method can yield good data if the measuring apparatus is kept clean, and if much care is exercised in its operation. It is generally agreed that the liquid saturation techniques yield low porosity values because of the inability to saturate samples completely with a liquid. Errors as great as 10 percent may be expected. The technique is convenient to use in many cases when samples are saturated with liquids for other tests.

PERMEABILITY. In principal, the determination of permeability is quite simple, involving only the measurement of the rate of flow of a fluid of known viscosity through a shaped sample under a measured pressure differential. Various forms of equipment and methods for sealing the sample are used. The sample itself is usually a small cylindrical plug, cut horizontally, or a rectangular sample which permits the measurement of both vertical and horizontal permeability. If

the sample is friable it is mounted in wax or plastic.

Air is usually the fluid employed in permeability measurement because of its availability and the simplicity and reproducibility of the measurement. Because of this reproducibility, the measurements with air are frequently used as a basis of reference, even on so-called dirty formations which may exhibit some swelling or reduction of permeability when water is used as the testing fluid. On such formations, theoretically, water or reservoir brine should be the ideal fluid for measuring permeability, but in practice such measurements often give variable and erratic results. Air permeability measurements often give variable and erratic results. Air permeability measurements are normally corrected to an "equivalent" liquid permeability (the Klinkenberg correction),

Permeability as low as 0.01 millidarcy may be measured routinely, and permeabilities lower than 0.01 millidarcy can be measured if proper equipment and operating techniques are used. Reproducibility of measurements as low as 0.1 millidarcy can be made within ± 2 percent for most cores.

LIQUID SATURATIONS. The residual oil and water saturations are commonly determined by retorting by vacuum distillation, or by solvent extraction and distillation. If the retort method is used, the heating is generally in two stages. Water

readings are taken after a definite time, as determined by calibration tests of the equipment; oil readings are taken after some additional elapsed time during which higher temperatures are reached. This is a rapid and efficient method for the determination of liquid content, and is capable of good accuracy by using appropriate corrections determined from blank and calibration tests. The water readings are taken early, on a plateau of the water recovery curve, so as not to include water of hydration which comes out at higher temperatures. Vacuum distillation is similar to the retort method except that the final temperature required is not so high. The extraction-distillation method (also known as the Dean-Stark method) consists of first distilling the water from the core sample by refluxing it in a solvent which is immiscible with water but miscible with oil. The extraction of oil is completed by continued refluxing, after which the sample is dried, and oil calculated from total weight loss minus the amount of water recovered. This method is considerably slower than the retort method, but is also capable of good accuracy if the distillation and extraction are carried out for a long enough period.

B. Whole-core (Full-Diameter) Core

Whole-core analysis is employed where, because of the presence of fractures, vugs, or erratic porosity development, the volume of individual pore spaces may be relatively large in comparison to the plug samples used in the conventional analysis. It involves the use of essentially all of the core, in as large pieces as possible, recovered from the interval to be tested.

Extraction or vacuum distillation methods are employed for the determination of fluid saturations. Horizontal permeability measurements are usually made in each of two perpendicular directions across the largest segment of whole core in the designated sample interval. In this case, the permeabilities are indicated by $K_{\max}$, the value measured in the direction of principal fracturing, and K_{90° , the value measured at right angles. Sometimes the horizontal permeability is a radial flow measurement, in which case this is made on a 4 to 6 inch length of faced core. One type of whole-core analysis gives a nondirectional permeability obtained from the rate of penetration of water into the extracted sample, although in this case the estimated permeability is probably influenced by other factors such as porosity and relative permeability. Porosity is usually measured by the summation of fluid or Boyle's law techniques.

C. Sidewall Core Analysis

Sidewall core annalysis is the analysis of cores recovered by any of the sidewall coring techniques. The small sample size and the conditions under which they are taken limit the value of the measured data in reservoir evaluation.

Modifications of conventional core analysis procedures are necessary for the analysis of the small amount of material available from sidewall cores. Not infrequently the quality of the cores may be poor owing to excessive flushing of the sample or even infiltration of drilling mud solids. Soft samples may be compacted or crushed. This is true more often of percussion-type samples than of drilled samples. Nevertheless, allowance can be made if this condition exists, and sidewall core analysis thus frequently provides a means of obtaining useful information which cannot be obtained in

any other way. The analysis techniques permit the usual determinations to be made on most samples.

D. Supplementary Tests.

The following more or less routine supplementary tests are made by the analyst when so instructed (except that oil gravity and fluorescence examination are frequently performed by the analyst for his own information). It is suggested that these tests be made more frequently, while the cores are still available, when there seems to be any possibility that they may be of value later on. Their cost is generally negligible compared to the amount already expended to obtain the core. In the following discussion, a few remarks as to the significance and use of the tests are included.

CHLORIDE CONTENT. This is measured by crushing a core sample, leaching with water, and titrating with silver nitrate. The result is expressed in terms of parts of chloride per million parts of water present in the sample. It is useful as an indication of the degree of flushing of the core by drilling mud filtrate.

OIL GRAVITY. The gravity of the oil may be estimated by various methods on small quantities of oil extracted from a core. It is used as an indication of the quality of the producible oil and its viscosity, which enter into the recovery estimate.

VERTICAL PERMEABILITY. In formations showing even occasional horizontal laminations or bedding planes, the vertical permeability may be of a much lower order of magnitude than the horizontal permeability. Frequent measurements of vertical permeability are very useful wherever cross-bedding flow is likely to be important, as for example,

in coning of gas or water, partial penetration of the well into an oil-bearing interval, perforation of only a part of the interval, or workover operations to reduce the gas or water flow from permeable strata.

It even appears conceivable that further development of computers in reservoir engineering may increase the application of vertical permeability measurements. This could, for example, permit more accurate calculations of the contribution of gravity drainage to recovery, the rate at which a secondary gas cap might be formed and gas-oil ratios controlled, the conformance factor in water flood operations, the recovery efficiency in low-permeability reservoirs with induced horizontal fractures, and the like.

FLUORESCENCE. Examination of cores for color and uniformity of fluorescence under ultraviolet light is useful in certain cases, such as the determination of the relative amount of flushing in the center and at the outside of a core; in differentiating between dry gas, condensate and oil sands; or in indicating the presence or absence of oil in fractures, thereby giving evidence of the position of the oil-water contact in fractured dense formations. In some dirty sands the character of the fluorescence, whether uniform or mottled, may give a clue as to whether water-free or mixed production may be expected.

PERMEABILITY TO WATER. Test of the permeability of cores to fresh and salt water may be made if it is suspected that there may be any significant reduction in permeability by contact with water. Such effects, sometimes quite pronounced, may occur in sands containing appreciable amounts

of swelling clays. It should be pointed out, however, that the determination of accurate values of permeability to water requires careful laboratory technique. The measurement is subject to many sources of experimental error which tend to give too low values for permeability to water. Among these may be mentioned reduction of permeability by suspended mineral matter or algae, by a Jamin effect due to formation of minute gas bubbles released from solution or a change in wettability, and by a sort of checkvalve effect which has been observed, possibly from microscopic dislodged particles within the sample. Considering these factors, the magnitude of at least some of the reported "reductions" of permeability from routine water permeability tests, particularly where salt water is used, should be viewed with skepticism. Probably a better evaluation of the susceptibility of a formation to fresh water swelling may be obtained from a relatively small (but statistically sufficient) number of carefully conducted laboratory tests rather than more numerous "routine" tests which may be more subject to the above-mentioned errors.

It should be pointed out that damage to a well's productivity by drilling mud filtrate is not merely a matter of clay swelling or chemical reaction with fresh water, but also involves relative permeability effects, ie., a physical blocking of the flow of oil due to the presence of infiltrated water in the pores. This can occur even in perfectly clean sands; in fact, clean oil-wet sands are theoretically more subject to such effects than waterwet sands.

IV. SPECIAL CORE ANALYSIS

A. GENERAL DISCUSSION

1. Effect of Coring Fluids:

Most coring fluids alter saturations present in the core prior to the time the core is pulled to the surface. During pressure depletion, additional saturation changes occur. Techniques are available to remove extraneous fluids introduced during coring and on the trip to the surface, whether these extraneous fluids are oil, water or air.

In addition to saturation changes, wettability changes may also occur when surface active agents that are used to control coring fluid properties contact the rock. Coring with oil base or inverted oil emulsion mud may alter reservoir core wettability and may change wettability of water-wet samples to an oil-wet condition. Routine water flood tests on cores that have been altered will not yield reliable results. Since these wettability changes do not always occur, it is advisable to preserve some samples and make laboratory tests to check wettability of the rock selected for special tests. If the samples prove to be oil-wet, the test program can usually be altered to yield reliable values of capillary pressure and residual oil values after water flood. Gas-oil relative permeability tests can be determined on oil-wet systems by leaving out the connate water on restored tests or

by testing fresh cores. Gas is a non-wetting fluid in any case and additives often do not influence gas-drive results if irreducible water is present in the cores.

Water base muds may also alter wettability in certain cases because of surface active agents added to the coring fluid, but wettability changes are less likely to occur in this system than with oil base or inverted oil emulsion muds. The water base fluid system is normally preferred if special tests are to be made. In some cases, cores have been taken using lease crude that has never been exposed to oxygen and that contains no surface active additives. This should be ideal in that no wettability change would be expected, no extraneous water would be introduced and water saturations measured on the routine core analysis would approach true irreducible water values present in the formation. Use of lease crude that has been exposed to oxygen is not desirable in that this fluid may also alter core wettability.

2. Fresh Versus Restored Cores:

Water flood performance and water-oil relative permeability tests should be made on fresh, preserved cores. Gas-oil relative permeability and single-point capillary pressure measurements can also be made on fresh samples.

The primary advantage of fresh core is that it has never been subjected to an extraction and drying

process that might alter wettability of the rock.

Tests can be and are often made on weathered, dried cores. This may present problems in heavy oil reservoirs where crude that has dried on pore walls is difficult to remove. When this occurs, the samples are very likely to be oil-wet. Firing of the samples may be required to return the core to a water-wet state. High gravity crudes are less difficult to remove and samples usually clean adequately.

Cores that are relatively fresh and that have never dried completely prior to cleaning usually can be cleaned, restored and tested to yield reliable results.

3. Whole Core Versus Plug Analysis:

Plug analysis is recommended in homogeneous formations. This includes carbonates as well as sandstones. Plug samples can be taken from the center of the core and consequently contain less drilling mud and other fines.

Heterogeneous type formations are best tested using whole core. Fluids are flowed down the axis of whole-core samples; therefore, cores containing shale laminae are not suitable.

Heterogeneous type rock usually requires a "full diameter" core analysis technique. Samples that have been vacuum retorted are normally not suitable for

special work. This means that special samples must be picked visually prior to analysis with no benefit of routine data in these cases.

Special flow studies on whole core require samples with parallel ends. Length should be eight inches long after trimming so special core analysis samples selected should be ten inches in length where possible.

Whole cores analyzed by Dean-Stark analysis or cleaned by solvent can be used for special work as no oil is coked on the sides of pores. With this type analysis any test not requiring fresh core can be selected after review and study of the routine data.

4. Refined Oils Versus Crude Oils:

Use of crude oils in room condition tests are often unsatisfactory. The crude plugs the cores in many cases despite the filtering that precedes flow through the core.

Crude from wells with a water cut is often difficult to clean. Pressure filtering and centrifuging are many times not sufficient. Extra care is needed for crude oil preparation if unusual problems are found.

Refined oils are adequate for most tests and are recommended unless crude is specifically required.

In those cases where crude is needed, it is recommended that tests be conducted at reservoir conditions with live oil containing dissolved gas. This often retards or prevents paraffin and asphaltene drop out that can plug pores.

5. Number of Samples:

A minimum number of samples has been recommended for each test. More samples may be required in heterogeneous rocks and where lithology varies widely. These cores should be selected to cover porosity, permeability and lithology ranges. Some engineers request that tests be made on samples from one permeability or porosity range as this is the "average" of their data.

It is recommended that rather than use this approach, a permeability or porosity spread be covered and cross plots made to give an average curve for any "average" parameter selected. Averages can vary as comparison of an arithmetic average, logarithmic average and harmonic average will show. Three cores of 100, 10 and 1 millidarcy yield average values of 37, 10 and 2.7, respectively. Even when the type of average is firm, data on new wells may change "averages" previously computed.

6. Time Required:

Timing is partially dependent on the preparation stage when the new study arrives in the laboratory.

Preparation may be delayed two weeks if a large number of low permeability and porosity cores must be cut and cleaned or if rubber-sleeve core requiring nitrogen drilling is being prepared. These type studies are sporadic and it is impossible to predict any reasonable time in advance.

The work in the laboratory also controls timing. The equipment is expensive and there is often a long time lag between ordering and delivery. Sufficient equipment is available to have excess capacity except on those occasions where multiple jobs all requiring a special test apparatus arrive at the same time.

Each test sample requires special individual attention. Results are checked, correlated with other data and questionable data are remeasured. Friable, shaly, vuggy and low permeability material require time consuming drilling or hand shaping, mounting and cleaning procedures.

At least two to three weeks time should be added to the timing of any friable or vuggy samples. These samples are normally coated which slows cleaning. In addition, friable cores require solvent-type cleaning and, if 17 centipoises oil has been used (required for K_g/K_o and K_w/K_o tests), cleaning time is often several weeks.

If a series of different tests must be performed on the same samples then the times must be compounded. This is often the cause of excessive time on studies. In those cases where timing is important, sufficient core should be made available so that tests

can be run concurrently on different samples.

In many cases, cores have been stored for long periods before the decision to have special core analysis is made. When the decision is made, the data is requested within short notice. The time to make tests is when the routine core analysis is completed. In this manner, special studies can be made without pressures because of timing and the information will be available whenever the decision to study the reservoir is made.

7. Unconsolidated Formations:

Rubber-sleeve core barrels now recover core from formations previously unsampled. Laboratory procedures to test this type of rock vary depending on the degree of core consolidation. Techniques now in use are discussed under sections "Overburden Permeability and Porosity" and "Sample Preparation and Selection."

B. SAMPLE PRESERVATION, PACKING AND SHIPPING PROCEDURES

Tests on homogeneous formations are normally made on one or one and one-half inch diameter cylindrical plugs approximately three inches long. Sufficient whole core should be available to drill samples of the above size. In heterogeneous formations, tests are made on whole-core samples. Whole cores should be eight inches in length and samples up to eleven inches in length can be tested. Whole-core diameters up to four and three-eighths inch can be used.

Whole-core samples must have parallel ends prior to testing and samples must be cylindrical. Short broken cores are not suitable.

Samples for preserved core floods should be taken as soon as cores are removed from the core barrel. Coring fluids should be wiped (and not hosed) from the samples with a damp rag. Each sample should be wrapped in Saran wrap and then in aluminum foil. The core can then be packaged in wax or "seal peal." Each sample should be identified by number and it is advisable to place a paper tag outside the aluminum foil and beneath the coating that can be read by the receiving laboratory.

Temperature of the coating should be just above the melting point so that cores are exposed to minimum temperature. Several wax coats are required, if the cores are dipped, to prevent cracking during shipment. Cores can be placed in ice cream cartons with wax poured around the sample. This procedure is safer than dipping. The samples should be insulated from each other to prevent damage and then placed in a strong container such as a wooden box. In some cases, individual samples have been placed in tin cans after first being coated with wax, and insulating material is placed between the sample and the can.

Weathered core can be sent in any strong container containing sufficient insulation to prevent breaking of the cores during transit. Weathered cores should be marked so that they are easily identified on arrival in the laboratory. Samples that have previously been reported using whole-core procedures are not adequate for water flood and most other special tests. An exception to this general rule are cores that have been cleaned by a Dean-Stark apparatus. In the

latter case, residual oil is removed from the core during cleaning and no fluid remains on the sides of the pore spaces.

A cover letter explaining desired tests and sample identification should be placed in the shipping container. Information concerning shipping times should also be furnished so tracing operations can be initiated in the event the core does not arrive as expected.

C. CAPILLARY PRESSURE TESTS

1. Use:

Primary use of these data is to relate water saturation to permeability or porosity and height above an oil-water contact in the reservoir. This information is subsequently used to calculate hydrocarbons in place. Other techniques used to arrive at this information are use of oil-base core water saturations and calculations of water saturation from electric logs. Of the three, capillary pressure and oil-base cores are considered the standard by most reservoir engineers. The high cost of coring with oil-base mud makes capillary pressure tests the most practical and reliable technique for determining water saturation.

Conversion of capillary pressure data to height requires knowledge of reservoir oil (or gas) and water densities. Estimates must be made for (1) interfacial tension existing between reservoir fluids and (2) the wettability of the reservoir as

reflected in the contact angle between rock and fluids. Reasonable values may be assigned for these parameters, and are presented under the equations section.

An important secondary use of capillary pressure data is to calculate pore size distribution information and relative permeability characteristics. A brief discussion of the former is included. See Relative Permeability Tests for a discussion of the latter.

2. Method:

(A) Restored State

- (1) Water saturated samples for air-water or oil-brine tests and oil saturated cores for air-oil tests are placed on a semi-permeable diaphragm, and a portion of the contained liquid is displaced with the appropriate fluid of air or oil. Liquid saturations are measured after equilibrium saturation has been reached at each of several successive pressure levels. Reservoirs with closure greater than 100 feet have one additional high pressure-saturation value determined in the centrifuge.
- (2) Three Phase Capillary Pressure Tests - These require a water saturated sample. The water is reduced to irreducible and the voided pores are saturated with oil.

The oil may then be displaced by gas to simulate a gas cap advance, or displaced by water to simulate water encroachment.

(B) Centrifuge

Cores are saturated with water (or oil) and spun under air or oil at increasing speeds. Average liquid content at each speed is calculated from observations of liquid spun out (liquid volume out is read with a stroboscope while the centrifuge is in motion). The average saturation data are operated on mathematically to establish a water saturation versus pressure curve. In reservoirs of large closure it is necessary to transfer the cores to a high speed centrifuge for data at a pressure of several hundred psi. This is the best technique for unconsolidated core mounted in metal jackets.

(C) Mercury Injection

The test specimen is evacuated and mercury is injected in measured increments into the core at increasing pressure levels. In this type of test the mercury represents the non-wetting phase, equivalent to oil or gas in the reservoir. This is recommended chiefly for samples of low permeability.

(D) Calculation of Connate Water as a Function of Both Height Above Water and Permeability (or Porosity)

This correlation requires sufficient capillary pressure data so that average curves can be drawn

for selected permeability or porosity ranges. This correlation allows the user to relate his routine core analysis permeability and/or porosity information to oil-water level data and calculate the reservoir water saturation versus height. It is one way to use the basic capillary pressure data.

(E) Calculation of Pore Size Distribution

This allows calculation of pore entry radii from capillary pressure data. Equations have been presented by Burdine et al for calculation of a distribution function used to calculate relative permeability of cores. This distribution function is no longer used in our relative permeability calculations but is used as a rock type correlation tool. Equations for pore size calculations are presented in the equations section.

3. Type of Tests:

- (A) Single-Point - Used primarily to obtain "irreducible minimum" values at high pressure levels, although any requested lower pressure can be used. Recommended only for zones of very permeable formation with thick oil columns or reservoirs containing no bottom water. Centrifuge technique is not recommended for this test.
- (B) Two-Point - Used in conjunction with complete curves. These data assist in obtaining an accurate correlation of water saturation as a function of height and permeability by supplementing the complete curve data. Centrifuge data are not suitable for this test.

- (C) Complete-Curves - Saturations measured at 6 or more pressure levels to define the saturation over the entire range of pressure. (Mercury injection yields approximately twenty data points and is best test if pore size distribution is to be studied.)

4. Type of Samples:

- (A) Restored state tests can be made on permeability plugs through whole core sizes.
- (B) Centrifuge is restricted to samples with maximum diameter of one inch and length of 1-1/2".
- (C) Mercury injection is restricted to permeability plugs. The 1-1/2" plugs are necessary for low permeability and porosity rock.

5. Minimum Number of Samples Recommended:

- (A) Single-points - 8 to 10
- (B) Complete study: Eight complete curves and eight two-points for homogeneous formation; 16 complete curves and 32 two-points for heterogeneous formation. Correlation of saturation versus height and permeability normally not obtainable when less than eight complete and eight two-point curves are measured.

6. Special Information Needed:

- (A) For single-point - (1) maximum height of productive reservoir above water level, (2) density of the

reservoir oil (or gas), (3) a sample, the composition, or the chloride content of the formation brine.

(B) For complete study - "Same as single-point"

7. Average Minimum Time Required:

(A) Single-point - 4 weeks

(B) Complete study - 6 to 8 weeks

8. Data Reported:

(A) For both single-point and complete curves as measured by restored state, centrifuge or mercury injection a tabular presentation of measured laboratory results is given. A graphical presentation of saturation versus permeability (or porosity) in single-point study is furnished when requested. A graphical presentation of water saturation versus pressure is given for all methods of complete curve measurements.

(B) Correlation of data to yield connate water versus height and permeability (or porosity) - Graphical and tabular presentation of connate water saturation as a function of permeability (or porosity) and height above the water table is presented.

(C) Calculation of pore size distribution - Data gives pore entry radii corresponding to each capillary pressure and the distribution function as a function of the average pore radii over the ΔR investigated. See equations.

9. Key Equations:

The following data and equations are presented -

- Typical Interfacial Tension and Contact Angle Constants
- Capillary Pressure Conversion to Height
- Example Equations for Conversion of Air-Mercury (A-Hg) Capillary Pressure Data to Air-Brine (A-B) Data
- Example Equations for Conversion of Air-Brine Capillary Pressure Data (P_c A-B) to Height above Free Water Level
- Pore Size Distribution Equations Including Pore Entry Radii Calculation and Distribution Function Calculation

TYPICAL INTERFACIAL TENSION AND CONTACT ANGLE CONSTANTS

<u>System</u>	<u>Δ Contact Angle</u>	<u>Cosine Contact Δ</u>	<u>γ Interfacial Tension</u>	<u>γ Cosine Δ</u>
Laboratory				
Air-water	0	1.0	72	72
Oil-water	30	0.866	48	42
Air-mercury	140	0.765	480	367
Air-oil	0	1.0	24	24
Reservoir				
Water-oil	30	0.866	30	26
Water-gas	0	1.0	50*	50

*Pressure and temperature dependent. Reasonable value to depth of 5000 feet.

CAPILLARY PRESSURE CONVERSION TO HEIGHT

$$\frac{P_{c_1}}{P_{c_2}} = \frac{(\gamma \cos \theta)_1}{(\gamma \cos \theta)_2}$$

Therefore: $P_{c_2} = \frac{P_{c_1} (\gamma \cos \theta)_2}{(\gamma \cos \theta)_1} \dots \dots \dots (1)$

Then: $P_{c_2} = (\rho_w - \rho_o) H \dots \dots \dots (2)$

or: $H = \frac{P_{c_2}}{\rho_w - \rho_o} \dots \dots \dots (3)$

where: subscript 1 refers to Lab data or values
 subscript 2 refers to reservoir data or values
 P_c = capillary pressure, psi
 γ = interfacial tension
 θ = contact angle
 ρ_w = water density, psi/ft.
 ρ_o = oil density, psi/ft.
 H = height above zero capillary pressure, ft.

Technique: (1) Convert lab P_c to equivalent reservoir P_c with eq. (1).
 (2) Calculate height above free water zone with eq. (3).

EXAMPLE EQUATIONS FOR CONVERSION OF AIR-MERCURY (A-Hg)
CAPILLARY PRESSURE DATA

TO

AIR-BRINE (A-B) DATA

$$\frac{P_c \text{ A-Hg}}{P_c \text{ A-B}} = \frac{(\gamma \cos \theta) \text{ A-Hg}}{(\gamma \cos \theta) \text{ A-B}}$$

$$P_c \text{ A-B} = P_c \text{ A-Hg} \frac{(\gamma \cos \theta) \text{ A-B}}{(\gamma \cos \theta) \text{ A-Hg}}$$

$$P_c \text{ A-B} = P_c \text{ A-Hg} \frac{72}{367}$$

$$P_c \text{ A-B} = \frac{P_c \text{ A-Hg}}{5.1}$$

EXAMPLE EQUATIONS FOR CONVERSION OF AIR-BRINE CAPILLARY
PRESSURE DATA (Pc A-B) TO HEIGHT ABOVE FREE WATER LEVEL

Convert Laboratory Pc Air-Brine to Pc at Reservoir Conditions

$$\begin{aligned} \text{Pc Reservoir Conditions} &= (\text{Pc A-B}) \frac{26}{72} \\ &= (\text{Pc A-B}) (0.361) \end{aligned}$$

Convert Pc at Reservoir Conditions to Height (H)

Given:

$$\rho_w^* = \text{water gradient in psi/ft} = 0.44$$

$$\rho_o^* = \text{oil gradient in psi/ft} = 0.33$$

$$\begin{aligned} H &= \frac{\text{Pc Reservoir Conditions}}{\rho_w - \rho_o} \\ &= \frac{\text{Pc Reservoir Conditions}}{(0.44 - 0.33)} \end{aligned}$$

Substitute for Pc Reservoir Conditions

$$\begin{aligned} H &= \frac{(\text{Pc A-B}) (0.361)}{(0.11)} \\ H &= (\text{Pc A-B}) (3.3) \end{aligned}$$

* At initial reservoir conditions of pressure and temperature.

PORE SIZE DISTRIBUTION EQUATIONS

Pore Entry Radii Calculation

$$R_i = \frac{2 \gamma \cdot \cos \theta \cdot C}{P_c}$$

Distribution Function Calculation

$$\overline{D(R_i)} = \frac{V_i \cdot 10^4}{\Delta R}$$

Where:

- R_i = Pore radii, microns (average value at midpoint of ΔR)
- P_c = Capillary pressure in laboratory, psi
- γ = Interfacial tension, dynes/cm
- θ = Contact angle, degrees
- $D(R_i)$ = Distribution function (as a function of R_i), cm^2
- V_i = Incremental volume of mercury injected
(fraction of total pore volume)
- C = Conversion constant equal to $145 \cdot 10^{-3}$
- ΔR = Incremental change in radius over which V_i was determined

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

D. WATER PERMEABILITY

1. Use:

This test is the best indicator of formation sensitivity to various brines. It is used to evaluate damage to a formation that would occur from various drilling filtrates and/or injection waters. A loss of permeability may be due to (1) swelling clays such as montmorillonite or (2) particle movement and subsequent pore blockage by fines or clays such as kaolinite. This test offers insight into the permeability reduction mechanism and can often differentiate between swelling and blockage.

Supporting tests that can be run are the benzidine dye test used on all test plugs and the determination of per cent and/or types of clays present. See Hydratable Clay Content section.

2. Method:

Tests consist of direct measurement of permeability during the flow of water through a saturated sample. Fresh water or brine of any desired composition can be used. Permeability to water as a function of throughput is normally recommended. If samples indicate permeability reduction, flow through the sample in a reverse direction is made to differentiate between swelling clays and particle movement. A sharp increase in permeability on the reverse flow test indicates moving particles. The reverse flow dislodges the particles from pore necks where they have accumulated and temporarily causes increased permeability.

Tests indicate that the presence of residual oil in the sample may retard the swelling of clays in some instances and give results closer to reservoir behavior. Results on fresh cores are sometimes more difficult to evaluate because of the relative permeability effect caused by the residual oil in the sample. This difficulty is overcome by first running a base permeability to the formation water and then following this with the proposed injection water. Comparison of these values indicate sensitivity.

In most cases, fresh core tests are recommended, but restored cores are adequate. In both instances the base permeability to formation brine should first be determined.

It is essential in all cases to duplicate the history and/or follow the proposed reservoir sequence of water injection. Cores tested with one water may be damaged and suffer a residual effect that may alter subsequent test data on the core. When various injection waters are to be evaluated, duplicate samples of essentially equal permeability are required.

3. Type of Tests:

- (A) Specific permeability to air and to water -
Used to obtain only an equilibrium permeability after a given quantity of water has flowed through the core. For example, permeability after 100 cc's or pore volumes of injection. Its primary value is to supplement throughput data.

- (B) Permeability as a function of throughput -
Permeability is determined at various injection fluid volumes to give insight into permeability reduction versus pore volumes injected.

4. Type of Samples:

Permeability plugs or larger that are fresh or weathered.

5. Minimum Number of Samples Recommended:

Three to ten with each liquid being evaluated.

6. Special Information Needed:

(A) To evaluate damage by drilling fluid - water sample, analysis, or approximate chloride content of both reservoir water and mud filtrate.

(B) To evaluate damage by water injection in water flood - water sample, water analysis, or chloride content of reservoir water and proposed injection waters.

7. Average Minimum Time Required:

Four - six weeks depending on core and complexity of study.

8. Data Reported:

Measured air and liquid permeability values (as a function of throughput when applicable) and liquid/air permeability ratios are reported in tabular form.

A graphical plot of permeability to air versus permeability to water when sufficient data are available or on specific request may be given.

9. Key Equations - Not applicable

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

E. FORMATION RESISTIVITY MEASUREMENTS

1. Use:

These measurements define for a given formation parameters used in electric log calculation of porosity and water saturation. They therefore refine log calculations and remove the necessity of relying on constants presented in the literature. Although many formations can be described by published constants, sufficient deviations occur so that resistivity measurements are required to verify the validity of published values.

The "B" factor allows improved log interpretation in shaly sands. Equation 9c shows the formation factor (Fa) for any one sample to vary with the resistivity of the saturating brine. For clean sands "B" has a value of zero, and the formation factor is a constant. In shaly sands the clays conduct electricity and effect the Fa value, especially in waters that are relatively fresh. Depending on what variables are known in Eq. 9c knowledge of the "B" factor can assist in calculation of a proper water resistivity or the resistivity of a shaly formation when 100 per cent saturated with water.

2. Method:

Direct measurement of resistivity of a 100 per cent or partially brine-saturated core.

3. Type of Tests:

(A) Formation resistivity factors (FF) - Ratio of resistivity of a 100 per cent brine saturated sample

to the resistivity of the saturating brine. Reported as a function of porosity, these tests evaluate "a" and "m" in equation $FF = a/f^m$ defined under 9 below.

- (1) Room condition tests at atmospheric pressure and room temperature are normally run. If porosities are less than 10 per cent, overburden pressure tests are recommended.
 - (2) Overburden pressure tests may indicate significant differences in the formation factor - porosity relationship for a low porosity formation (<10%) or for formations at great depth subjected to large net overburden conditions. The cementation constant "m" is normally higher under overburden pressure conditions. The compressibility of rock is small, and even though porosity changes only slightly under overburden, the reduction in pore size causes measurable differences in electrical resistivity. Several tests to define FF versus confining pressures equal to 1/2 the depth are normally obtained. Equipment limitations are approximately 8000 psi.
- (B) Resistivity index (RI) - Ratio of the resistivity of a partially saturated sample to the resistivity of the 100 per cent brine saturated sample. Reported as a function of brine saturation, these tests evaluate "n" in formula presented in Section 9.

Tests are made at room conditions. While it would be advantageous to measure resistivity ratios under overburden pressure conditions, we have not successfully mastered the lab techniques. It is necessary to desaturate the samples and yet not evaporate any water from the core. This is to prevent a change in the salt content and hence resistivity of the saturating brine. Flowing oil through the core will accomplish the desaturation, but a thin film of oil between the sample and the electrode forms that breaks the electron flow and results in erroneously high resistivities.

- (C) Calculation of "B" Factor - Formation factors are determined in the laboratory with four different salinity saturating brines. These data are plotted and extrapolated to yield the value of $F_{.01}$. Equation 9c is solved using the measured data, to yield "B". Note: This calculation requires 4 formation factor tests per core, with their related cost. The charge for the calculation of "B" is additional to formation factor charges.

Experiments are now being made to evaluate "B", which is related to clay content and cation exchange capacity, in a more direct manner than just discussed. Hopefully this will furnish an additional technique for calculation of "B" at less expense to the client. This method involves cleaning, determination of porosity and then reduction of the sample to grain size. It is

washed with chemicals and put in a water slurry where the conductance of the slurry is measured during a titration with magnesium sulfate.

4. Type of Samples:

Room condition tests use small permeability plugs, or larger, including whole cores.

Overburden tests require 1" or 1-1/2" cylindrical plugs.

5. Minimum Number of Samples Recommended:

Formation factor, resistivity index and "B" factor should have a minimum of ten samples tested. Overburden FF are run at several pressures equal in maximum value to 1/2 the formation depth. Resistivity indices should be run on a minimum of three saturations on each sample.

6. Special Information Needed:

Resistivity, water sample, water analysis or chloride content of formation water. Depth of formation and original reservoir pressure.

7. Average Minimum Time Required:

- (A) Formation resistivity factors - Four weeks.
Tests are repeated until stabilized FF values are obtained.
- (B) Resistivity indices - dependent upon amount of associated capillary pressure or other

tests requiring desaturation. Normally 4 additional weeks after formation factor tests are completed.

- (C) "B" factors - currently require several months. New technique should reduce this to several weeks.

8. Data Reported:

- (A) Tabular and graphical presentation of formation factor versus porosity and resistivity index versus saturation. Normally a composite plot containing all FF and a composite plot showing all RI data are presented. Calculations of "a", "m" and "n" are made and the mathematical relationships of porosity to formation factor and resistivity index to water saturation are given.

The value of "B" for each core is presented in tabular form.

9. Key Equations:

- (A) Formation factor

$$FF = \frac{a}{f^m} = \frac{R_o}{R_w}$$

where:

FF = formation resistivity factor

f = porosity (fractional)

m = cementation factor (ranges from 1.8 to 2.5)

R_o = resistivity of 100 per cent brine saturated sample

R_w = resistivity of saturating brine

a = FF value at fractional porosity of 1.0 Value of " a " can range from 0.6 up to 1.42

(B) Resistivity index

$$RI = \frac{R_t}{R_o} = \frac{1.00}{S_w^n}$$

where:

RI = resistivity index

R_t = true resistivity at a given water saturation

R_o = resistivity of 100 per cent brine saturated sample

S_w = water saturation (fraction of pore volume)

n = saturation exponent (ranges from 1.4 to 2.2)

(C) "B" factor

$$F_a = F_{.01} (100 R_w)^B \log(100 R_w)$$

where:

F_a = apparent formation resistivity factor measured with various R_w brines

$F_{.01}$ = formation factor when sample is saturated with brine of 0.01 ohm-meter solution. This value is normally found by extrapolation of F_a measured with various salinity brines in the core

R_w = resistivity of saturating brine

B = constant of negative sign related to clay content in a core

Company _____
 Well _____
 Field _____

Formation _____
 County _____
 State _____

Company _____ Formation _____
 Well _____ County _____
 Field _____ State _____

F. WATER FLOOD TESTS

1. Oil Reservoirs

(A) General Observations

These tests are designed to furnish the effective permeability to oil ahead of the flood front, residual oil content after water flood, and the effective permeability to water behind the flood front. These data are used with permeability distribution and injection pattern efficiency to make predictions of reservoir performance.

Several tests may be run in the laboratory to furnish the required information. These tests vary in complexity and ease of application from the Basic Flood through Water Flood Susceptibility (WFS) test to water-oil relative permeability (K_w/K_o) measurements.

Performance relating oil recovery to pore volumes of water injected and to water-cut is usually desired. These data are not developed in the Basic Flood tests, and are reported only for the Water Flood Susceptibility measurements. The performance data can be calculated by the user from the K_w/K_o using the fractional flow equations, but many persons requiring water flood performance are not familiar with use of these equations. It is necessary to discuss with the client his proposed calculation technique when recommending types of water flood tests. Unless a definite

requirement for K_w/K_o is expressed, WFS tests can be recommended with confidence.

(B) Reservoir Condition Versus Room Condition Tests

Basic flood and WFS tests can be made under reservoir conditions of temperature and pressure using live reservoir oil. This is an improvement over room condition techniques where tests are made at atmospheric conditions with refined laboratory oils. Use of the live crude exposes the rock to compounds present in the oil that might influence wettability, and establishes a plug environment as close as possible to reservoir conditions.

Those cases where reservoir condition tests cannot be performed, room condition Basic Flood and WFS tests are in many cases satisfactory substitutes. These tests require refined oils specifically selected so that the laboratory oil-water viscosity ratio equals the oil-water ratio existing under reservoir conditions.

(C) Fresh Preserved Core Versus Restored Core Tests

It is desirable to perform all flood tests on fresh core samples when possible. Drying and cleaning of the samples prior to analysis may alter the wetting properties of the formation, thereby altering flood performance. Exposure to air for a sustained length of time may invalidate fresh core tests. It is essential that cores for fresh floods be stored under air free conditions. Samples

brought to the field laboratory that are exposed six to eight hours during routine analysis often suffer from water evaporation and exposure and may not be suitable for fresh flood tests. Where possible, fresh core should be preserved immediately after removal from the core barrel by wrapping with Saran wrap and foil, and then dipping in paraffin or plastic.

(D) Tests on Cores Simulating High Reservoir Oil-Water Viscosity Ratio

Water flood tests are normally carried to water cuts in excess of 99.9 per cent. During Basic Flood and WFS tests several hundred pore volumes of injected fluid are required to reach 99.9 per cent water cut when oil greater than four or five centipoises viscosity is present. Basic Flood tests yield only the residual oil value at the terminal condition of the laboratory test when several hundred pore volumes of water are injected. Much of the oil recovered in the laboratory is at a water cut and at injected volumes greatly in excess of field conditions. Most field water floods have only one or two pore volumes of fluid injected and become uneconomic at water cuts in excess of 95 per cent. The Basic Flood test may indicate optimistic recovery values and is not recommended for reservoirs with viscous oil. WFS tests or K_w/K_o tests are recommended in these cases as performance as a function of injected water volume is presented or can be calculated.

(E) Comments on K_w/K_o

(1) Unsteady State Technique

Water-oil relative permeability tests normally require that a viscous oil be used. This results in a high oil-water viscosity ratio and forces an early breakthrough of the water phase with a long subordinate production phase (where both oil and water flow). The unsteady state K_w/K_o measurement technique employed requires both oil and water flowing before K_w/K_o can be calculated.

On certain occasions where the actual reservoir oil-water viscosity ratio is low, K_w/K_o residual oil saturations obtained with viscous oil in the samples are higher than obtained when comparison flood tests simulating the reservoir viscosity ratio are made. Equal saturations would probably be reached if the K_w/K_o tests could be extended to infinite pore volumes of injection. This is not feasible, and where the absolute residual oil at essentially 100 per cent water cut (99.99%) is required, Basic Flood tests simulating the reservoir oil-water viscosity ratio conditions can be used to furnish supporting residual oil values for the K_w/K_o tests.

Where the reservoir oil-water viscosity ratio equals five to ten, it is usually possible to calculate K_w/K_o data from a WFS test.

Requests are often made for K_w/K_o data under reservoir conditions. As noted above, if the reservoir oil-water viscosity ratio is high a reservoir condition WFS test can be made and K_w/K_o can be calculated from the data. Where the reservoir oil-water viscosity ratio is low, normally a late water breakthrough and small subordinate production period is observed, and K_w/K_o can be calculated for only a limited water saturation range and in some cases not at all. Use of refined viscous laboratory oils at reservoir conditions of temperature and pressure is not recommended. This is easy enough to do in the laboratory, but the main advantage of using reservoir crude is lost. Therefore, unless the oil-water viscosity ratio is high, reservoir condition K_w/K_o over a large saturation range is often not available. Sometimes calculated points at the terminal conditions of the low oil-water viscosity ratio reservoir flood can be extrapolated over the saturations prior to water breakthrough to yield additional data.

(2) Steady State Technique

Low viscosity refined oil is used in these tests and all work is done at room conditions of temperature and pressure. This service is currently under development and is discussed more fully under Water-Oil (K_w/K_o) Relative Permeability.

2. Gas Reservoirs

Water flood tests on gas reservoirs furnish residual

gas after water encroachment into a gas saturated zone. These data are needed for (1) natural gas reservoirs with water drive, and (2) for gas storage projects in aquifers where a portion of the gas injected into the reservoir is trapped and is unrecoverable as production occurs and the gas bubble shrinks.

Residual trapped gas is a function of the initial gas in place. Where a water-gas saturation profile exists in the reservoir, several tests should be made on a given core for various initial gas saturations. This will define a curve of initial versus trapped gas for a given permeability rock. This applies to naturally occurring gas reservoirs with a long initial water-gas transition zone and all aquifer storage projects. In most naturally occurring gas reservoirs, the large density difference between water and gas results in a negligible gas-water transition zone and trapped gas tests at irreducible water are all that are needed.

3. Basic Flood

(A) Use:

Data from this test are used in Stiles and Dykstra-Parsons type calculations that require values of oil permeability at connate water and water permeability at residual oil to predict water cut versus cumulative oil recovery.

Test data do not yield oil recovery versus water cut and pore volumes of fluid injected as given in Water Flood Susceptibility test.

(B) Method:

(1) Room Condition Tests

- a. Extracted Cores - Extracted and dried cores are saturated with brine. These samples are restored to reservoir oil and water contents by centrifuge, capillary pressure cell, dynamic displacement or evaporation of brine and subsequent saturation of voided pores by oil. Test fluids are selected so that the reservoir oil-water viscosity ratio is reproduced in the laboratory test. Effective permeability to oil in the presence of connate water is determined and the cores are then water flooded to 99.9 per cent water cut. Total oil produced is recorded. Permeability to water in the presence of residual oil is then determined.
- b. Fresh Cores - Fresh core is evacuated shortly under oil and then flushed with oil to remove all gas. Extraneous water introduced during coring is displaced by centrifuge, capillary pressure cell or dynamic displacement. The reservoir oil-water viscosity ratio is reproduced in the laboratory test. Effective permeability to oil is measured. The samples are then flooded, as above. Fluid contents are measured by distillation and air permeability and porosity on the clean dry sample are determined. Saturations present in the core at initiation of flooding are calculated by material balance.

(2) Reservoir Conditions Tests

- a. Extracted Cores - Procedures are the same as for room condition extracted cores through the determination of effective permeability to oil in the presence of connate water. After this measurement the cores are placed in a controlled temperature environment and raised to reservoir temperature. Pressure on the system is increased to exceed the saturation pressure of the live oil. The laboratory oil within the sample is then displaced by live crude. The core is soaked at temperature and pressure for approximately 24 hours. One additional pore volume of oil is flushed through the core to displace the soak oil and the sample is then water flooded to 99.9 per cent water cut. Oil and water are flashed through a back pressure regulator and measured at room conditions. Total oil produced is determined. Permeability to water in the presence of residual oil is measured. Pressure on the system is reduced to atmospheric and oil and water produced during pressure blow down are measured. Produced oil volumes are corrected to reservoir volumes using an appropriate flash formation volume factor.
- b. Fresh Cores - Procedures are the same as for room condition fresh floods through measurement of the oil permeability in the presence of connate water. The samples are then placed in the temperature environment and raised to reservoir temperature.

Pressure on the system is increased to exceed the saturation pressure of the live oil. The tests then follow the same procedures as for reservoir condition extracted core floods through the completion of the pressure blow down. The sample is then removed from the holder. Fluid saturations are measured by distillation. Air permeability and porosity are determined on the clean dry sample. Saturations present in the core at initiation of flooding are calculated by material balance, after room condition oil and water volumes have been corrected to reservoir volumes using an appropriate flash formation volume factor.

(C) Type of Tests:

- (1) Room Conditions (Plug and Whole Core)
 - a. Extracted cores
 - b. Fresh cores.
- (2) Reservoir Conditions (Plug and Whole Core)
 - a. Extracted cores
 - b. Fresh cores

(D) Type of Samples:

- (1) Room Conditions - Whole core or 1 - 1 1/2" diameter plugs only.

(E) Minimum Number of Samples: - Four to eight.

(F) Special Information Needed:

- (1) Room Condition Tests (Extracted or Fresh Cores)

- a. Oil viscosity at reservoir conditions existing at time of flood.
- b. Injection water viscosity at reservoir conditions existing at time of flood.
- c. Salinity (chloride) of (a) formation water and (b) injection water, including sodium, calcium and magnesium content, if available. These data are extremely important as any reaction between rock and water will effect the test results.
- d. Height above water at which the major portion of the reservoir exists. Water-oil contact, crest of structure and gasoil contact will help. These data are to assist in calculating capillary pressures to use when restoring interstitial water saturations in the cores. If these data are unknown, irreducible waters will be established.
- e. If reservoir overlies a water-oil contact, the oil reservoir density in lb/ft^3 or gradient from a pressure traverse in psi/ft is needed in conjunction with item 4. The water gradient is also desired.
- f. If oil and water viscosity are not know, reasonable estimates can be made if following information is furnished.

.Chloride content of water (from water analysis or resistivity of sample).

.Reservoir temperature.

.Reservoir pressure at (1) original and (2) current conditions.

.Original oil solution gas-oil ratio.

.Oil gravity (can be determined from sample).

(2) Reservoir Condition Tests (Extracted or Fresh Cores)

- a. Water and reservoir information required on room condition tests is needed. This includes data on connate and proposed injection water.
- b. Oil data including viscosity and flash formation volume factor will be developed in the Reservoir Fluid Laboratory for a charge of approximately \$400.
- c. Oil samples, either bottom hole or separator products, for recombination are required. Associates key sampling data are needed as follows.

.Bottom Hole Samples

- Bottom hole temperature & its associated depth.
- Bottom hole pressure & its associated depth.
- Perforation interval.
- Sampling depth.

.Recombination Samples

- Bottom hole temperature & its associated depth.
- Bottom hole pressure & its associated depth.
- Gas-oil ratio & whether oil is stock tank or separator barrel.
- Pressure & temperature base used in GOR calculation.
- Specific gravity & specific gravity factor (f_g) used in GOR.
- Compressibility factor (f_{pv}) used in GOR.

- d. Sufficient oil to flow 3 to 5 pore volumes of fluid through each flood sample are required. For each plug sample, 100 cc of reservoir fluid sample is normally sufficient. Whole core volumes vary widely because of sample length and porosity and must be evaluated at time of study initiation.

(G) Average Minimum Time Required - Six to eight weeks

(H) Data Reported: - Tabular data including air permeability, porosity, connate water, effective permeability to oil at connate water saturation (ahead of flood front), oil recovered by flood, residual oil saturation and effective permeability to water at residual oil (behind the flood front).

(I) Key equations: - Not applicable

4. Water Flood Susceptibility

(A) Use:

Data can be used in Stiles and Dykstra - Parsons type calculations that require values of oil permeability at connate water and water permeability at residual oil.

Oil recovery is determined as a function of pore volumes of water injected and water cut. These data furnish a graphic display of expected reservoir performance in those areas of the reservoir swept by water and as such offer more insight into flood performance than do Basic Floods.

Method:

(1) Room Condition Tests

- a. Extracted cores - Same as Basic Flood except incremental production and rates of flow of oil and water are recorded.
- b. Fresh cores - Same as Basic Flood except incremental production and rates of flow of oil and water are recorded.

(2) Reservoir Condition Tests

- a. Extracted cores - Same as Basic Flood except incremental production and rates of flow of oil and water are recorded.
- b. Fresh cores - Same as Basic Flood except incremental production and rates of flow of oil and water are recorded.

(C) Type of Tests: - Same as Basic Flood.

(D) Type of Samples: - Same as Basic Flood.

- (E) Minimum Number of Samples: - Four to eight.
- (F) Special Information Needed: - Same as Basic Flood.
- (G) Average Minimum Time Required - Six to eight weeks.
- (H) Data Reported: - Oil recovery as a function of injected water volumes and water cut are presented in tabular and graphical form in addition to air permeability, porosity, connate water, effective permeability to oil at connate water saturation (ahead of flood front), oil recovered by flood, residual oil saturation and effective permeability to water at residual oil (behind the flood front).

When K_w/K_o is calculated from WFS, tabular and graphical presentation of the K_w/K_o ratio curve and individual relative permeability to water (K_w/K) and to oil (K_o/K).

- (I) Key Equations: - Not applicable.

G. Relative Permeability

Darcy's Law as originally written applies to a porous medium where a single fluid completely saturates the rock. When two or more fluids are present, they compete for flow space within the rock and the concepts of effective permeability and relative permeability have been introduced to properly account for this multiphase condition.

The following definitions apply:

- (1) Specific Permeability - Refers to permeability (K_s) when a single fluid at 100 percent saturation is present. Units are darcys or millidarcys.
- (2) Effective Permeability - Applies to the permeability of each phase at specified saturations when two or more fluids are present. Examples are effective permeability to water (K_w) and effective permeability to oil (K_o). Units are darcys or millidarcys.
- (3) Relative Permeability - Equals Effective Permeability at specified saturation divided by Specific Permeability; i.e. $K_{ro} = \frac{K_o}{K_s}$ - Fraction or percent.
- (4) Relative Permeability Ratio - Relative Permeability to one phase divided by Relative Permeability to second phase at a common saturation; i.e. $K_{rw}/K_{ro} - K_w/K_o$ - Dimensionless.

The effective permeability and the relative permeability require that the saturation of the phases be known before much practical use can be made of the data. The saturation present is dependent on the wetting characteristics of the rock and the saturation history of the sample. In general, laboratory samples

should follow the same sequence of saturation changes during preparation and test that the reservoir has undergone.

Relative permeability requires that the effective permeability be made relative to some base permeability. In most cases this base is the specific air permeability that has been corrected for klinkenberg effect. An exception to this rule is that in Canada the base is normally the oil permeability existing at connate water saturation.

The base of air permeability is most often used since core analysis permeabilities are air permeability values. These are grouped and average into permeability or porosity ranges and used as the correlating tool. It is convenient to have these correlating values as the base in the relative permeability calculation.

Relative permeability values reported can be shifted to a new base by use of equation (3) above. This does not change the relative permeability ratio values only individual phase relative permeability. The base values for Special Core Analysis samples are reported on the bottom of the tabular data sheets so that they are easily available and part of the permanent data record.

1. Water-Oil (K_w/K_o) Relative Permeability

(A) Use: These data are preferred by many engineers evaluating water flood performance. Reservoir performance relating oil recovery as a function of water cut and porevolumes of water injected (similar to water flood susceptibility data) can be calculated using fractional flow equations for any set of

oil-water viscosity conditions. An example is included under Section (1). When used in the fractional flow formula in conjunction with capillary pressure data, it offers insight into water cut versus height above the water-oil contact, and often assists in explaining injectivity difficulty into disposal wells.

(B) Method:

(1) Unsteady State Tests (Normal system used in water floods)

- a. Room Conditions - Extracted cores- identical with water flood susceptibility (WFS) procedures except a viscous refined oil (17 centipoises) is used to yield a high oil-water viscosity ratio and force an early breakthrough of water. On request crude oil can be substituted for the refined oil. Crude often partially plugs the samples during restoration and during oil permeability measurements and is not recommended except in unusual circumstances.

When the oil-water viscosity ratio exceeds 5 to 10 in the normal WFS test, K_w/K_o values can often be calculated from the WFS data.

Fresh Cores - Identical to fresh core Water Flood Susceptibility procedures except a viscous refined oil (17 centipoises) is used to yield a high oil-water viscosity ratio and force an early breakthrough of water. As noted above, crude oil can be used but is not recommended.

- b. Reservoir Conditions - Extracted cores Water-oil relative permeability is calculated from extracted core Water Flood Susceptibility Tests. If the reservoir oil-water viscosity ratio exceeds 5 to 10, the K_w / K_o relationships can often be calculated. There is no benefit to be gained from testing refined oil at reservoir temperature and pressure as it is the reaction between actual reservoir oil, water and rock that is desired.

Fresh cores - Water-oil relative permeability is calculated from fresh core reservoir condition WFS tests.

(2) Steady State Tests

- a. Room Conditions - Extracted cores - Samples are prepared as for room condition water flood tests through measurements of an oil permeability at connate water. The sample will then be placed in the steady state apparatus and will have a selected water-oil ratio flowed through it. Flow will continue until capillary equilibrium is obtained and the effluent ratio equals the injection ratio. This is verified by a constant pressure drop across the core which is monitored on a chart recorder. Rate of flow will be monitored and effective permeability to oil and water will be calculated.

The sample is removed from the apparatus, weighted, returned to the apparatus and

the water oil ratio is increased. The procedure is repeated for five to six ratios and will take approximately one week per core. Water saturation in the core when equilibrium was obtained at each ratio will be calculated from the weight changes that occurred and known densities of the water and oil.

Fresh cores - Samples are prepared as for fresh room condition water floods through permeability to oil determination at connate water. The steady state process as described above is then followed. At the conclusion of the test, fluid contents are determined by distillation. Air permeability and porosity on the cleaned and dried core are measured and saturations present in the core at each water-oil ratio are calculated by material balance.

- (3) Calculated from pore size distribution (capillary pressure data). Equations are last resort technique since water flood is an imbibition process and drainage capillary pressure curves are often all that are available. Imbibition capillary pressure data can be utilized, but question exists as to the proper tortuosity to use for the imbibition case.

(C) Type of Tests:

- (1) Unsteady State Technique
 - a. Room Condition (Extracted or fresh core)
 - b. Reservoir Condition (Extracted or fresh core)

(b) Type of Samples

(1) Unsteady State Technique

- a. Room conditions - Whole Core or 1", 1-1/2" 2" plugs with 1-1/2" preferred.
- b. Reservoir conditions - Whole core of 1 1/2"

(2) Steady state apparatus limited to 1-1/4" diameter cylindrical plug.

(E) Minimum Number of samples: - Three to five.

(F) Special Information Needed:

(1) Unsteady State Technique

- a. Room conditions (Fresh or extracted cores)
Requires composition, chloride or resistivity of formation water. Requires composition, chloride or resistivity or injection water.
- b. Reservoir Conditions - K_w/K_o is calculated from the reservoir condition Water Flood Susceptibility data. See Water Flood section for details of test and information required.

(2) Steady State - No special information is required.

(G) Average Minimum Time Required - Eight Weeks.

(H) Data Reported - Permeability to air, permeability to oil at connate water saturation, porosity, connate water, residual oil, oil recovery, permeability to water at residual oil. Graphical and tabular presentation of relative permeability to oil, relative permeability to water, and water-oil relative permeability ratio as a function of water saturation.

(i) Key Equations - Presented are (1) equations relating

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

RELATIONSHIP OF WATER-OIL RELATIVE PERMEABILITY AND FRACTIONAL FLOW

$$Q_o = \frac{(K_{ro} \cdot K_a)(A)(dP)}{(\mu_o)(L)}$$

$$Q_w = \frac{(K_{rw} \cdot K_a)(A)(dP)}{(\mu_w)(L)}$$

$$\text{Fractional Flow of Water} = \frac{\text{Water}}{\text{Water} + \text{Oil}} = f_w$$

$$f_w = \frac{Q_w}{Q_o + Q_w}$$

$$f_w = \frac{\frac{(K_{rw} \cdot K_a)(A)(dP)}{(\mu_w)(L)}}{\frac{(K_{ro} \cdot K_a)(A)(dP)}{(\mu_o)(L)} + \frac{(K_{rw} \cdot K_a)(A)(dP)}{(\mu_w)(L)}}$$

$$f_w = \frac{\frac{K_{rw}}{\mu_w}}{\frac{K_{ro}}{\mu_o} + \frac{K_{rw}}{\mu_w}}$$

Now Divide Through By $\frac{K_{rw}}{\mu_w}$ and

$$f_w = \frac{1}{\frac{K_{ro}}{\mu_o} \cdot \frac{\mu_w}{K_{rw}} + 1}$$

$$f_w = \frac{1}{1 + \frac{K_{ro}}{K_{rw}} \cdot \frac{\mu_w}{\mu_o}}$$

EXAMPLE CALCULATION OF FRACTIONAL FLOW

Given: Oil Viscosity = 1.65 cp = μ_o
 Water Viscosity = 0.55 cp = μ_w
 Relative Permeability (Water-Oil)

(1) <u>Sw</u>	(2) <u>Kro</u>	(3) <u>Krw</u>	(4) <u>$\frac{Krw}{Kro}$</u>	(5) <u>$\frac{Kro}{Krw}$</u>	(6) <u>$\frac{\mu_w}{\mu_o}$</u>	(7) <u>$\frac{Kro}{Krw} \cdot \frac{\mu_w}{\mu_o}$</u>	(8) <u>1.0 + (7)</u>	(9) <u>$\frac{fw}{1.0/(8)}$</u>
.27	0.60	0.0	0		0.333			0.0
.30	.34	.002	.0059	170.	0.333	56.5	57.5	.017
.40	.10	.01	.10	10.	0.333	3.33	4.33	.231
.49	.03	.03	1.0	1.	0.333	.333	1.33	.751
.60	.009	.09	10.0	.1	0.333	.033	1.03	.968
.65	.0031	.125	40.3	.025	0.333	.0083	1.008	.993
.70	.001	.17	230.0	.0043	0.333	.00143	1.001	.996

Where:

Sw = Water Saturation, Fractional Pore Volume
 Kro = Relative Permeability to Oil, Fraction
 Krw = Relative Permeability to Water, Fraction
 μ_o = Oil Viscosity, Centipoise
 μ_w = Water Viscosity, Centipoise
 fw = Fractional flow of water

$$fw = \frac{1}{1 + \frac{Kro}{Krw} \cdot \frac{\mu_w}{\mu_o}}$$

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

Water Saturation, Fractional Pore Volume

EXAMPLE CALCULATION OF WATER FLOOD
PERFORMANCE CALCULATED USING K_w/K_o
AND FLUID PROPERTIES OF MUDDY SAND

(1)	(2)	(3)	(4)	(5)	(6)	(7)
<u>Sw1</u>	<u>Sw2</u>		Cumulative			Qi
<u>End Face</u>	<u>Average</u>	<u>fw @ Sw1</u>	Oil Produced		fo	Water Injected
			(Fractional PV)		(1.0-fw)	(Pore Volumes)
			<u>Sw2-Cw</u>	<u>Sw2-Sw1</u>		<u>(5)/(6)</u>
0.270	0.270	0	0	0	1.0	0
.505	.554	.829	.284	.049	.171	.286
.550	.607	.925	.337	.057	.075	.760
.600	.646	.965	.376	.046	.035	1.31
.650	.677	.994	.407	.027	.006	4.5
.700	.700	1.00	.430	0	0.0	∞

Basic Equation: $Sw1 = Sw2 - fo Qi$
or $Qi = (Sw2 - Sw1) / fo$

Where:

- Sw1 = Water Saturation at Producing Well-Fraction of Pore Volume
- Sw2 = Average Water Saturation Between Producing and Injection Well - Fraction of Pore Volume
- fw = Fractional Flow of Water
- Cw = Interstitial Water Saturation (Initial Water in Reservoir at Start of Water Injection)
- fo = Fractional Flow of Oil = (1.0-fw)
- Qi = Cumulative Water Injected, Pore Volumes

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

K_w/K_o to fractional flow of water which is in reality water cut at reservoir conditions in the producing well bore; (2) example calculation of fractional flow of water using K_w/K_o data for Muddy sand; (3) plot of fractional flow of water versus water saturation; (4) calculation of water flood susceptibility from fractional flow data of Muddy sand (5) plot of water flood susceptibility.

2. Water Floods on Cores Containing Trapped Gas

- (A) Use: These tests are made to simulate water flooding of a pressure depleted oil zone where flood pressures are so low that free gas that occurred due to pressure drop and production will not go back into solution in the oil. In this situation the trapped gas will affect relative permeability and residual oil values.
- (B) Method: Extracted and dried samples are saturated with brine. They are restored to initial oil and water saturations as discussed in basic floods. They are then gas flooded to the current reservoir gas saturation. The cores are subsequently flooded with oil to simulate the formation of an oil bank and to establish a trapped gas saturation. Water is then injected and performance is monitored as in a WFS test. These tests are normally made at elevated pressures to minimize gas solubility in the oil and water.
- (c) Type of Tests: - Extracted cores at room temperature but elevated pressure.
- (D) Type of Samples - Whole core, 1-1/2" or 2" diameter cylindrical plugs.

(E) Minimum Number of Samples - Four to eight

(F) Special Information Needed

(1) Same data as room condition Basic Flood.

(2) Gas saturation in reservoir at time of initiation of water flood.

(G) Average Minimum Time Required:- Eight to ten weeks.

(H) Data Reported: Tabular and graphical oil recovery versus water cut and water volumes injected. Initial gas and final trapped gas saturations are given as well as oil permeability at trapped gas saturation.

Tabular data also include air permeability, porosity, connate water, effective permeability to oil at connate water saturation (ahead of flood front), oil recovered by flood, residual oil saturation and effective permeability to water at residual oil (behind the flood front).

(I) Key Equations - Not applicable.

3. Gas Oil (K_g/K_o) Relative permeability

(A) Use - These data are used in conjunction with fluid properties and material balance equations to predict pressure, gas-oil ratio and production performance for solution gas-drive reservoirs. K_g/K_o is also required for gas-cap advance, gravity drainage, productivity decline, gas coning and fractional flow equations.

(B) Method:

- (1) Gas drive (also called Welge or unsteady state method) with no connate water - Gas displaces, at a high rate, the viscous oil from an oil saturated core with no connate water present. Rates and volumes of effluent are measured throughout the test. Relative permeability is calculated by digital computer using equations by Johnson, Bossler and Naumann "Calculation of Relative Permeability from Displacement Experiments" AIIME Transactions, Vol 216 (1959). Tests are normally made at room conditions temperature and pressure on extracted and restored cores.
- (2) Gas drive with connate water present - K_g/K_o tests should be run with connate water in most cases. This is particularly important in sands containing hydratable clays and in low permeability rock. This test allows only two mobile phases; so when water is present, it must be at an immobile saturation. This deviates from reservoir conditions in those cases where both oil and free gas are present and the reservoir is close to the oil-water contact so that water also flows. Tests can be made on fresh core but normally are made on extracted, restored cores.
- (3) Relative permeability can be calculated from pore size distribution data. See section on Relative Permeability Calculated from Pore Size Distribution.

(C) Type of Tests:

- (1) Restored core tests with or without connate water at room temperature normally using a viscous (17 centipoises) refined oil.
 - (2) Fresh core tests can be made if requested and normally a viscous refined oil is used.
- (D) Type of Samples - Whole core or cylindrical plugs 1", 1-1/2" or 2" in diameter.
- (E) Minimum Number of Samples - Three to five.
- (F) Special Information Needed:
- (1) When no connate water is requested no special information is needed.
 - (2) With connate water requires composition, chloride content or resistivity of formation water.
- (G) Average Minimum Time Required: - Eight weeks
- (H) Data Reported: Permeability to air, permeability to oil at connate water saturation, porosity, connate water, tabular and graphical data of relative permeability to gas, relative permeability to oil, and gas-oil relative permeability ratio as function of liquid saturation.
- (I) Key Equations: - Example of fractional flow is given in Water-Oil Relative Permeability Section and similar equations apply in gas-oil system.

4. Gas-Water (K_g/K_w) Relative Permeability

- (A) Use - These data are used for calculation of gas bubble formation in gas storage projects where gas displaces aquifer water from a zone originally

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

100 per cent water saturated. Also used for gravity drainage and theoretical productivity calculations in gas storage wells.

(B) Method:

- (1) Gas drive (Welge or unsteady state method) - Gas displaces, at a high rate, water from a 100 per cent water saturated core. Rate and volume are measured throughout the test. Relative permeability is calculated by digital computer using similar equations to K_g/K_o calculations.
- (2) K_g/K_w can be computed from pore size distribution data derived from capillary pressure test. See section on calculation of Relative Permeability from Pore Size Distribution.

(C) Type of Tests - Gas-drive tests are normally made on restored core at room temperature. Fresh samples could be used if requested.

(D) Type of Samples - Cylindrical plugs 1", 1-1/2" or 2" in diameter or whole core.

(E) Minimum Number of Samples - Three to five

(F) Special Information Needed - Composition, chloride content, or resistivity of formation water.

(G) Average Minimum Time Required - Eight weeks

(H) Data Reported - Porosity, permeability to air and to water. Tabular and graphical presentation of relative permeability to gas, relative permeability to water, and gas-water relative permeability ratio as function of water saturation.

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

Company _____ Formation _____
 Well _____ County _____
 Field _____ State _____

- (1) Key Equations - Example of fractional flow is given in Water-Oil Relative Permeability Section and similar equations apply in gas-water system.

5. Relative Permeability Calculated From Pore Size Distribution.

- (A.) Use: Capillary pressure data can be used for the calculation of pore size distribution and relative permeability. These calculations were developed for a capillary drainage situation where a non-wetting phase (gas) displaces a wetting phase (oil in gas-oil system and water in a gas-water system).

Gas-drive tests discussed elsewhere are recommended where possible, but there are cases where calculated data are helpful. Examples are when rock samples are too small for flow tests but adequate for capillary pressure tests, or capillary pressure data have been run in preceeding years and rock no longer exists for gas-drive testing. Another application is in extremely tight reservoirs where flow tests are impractical but mercury injection capillary pressures can be obtained.

As noted above, these techniques were primarily developed for gas-oil relative permeability since this is a drainage situation. Water-oil data can be calculated, but the latter contains a great uncertainty since water encroachment into an oil reservoir is an imbibition process rather than drainage. The resulting water-oil data are at best an approximation.

One additional use of these data is in gas-condensate reservoirs where oil saturation builds up as pressure drops, causing a reduction in gas well productivity.

The normal gas-drive (K_g/K_o) flow test does not yield relative permeability at the high gas saturations (low liquid saturation) needed for gas condensate reservoir calculations. The calculated relative permeability furnishes relative permeability values for gas saturations of 100 per cent to zero and can be used for engineering approximations.

- (B) Method - Experimental and theoretical work were carried on simultaneously by Burdine and Purcell. Equations utilized are a combination of the two calculation techniques. Burdine's contribution was in the handling of the tortuosity factor. Purcell's integration of $1/P_c^2$ has been adopted as the most practical. This calculation requires that a complete capillary pressure curve be available. Mercury injection complete curves are preferable because of the multiplicity of points and good definition. See Equations Section (1).
- (C) Type of Tests - Not applicable
- (D) Type of Samples - Requires core suitable for capillary pressure test. Permeability plugs, 1" or 1-1/2" diameter satisfactory. Low porosity cores require 1-1/2" sample for accuracy. Maximum plug length is approximately 2".
- (E) Minimum Number of Samples - Three to five.
- (F) Special Information Needed - Calculation from pore size distribution requires knowledge as to approximate height in feet above oil-water contact at which top of the oil column exists. Also requires reservoir oil

gradient and water gradient in psi/ft so proper water saturation in reservoir at top of zone can be estimated from capillary data. This is needed in cases where little closure exists and the total oil zone is close to the water-oil level with a reservoir water saturation greater than irreducible.

- (G) Average Minimum Time Required - Two to three weeks in addition to time to run capillary pressure.
- (H) Data Reported - Capillary pressure data used in calculations are reported. Tabular and graphical presentation of relative permeability to wetting phase (oil in gas-oil system and water in gas-water system) and non wetting phase (gas in gas-oil system and gas in gas-water system).
- (I) Key Equations - See next page.

RELATIVE PERMEABILITY CALCULATED
FROM PORE SIZE DISTRIBUTION

$$K_{rw} = \left[\frac{SL - S_{wi}}{1.0 - S_{wi}} \right]^2 \frac{\int_{S_{wi}}^{SL} \frac{dS_w}{(P_c)^2}}{\int_{S_{wi}}^{1.0} \frac{dS_w}{(P_c)^2}}$$

$$K_{rnw} = \left[\frac{1.0 - SL}{1.0 - S_{wi}} \right]^2 \frac{\int_{SL}^{1.0} \frac{dS_w}{(P_c)^2}}{\int_{S_{wi}}^{1.0} \frac{dS_w}{(P_c)^2}}$$

$$\frac{K_g}{K_o} = \frac{K_{rg}}{K_{ro}} = \frac{K_{rnw}}{K_{rw}}$$

Where:

K_{rw} = Relative permeability to wetting phase (K_{rw} & K_{ro})

K_{rnw} = Relative permeability to non-wetting phase (K_{rg})

S_{wi} = Minimum connate water saturation

SL = Total liquid saturation = (1.0 - gas saturation)

P_c = capillary pressure

S_w = Wetting phase saturation from P_c curve

Note:

Equations as written apply to case where initial water in sample is at irreducible (S_{wi}).

H. Overburden Permeability and Porosity

- (1) Use - The advent of rubber sleeve cores taken in formerly unrecoverable unconsolidated formations has been the primary factor in development of this service. It has been observed in competent formations that water present in the pore spaces during overburden test lubricate the sand grains and/or soften the matrix yielding greater compression than when cores are tested in the dry state. This has not proven to be important a factor in many of the unconsolidated sands and the service offered herein is performed on clean, dry cores.

Air permeability and porosity under overburden conditions are necessary for approximation of reservoir condition values when the core is unconsolidated.

Relaxation of the grain contacts occur during coring, movement to the surface, or during the removal of the core from the rubber sleeve. This results in erroneously high values of permeability and porosity unless a correction is made for this relaxation prior to the time the physical parameters of the core are determined.

One technique used to minimize disturbance of the sand grains during preparation is to freeze the rubber sleeve and drill the test plug using liquid nitrogen. It is then mounted while in the frozen state and ready for further testing. A more common method is to insert a punch through a window cut in the rubber sleeve and extract a core sample which is displaced into a thin wall metal sleeve with screens over the end to minimize grain loss. The sleeve is seated to the sand (containing residual fluids) by squeezing at a selected overburden pressure. After the sample has been cleaned it is then ready for overburden measurements.

Increased overburden pressure causes a reduction in porosity and permeability. The net overburden pressure on the formation that causes compression of the rock can be calculated by assuming the overburden gradient due to rock weight is 1.0 psi/ft and the internal gradient due to hydrostatic pressure is 0.5 psi/ft (fresh water is 0.433 psi/ft). This results in an approximate expression that yields the net pressure (frame) causing compaction and states this frame pressure is equal to $(1.0 \text{ psi/ft} - 0.5 \text{ psi/ft}) \times \text{depth in feet}$. This simplifies to the expression that net overburden pressure equals one-half the depth. For example, the laboratory overburden overburden pressure used to measure permeability and

porosity should be approximately 5000 psi if the formation were 10,000 feet deep.

Boundary loading conditions causing compression of the rock in the laboratory differ from those in the reservoir. One investigator states that a better approximation in the laboratory is to use one-fourth the depth rather than one-half. On a study conducted by an engineering and consulting lab, it was found that a factor slightly greater than one-fourth the depth was valid. Either the one-fourth or one-half approximation is better than applying no correction. The greatest reduction in permeability and porosity is often seen with the first 500 psi overburden pressure and use of either one-fourth or one-half the depth often yields little difference in results. The best approach to the problem is to measure both permeability and porosity at several overburden pressures so that the trend can be determined.

2. Method:

- (A) Air Permeability - Samples (consolidated cores or unconsolidated samples mounted in thin wall metal sleeves) are first cleaned and dried. Lengths and areas are determined where appropriate. The samples are placed in triaxial holders and subjected to a low overburden pressure (approximately 100 psi). Flow of air through the core is measured using the standard permeameter. Overburden pressure is never removed between measurements and is incrementally increased until the maximum pressure is obtained.

The overburden pressure limitation is approximately 6000 psi due to equipment.

- (B) Porosity (Boyle's Law) - Cores are prepared as discussed under Air Permeability. At selected overburden pressures helium is injected into the pore space and pore volume is read from the helium porosimeter gauge. Overburden pressure is then increased and pore volume is again determined. Several pore volume measurements are made at each pressure to assure that equilibrium has been reached and no further compaction of the pore space is occurring. Overburden pressure is never removed from the sample during the test and is increased until maximum pressure is obtained. It is assumed the pore volume reduction also reflects a corresponding and equal reduction in bulk volume.

Permeability and Porosity, these two tests are often measured in conjunction with one another. At any given overburden both permeability and pore volume are determined. Overburden is increased and the measurements are repeated as discussed above.

3. Type of Test

- (A) Single overburden - Permeability and/or porosity can be determined at a single designated overburden pressure.
- (B) Multiple overburden - Permeability and/or porosity are usually determined at a number of overburden pressures. These type tests are recommended as the decrease of porosity and permeability gives insight into the sensitivity of these parameters to overburden pressures. Anomalous data can also be identified more easily.

4. Type of sample - All tests can be made on 1 or 1-1/2 inch diameter cylindrical plugs. Unconsolidated cores are jacketed with thin wall metal sleeves of 1 or 1-1/2 inch with screens over the ends to inhibit grain loss.
5. Minimum Number of Samples:
 - (A) Permeability - 10
 - (B) Porosity - 10
 - (C) Permeability and Porosity - 10
6. Special Information Needed: - Coring procedures and handling prior to arrival are helpful.
7. Average Minimum Time Required:
 - (A) Permeability - 6 weeks
 - (B) Porosity - 6 weeks
 - (C) Permeability and Porosity - 6 weeks
8. Data Reported:
 - (A) Permeability- permeability at each overburden
 - (B) Porosity - porosity at each overburden
 - (C) Permeability and Porosity - value of both at each overburden.
9. Key Equations: - Not applicable.

I. RESIDUAL GAS

1. Use

These tests furnish trapped gas saturation after water-drive. Data are needed for gas storage projects in aquifers and for naturally occurring gas reservoirs that are underlain by water. Trapped gas may represent appreciable pore space and should be accounted for in reservoir calculations.

Trapped gas is often a direct function of initial gas saturation and in aquifer storage projects this relationship must be developed by running tests at various initial liquid saturations. Naturally occurring gas reservoirs typically have a short gas-water transition zone and tests with irreducible water in the core will suffice.

2. Method:

(A) Imbibition Tests

- (1) Liquid saturation comparable to Irreducible Water - Cleaned and dried cores are saturated with water or toluene. The samples are saturated with water in most cases where swelling clays exist and where the cores have never been contacted with oil; i.e., a gas storage aquifer originally 100 per cent water saturated. In cases where oil has once been in the cores, toluene is superior to water as the saturating wetting phase in that it strongly wets the core and reduces wettability difficulties. When toluene is used, it takes the place of the water and the test simulates the case of a strongly water-wet reservoir system.

The saturation of the wetting fluid is reduced to a desired value by evaporation. The sample is weighed and then suspended from a balance under the saturating liquid. As the fluid imbibes into the core and displaces gas, the sample changes in weight. Weight is plotted as a function of time until equilibrium is reached in the sample. The residual gas is determined from the weight plot at a point on the curve indicated by a change in slope where diffusion processes are minimum. This gives one value of residual gas for one initial gas saturation.

(2) Multiple Liquid Saturations- If trapped gas is required for liquid saturations in addition to irreducible, the sample is again 100 per cent liquid saturated and the evaporation process is repeated to establish a different liquid saturation. The imbibition process is again performed to establish a second residual gas. This process is repeated for various initial saturations as requested.

(B) Dynamic Displacement - Cleaned and dried cores are saturated with water. A reduced water saturation is established by centrifuge, capillary pressure cell or evaporation. The voided pores contain air for the test. The core is then placed in a core holder. Mean pressure on the system is increased to about 500 psi and gas saturated water is injected into the core at a low pressure differential. Gas produced is measured at the elevated pressure and residual gas can then be calculated by material balance.

3. Type of Tests

(A) Imbibition

(1) At irreducible Liquid Saturation

(2) At multiple Liquid Saturations

(B) Dynamic Displacement

4. Type of Samples

(A) Imbibition Tests - 1" or 1-1/2" cylindrical plugs preferred. Tests can be made on irregular shaped cores.

(B) Dynamic Displacement - 1" or 1-1/2" cylindrical plugs.

5. Minimum Number of Samples:

(A) Imbibition Tests - Four to eight

(B) Dynamic Displacement - Four to eight

6. Special Information Needed

(A) Imbibition Tests

(1) At irreducible Liquid Saturation - If water is used, irreducible can be established by centrifuging core. Connate water salinity, composition or resistivity is required. If toluene is used, information on irreducible water saturation must be furnished.

(2) At multiple Liquid Saturations - If no liquid values are furnished, several saturations

will be selected. If water is used, the salinity, composition or resistivity is required.

- (B) Dynamic Displacement - Salinity, composition or resistivity of connate water is required.

7. Average Minimum Time Required.

- (A) Imbibition Tests - Six to eight weeks
- (B) Dynamic Displacement - Eight weeks

8. Data Reported

- (A) Imbibition Tests - Tabular data include air permeability, porosity, connate water, initial gas and gas recovered.
- (B) Dynamic Displacement - Identical data to imbibition tests.

9. Key Equations - Not applicable.

J. THERMAL RECOVERY TESTS

Thermal recovery is primarily used to increase production from low API gravity reservoirs containing viscous oil. A valid thermal prospect typically has low primary production recovery and is often a poor risk for more conventional secondary recovery operations such as water flood.

Addition of thermal energy to the reservoir results in expansion of the oil in place and a dramatic reduction in oil viscosity. An example of the latter would be reduction of viscosity from 1000 centipoises to 1 centipoise by raising reservoir temperature from 100°F to 500°F. This oil viscosity reduction is the principal factor yielding increased recoveries.

Several types of tests may be run in the laboratory to assist engineers in selection of the proper thermal recovery process to use. These include (1) hot water injection (2) steam injection and (3) in-situ combustion. Each process offers advantages in certain situations and is likely to be unsatisfactory in others. Fewer people have practical experience in thermal operations than in routine water flood operations and it is therefore highly desirable that each prospect be studied critically in making a final selection of the most promising process.

In general, most thermal projects are relatively shallow and both hot water and steam injection are conducted at depths less than 2500 feet. A rule of thumb of 1000 barrels of oil per acre-foot as a minimum volume to support a thermal operation can be used. Steam and hot water injection require thick sands (greater than 50 feet) to minimize heat loss while

in-situ combustion may operate satisfactorily in sands less than 50 feet in thickness.

1. Hot Water Flood

- (A) Use - These data are used to predict oil recovery by injection of hot water. Recovery in this case is enhanced by (1) viscosity reduction of the crude and (2) thermal expansion of the oil. Effective permeability to oil in the presence of connate water and water permeability at residual oil are given, in addition to other information. These data may be used with permeability distribution and injection pattern efficiency to make predictions of reservoir performance. Equations such as those proposed by Marx and Langeheim are used to investigate the cumulative heated area, the thermal invasion rates and to derive the economic limits for hot water injection. These equations require a residual oil value which is furnished by the hot water flood test.

In addition, Water Flood Susceptibility tests, using hot water as the injection fluid, present oil recovery as a function of pore volumes of water injected and water cut. A graphic display of reservoir performance in a given strata swept by water is presented and thereby offers more insight into flood performance than do Basic Flood tests.

Hot water floods are normally made on heavy oils that have little or no gas in solution in the reservoir. Crude oil is normally used in these tests and floods are made at the temperature

proposed for injection. In these cases, the viscosity of the crude oil used in the laboratory test will approximate the viscosity of the crude in the reservoir when brought to the injection temperature. These floods therefore approach reservoir condition floods where no reservoir pressure is present.

(B) Method:

(1) Basic Flood

- a. Extracted cores - Extracted and dried cores are saturated with formation brine. Connate water is established by centrifuge, capillary pressure cell, dynamic displacement or evaporation. Voided pores are then saturated with crude oil. The samples are placed in an air bath and the temperature is elevated to that of the hot water flood. Permeability to oil is determined. Hot water is injected and total oil recovery is recorded for the Basic Flood test. Permeability to water in the presence of residual oil is also determined.
- b. Fresh cores - Plugs drilled from fresh core are evacuated under oil and then flushed with oil (may require elevated temperatures) to remove free gas. Extraneous water introduced during coring is displaced by centrifuge, capillary pressure cell or dynamic displacement. Effective

permeability to oil is measured and the temperature of the samples is elevated and the samples are flooded, as above. After the water flood, residual contents are measured by distillation. Air permeability and porosity are determined on the clean sample. Saturations present at the start of the flood are calculated by material balance.

(2) Water Flood Susceptibility

- a. Extracted cores - Same procedure as Basic Flood with addition of incremental water cut, injected volumes and oil recovery measurements.
- b. Fresh cores - Same procedure as Basic Flood with addition of incremental water cut, injected volumes and oil recovery measurements.

C. Type of Tests:

- (1) Basic Flood tests at desired temperature and atmospheric pressure for end point permeabilities and saturations. Tests are made on fresh or restored cores.
- (2) Water Flood Susceptibility tests at desired temperature and atmospheric pressure for end point values of permeability and saturations in addition to incremental oil recovery versus water cut and injected volumes. Tests are made on fresh or restored cores.

D. Type of Samples:

- (1) Basic Flood (fresh or restored core) - Whole core or cylindrical plugs 1", 1-1/2" or 2" in diameter.

- (2) Water Flood Susceptibility (fresh or restored core)
Same as Basic Flood except 1-1/2" or larger
are preferred.
- (E) Minimum Number of Samples: - Three to five.
- (F) Special Information Needed: - The following data
are needed for fresh, restored plug and whole core
floods. A sample of the crude oil and the composition,
chloride content or resistivity of formation water and
injection water are required. Also required are
formation temperature and temperature of the hot
water flood. Information as to the approximate
height above the oil-water contact of the centroid of
the oil column is helpful in establishing the
magnitude of the connate water on the restored flood
samples.
- (G) Average Minimum Time Required: - Eight weeks.
- (H) Data Reported:
- (1) Basic Flood - Tabular values of porosity, per-
meability, connate water, permeability to oil at
connate water, oil in place, residual oil, oil
recovered, permeability to water at residual oil.
- (2) Water Flood Susceptibility - Incremental oil
recovery versus injected water volumes and
water cut are given in tabular and graphical form
in addition to the data reported for the Basic
Flood.
- (I) Key Equations - Not applicable.

2. Steam Floods

- (A) Use - These test furnish data as to the susceptibility of a formation to steam injection. The laboratory test simulates a frontal drive displacement mechanism and not the "huff and puff" technique where steam is injected into and produced from the same well in cycles.

Oil recovery in a steam flood process results primarily from (1) steam distillation of the crude, (2) thermal expansion of the crude and (3) viscosity reduction. Other less important factors that may have some influence on recovery are gas-drive effects and solvent extraction. The oil properties are of maximum importance in these tests and it is therefore essential that crude oil be used during steam displacement tests.

The Marx and Langenheim equations require residual oil values after steam injection and are often used to calculate thermal invasion rates, heated area and economic limits of steam injection. This equation requires a valid value for residual oil which is furnished in the laboratory steam flood.

(B) Method:

- (1) Extracted cores - Extracted and dried cores are saturated with formation brine. Connate

water is established by centrifuge, capillary pressure cell, dynamic displacement or evaporation. The voided pores are saturated with crude oil. Permeability to oil is determined. Samples are then placed in an air bath and the temperature elevated to that used for steam flooding. This procedure simulates conditions in that portion of the reservoir that has been increased to the steam temperature.

Other variations of this flooding technique may be accomplished by elevating the temperature of the sample only to reservoir temperature and then heating it further by steam injection. This laboratory technique has the disadvantage that in low permeability cores the rate of steam injection through a sample may be so slow that a true steam flood is never reached in the laboratory and at best a hot water flood is performed on the core. In most cases, it is advantageous to raise the temperature of the sample to that of the injected steam prior to or during the actual injection of the steam. After the desired temperature has been reached, steam of approximately 80 per cent quality is injected into the core. Oil recovered and condensed water volumes are monitored.

Flow rates and heat losses cannot be precisely scaled to reservoir conditions and therefore the incremental recovery data are only a qualitative indication of reservoir performance. The final quantitative value of residual oil after steam flooding is

secured by distillation of the tested sample.

- (2) Fresh cores - Plugs drilled from the fresh core are evacuated under oil and then flushed with oil to remove free gas when the oil is available and of low enough viscosity that it can be flowed through the cores. In many cases, this is not feasible because the oil viscosity is so high and/or oil from the formation to be steam flooded is not available. Data reported in the literature indicate that the residual oil after steam flooding is independent of the initial saturation in most cases. This means that floods can be made on samples as recovered from the core barrel. Once the sample has been placed in the steam flood apparatus and brought to temperature, the flooding procedure is the same as discussed under extracted cores above. After flooding, the residual oil content in the test core is determined by distillation. Porosity and permeability of the clean core are determined. Where possible, the saturations present at the start of the flood are computed by material balance. In most cases, an adjacent plug to the steam sample is secured and analyzed to yield water and oil saturations that are assumed to be initially present in the steam flood core. When this is done, it is indicated on the summary data sheet.

Emulsions often form in the produced fluids and it is difficult to separate the produced crude oil from the condensed water. In most cases these emulsions can be broken by the addition of chemicals and/or centrifuging to yield recovery as a function of injected

volumes. Even where this cannot be accomplished, reliable values of the residual oil saturation at the conclusion of the steam flood are obtained by distillation.

- (C) Type of Tests: - Tests are made on fresh or restored cores and are not "huff and puff" but displacement type tests. Water used in forming the steam must be distilled because of equipment limitations. This prohibits addition of chemicals to a furnished field water to evaluate possible damage to the sample from chemical carry over.

The maximum steam temperature that can be sustained for any length of time is 500°F. Steam flood tests often approach one day testing time and difficulty is experienced with the "O" rings and other equipment at temperatures approaching 550°F. In most cases, steam flood tests are limited to approximately 500°F.

- (D) Type of Samples - Cylindrical plugs one and one-half inches in diameter are preferred. Whole core can be tested in some cases but equipment is not designed for delivery of large steam volumes that are typically required for whole core steam floods.
- (E) Minimum Number of Samples - Three to five.
- (F) Special Information Needed: - Similar data is required for fresh, restored, plug and whole core analysis. An actual sample of the crude is required for restored core tests although not needed for fresh core tests.

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

The desired temperature of steam injection must be furnished although the maximum temperature can be estimated from the formation depth. This is accomplished by assuming that the maximum injection pressure is that which will not fracture the formation. This fracture pressure can be estimated by multiplying an overburden pressure gradient of one psi/foot of depth times the depth in feet. The temperature of the steam can then be found from the relationship of steam temperature and pressure corresponding to the calculated fracture pressure.

- (G) Average Minimum Time Required: - Six to eight weeks
- (H) Data Reported: - Incremental oil recovery and water cut versus throughput volumes (condensed water volumes) are given in tabular and graphical form. Tabular values of porosity, permeability, initial water, oil in place, oil recovered and residual oil are presented.
- (I) Key Equations - Not applicable.

3. Steam Soak

- (A) Use - These data are used to evaluate changes in permeability and porosity of cores after exposure to steam vapor for extended periods of time. Chemicals may be added to the system so that their effects on the rock can be evaluated. For example, steam soaking certain formations with ammonia may inhibit clay swelling in some cases and result in better injectivity in the formation.
- (B) Method: - Porosity and air permeability are determined on the clean dry core. The core is then evacuated and pressure saturated with a prescribed

salinity fluid (normally fresh water). Permeability to the saturating fluid is determined. If clays are present, liquid permeability is normally lower than the Klinkenberg corrected air permeability. The core is then placed in a high temperature and pressure autoclave and soaked in steam vapor for one week at temperatures comparable to the proposed steam flood. After removal from the autoclave, porosity and air permeability are remeasured. The sample is again saturated with liquid and its liquid permeability is redetermined.

The soak may then be repeated with a desired chemical. Permeabilities are remeasured and comparison to initial nonchemical values give insight into changes occurring within the sample after exposure to the chemical.

- (C) Type of Tests: - These tests are static soaks of extracted core (no dynamic flow of steam through the core) by steam vapor.

Temperature and pressure restrictions of the equipment are approximately 700°F and 3200 psi, respectively.

- (D) Type of Samples: - This test is limited to one inch, one and one-half inch or two inch diameter cylindrical plugs.

- (E) Minimum Number of Samples: - Three to five.

- (F) Special Information Needed: - Chemicals to be and the soak temperature are required. Any data pertaining to swelling clay are helpful, if available.
- (G) Average Minimum Time Required: - Six weeks
- (H) Data Reported: - Porosity, permeability to air and water prior to and after steam soak are presented.
- (I) Key Equations - Not applicable.

4. Fire Tube

- (A) Use - These tests furnish data required to evaluate the feasibility of the in-situ combustion process as a method of producing crude oil. In essence, the process consist of (1) gas injection to establish permeability to air (2) propagation of the combustion front through the reservoir. These three steps are also accomplished in the laboratory tests.

Primary data required from the laboratory analysis are the pounds of fuel per unit volume of pack consumed during the burn and the standard cubic feet of air required to burn one pound of fuel. The former concerns recovery, since oil burned is unrecoverable, and the latter influences quantity and cost of surface facilities required to inject needed air volumes.

- (B) Method:

- (1) Fresh core - Tests are normally made on fresh core as recovered from the barrel. The rock must be reduced to grain size and packed in the thin walled combustion tube that is approximately five feet in length and two inches

in diameter. This tube is placed within a larger metal cylinder approximately eight inches in diameter. The annulus between the two is packed with insulating material. The outer tube is swiveled in the middle and can be rotated about the axis perpendicular to its length. This allows access to the combustion tube while serving as a holder and blow-out preventer.

A clamp heater is installed on the upper end of the combustion tube to give ignition when a run is started. Nitrogen is injected into the tube to establish permeability to gas and at the start of injection the heater is turned on. When the temperature reaches approximately 450°F, the nitrogen supply is terminated and air is injected. Combustion occurs at this point and the heater is then turned off. Typical combustion temperatures range from 800°F to 1300°F.

A thermocouple well is centered within the small tube and runs its full length. This allows the combustion front to be tracked during the burn. Temperatures are monitored throughout the test and recorded automatically on a strip chart. During the burn, air is injected at a desired flux rate. Pressures on the injection face and downstream end of the tube are monitored. Combustion gases are metered and samples are taken at intervals. These samples are subsequently analyzed by chromatograph.

- (2) Extracted core - Technique for extracted cores is the same as for fresh cores except for sample preparation. See discussion under Type of Samples.

- (C) Type of Tests: - Evaluation is limited to the forward combustion process and the equipment is not suitable for the reverse combustion process.

Initial design of this equipment was for injection of air alone. Some data indicate simultaneous injection of water with air may give better performance and result in less fuel being burned. The modification of the tube could be accomplished to allow water injection if warranted on a particular project.

- (D) Type of Samples - Rock must be reduced to grain size prior to analysis. Rubber sleeve cores are excellent for these tests. Rock used should be from the reservoir being evaluated as grain size, shale and clay content affect fuel consumption. The core may be fresh and burned with saturations found after coring.

An analysis of the sample used in packing the fire tube is made so saturations in the tube prior to burning are known. Very heavy oil (11° to 12° API) with high oil saturations may necessitate having to reduce this saturation prior to burning. Experience indicates the formation of an oil bank in front of the burning front. With very viscous crudes the permeability to air is reduced such that sufficient air to sustain combustion cannot be injected. The fire then smolders and eventually goes out.

In rare cases, the core may be cleaned and then have oil and water added to arrive at desired saturations. These components would be premixed and then tamped into the tube. This process might be required where oil base coring fluids were used that contaminated the fresh samples. This contaminant could be removed

by washing the rock grains with solvent and then re-saturating with a sample of crude oil and water.

Approximately 13 pounds of mix are required for one tube pack. Sufficient core for several tube mixes should be sent to the laboratory in the event that alternates are needed during the testing phase.

Cores taken with oil base fluids are not desirable. Filtrate loss during coring may flush natural hydrocarbons. A fire tube test on contaminated samples would not yield reliable fuel consumption values.

- (E) Minimum Number of Samples: - One
- (F) Special Information Needed - Information on current saturation of oil and water in the reservoir is desired as well as the reservoir porosity. If swelling clays are known to be present, this information is helpful.
- (G) Average Minimum Time Required: - Five weeks.
- (H) Data Reported: Composition of the effluent combustion gas, in terms of carbon monoxide, carbon dioxide, oxygen and trace hydrocarbons, pounds of fuel burned per unit volume of sand pack, standard cubic feet of air required to burn a pound of fuel, gravity of the produced oil, pH of the produced water, pack porosity, oil and water saturations prior to burning, temperature at the combustion front and air flux rate.
- (I) Key Equations - Equations for laboratory calculations and application of Fire Tube data to reservoir evaluation are presented in Producers Monthly of May, 1961 in an article entitled "How to Engineer an In-Situ Combustion Project" by T. W. Nelson and J. S. McNeil of Socony Mobil Oil Company.

5. Steam Distillation of Crude

- (A) Use - These data assist in evaluating the additional oil recovery in a steam injection project by the single recovery mechanism of steam distillation of the crude. It may also give insight into the texture of the heavy crude remaining after the light ends are removed during steam distillation. This has proven important in some cases where the heavy material remaining after steam flooding would not flow and caused partial plugging of the formation.
- (B) Method: - A known volume of stock tank oil is placed in a pressure vessel and steam is bubbled through the oil. The light hydrocarbons are removed during this steam distillation process. Hydrocarbons remaining after steam distillation are determined.
- (C) Type of Test - Only one type of test described above is available with temperature limited to approximately 700°F. Demand for this service has been low for the past several years and the equipment has consequently been disassembled.
- (D) Type of Sample: - Approximately 400 cubic centimeters of crude oil are required.
- (E) Minimum Number of Samples: - One.
- (F) Special Information Needed: - The temperature of the steam distillation is required.
- (G) Average Minimum Time Required: - Four weeks.
- (H) Data Reported: - The volume recovered by steam

distillation as per cent of initial charge and gravity of the residual crude are given

(1) Key Equations - Not applicable.

K. Caprock Analysis

1. Use - The development of gas storage reservoirs requires information on both the caprock overlying the storage zone and the properties of the storage zone itself. Where depleted reservoirs are used for gas storage, data on the caprock are often not required as the caprock ability to hold fluids has been proven. Where aquifers are to be used as storage projects this confidence does not exist and matrix permeability to water and threshold permeability in the range of 1×10^{-6} millidarcys. In addition, the pressure (threshold pressure) at which gas will first penetrate into a sample containing 100 per cent water should approach or exceed 1000 psi.

As the gas bubble forms in the aquifer it displaces water. At the top of the storage zone, gas is prevented from escaping by the overlying water saturated caprock. The pressure in the gas bubble increases as it grows and it is pressured by injected gas. It is the ability of the matrix caprock to prevent the non-wetting phase (gas) from entering and hence escaping vertically that is tested in the laboratory threshold pressure test.

The tests discussed herein define matrix properties of the caprock. Geologic features such as faulting or fracturing near the crest of the structure may void a storage reservoir prospect that has excellent matrix properties.

The required analysis of the gas storage zone may be made with a variety of tests normally used for gas or oil reservoir evaluation.

(2) Method:

- A. Permeability (down to 1.0×10^{-6} md) - Samples should be 100 percent water saturated for this test. If drying has occurred during shipment to the laboratory the cores are placed under water and evacuated to resaturate the voided pore spaces.

The sample is placed in a triaxial core holder and subjected to a squeeze pressure equal to 1500 psi. Water comparable to that found in the underlying storage zone is flowed through the core until equilibrium flow is obtained. Testing and adjusting may take several hours to a day or longer since the rock tends to compress under the overburden pressure and must stabilize before permeability can be determined. Fluid flow through the core is monitored on a pipette.

- B. Threshold (entry) pressure - The liquid source for permeability measurement is removed and gas is introduced on the face of the sample. Gas flow into the core is attempted at increasing pressure levels. Flow from the core is again monitored by pipette. The pressure at which gas first penetrates the largest pores is designated as the threshold pressure and is accompanied by an appreciable increase in flow rate from the core.

- (3) Type of Tests - Permeability and threshold pressure tests may be determined independently, but a proper analysis requires both. Flow is down the vertical axis of whole core and plugs are drilled vertically for these tests.

(4) Type of Samples

- A. Permeability (down to 1.0×10^{-6} md) - Full diameter

core is preferred although a plug type analysis will yield reliable data in homogeneous caprock. Plugs are usually restricted to 2" diameter samples drilled in a vertical direction from the whole core.

B. Threshold (entry) pressure - Same as permeability samples.

5. Minimum Number of Samples

A. Permeability (down to 1.0×10^{-6} md) - One sample per foot or more is required if whole core has broken at lithologic changes.

B. Threshold (entry) pressure - Same as permeability.

6. Special Information Needed:

A. Permeability (down to 1.0×10^{-6} md) - Water from storage zone beneath caprock, analysis of this water or salinity.

B. Threshold (entry) pressure - No special data needed.

7. Average Minimum Time Required:

A. Permeability (down to 1.0×10^{-6} md) - Depends on availability of whole core holders also used for waterflood and the number of samples to be tested. Normal for 20 feet of core - 8 weeks.

B. Threshold (entry) pressure - For 20 feet of core - 8 weeks.

8. Data Reported:

- A. Permeability - Sample permeability in millidarcys is given.
- B. Threshold (entry) pressure - Pressure at which gas enters the core is given. If no penetration of gas has occurred at pressures of 1000 psi the test is terminated and data presented states threshold pressure is greater than 1000 psi.

9. Key Equations: - Not applicable.

L. Rock Compressibility

1. Use: - These data are used to compute the reduction in pore volume that occurs within the pore space of the reservoir during pressure depletion. This pore reduction is the result of a change in balance between the overburden pressure (caused by weight of the overlying sediments) and the internal reservoir pressure normally established by hydrostatic gradient. The pressure difference between overburden and internal pore pressure is referred to as "effective overburden" or "frame" pressure.

During pressure depletion operations the internal pressure of the reservoir drops. Since overburden pressure remains constant the frame pressure is increased. The effect of increasing frame pressure is to reduce the bulk volume of the reservoir while at the same time the sand grains within the pore spaces expand because of the internal pressure drop. These two volume changes tend to reduce the pore space and hence the porosity of the rock.

Often these data trend both with porosity and the frame pressure existing on the system. Compressibility typically decreases as porosity increases, and also decreases as frame pressure increases. Typical values of rock compressibility range from 3×10^{-6} to 25×10^{-6} pore volume/pore volume/psi. This means that for each million barrels of pore space a reduction of 3 to 25 barrels would occur for each psi of reservoir pressure drop.

Although these values are small they become important in reservoirs that are undersaturated when calculations are made to define oil-in-place or aquifer constants that will be used to predict future pressure performance. The sum of the rock compressibility and of the water compressibility can be as great as the oil compressibility and of the water compressibility can be as great as the oil compressibility and ignoring of the rock and water compressibility data will yield optimistic values for oil-in-place and aquifer strength. Inclusion of this compressibility data is especially important during the early life of a field when little history exists and the match of the past performance of the reservoir is based on limited history.

2. Method:

- (A) Hydraulic Loading of Core Sample - Hydraulic loading (pressure applied equally on all sides and ends) is easily accomplished in the laboratory, but for a given frame pressure it results in greater rock compressibility than in the reservoir. Laboratory data must be reduced in magnitude prior to application. (See Key Equations).

Extracted and dried samples are jacketed with heat shrinkable plastic tubing that conforms to the cylindrical surface and overlaps attached end-butts. The jacketed sample is placed in a core holder, and hydraulic pressure of 200 psi is applied. Pore volume is measured by helium injection.

The sample is evacuated and saturated with water while maintained under 200 psi hydraulic pressure. It is connected to a water filled high-pressure

pipette graduated in 0.001 cc divisions. A mercury slug is placed in the pipette to assist in monitoring the pore volume changes during the test. The system is placed in an air bath maintained at a constant temperature of 90°F. After stabilized conditions of pressure and temperature are reached at the effective overburden pressure of 200 psi, the position of the mercury slug is noted. The external and internal pressures are then elevated to the levels specified, and movement of the mercury is recorded.

Pore volume at each effective overburden pressure is determined by applying the corrected incremental pore volume change to the reference pore volume. Pore compressibilities are calculated by graphically differentiating the plot of pore volume versus effective overburden pressure.

- (1) Technique One - External confining pressure is raised to a value equal in magnitude to the reservoir depth times 1 psi per foot. Internal pore pressure is maintained at 200 psi less than external as the latter is increased. After obtaining maximum pressures, internal pressure is dropped to a selected value. The change in pore volume results in water movement from the core which is monitored on a micropipette. Water expansibility within the pore spaces is accounted for.
- (2) Technique Two - Internal pressure is elevated to approximately 200 psi with external pressure increased to approximately 400 psi. The external pressure is raised to selected values, with internal pressure remaining constant at 200 psi. Reduction in pore volume is indicated by water movement from the pore space which is monitored on a micropipette. Water expansibility is not a factor as internal pressure remains constant.

- (3) Technique Three - Techniques above apply to consolidated sandstones and carbonates. Cores so poorly consolidated that they have been mounted in thin-walled metal sleeves are tested with a less complicated procedure in which the external pressure is varied while the internal pressure is maintained at atmospheric conditions.
- (B) Uniaxial Loading of Core Sample - Uniaxial loading is accomplished by maintaining a constant cross-sectional area of the core and allowing only vertical deformation due to end loading. Vertical deformation is measured by dial indicator. These boundary conditions are more representative of those in the reservoir and do not require data conversion. Samples contain air in the pore space so water expansibility presents no problems. Temperature is at ambient conditions. Pore volume at each effective overburden pressure is determined by applying the corrected incremental change to the reference pore volume. Pore compressibilities are calculated by graphically differentiating the plot of pore volume versus effective overburden pressure.

3. Type of Tests:

- (A) Single frame pressure - Compressibility is calculated at a single effective overburden (frame) pressure. This case is applicable for gas storage reservoirs where pressure within the formation is expected to fluctuate only within several hundred pounds.
- (B) At three or more frame pressures - In this test compressibility is evaluated at three or more frame pressures so that the trend with net overburden pressure

can be established. This is applicable to those conditions where internal reservoir pressure continues to decline during the production history and the frame pressure continually increases. In many cases internal pressure may drop several thousand psi. Since compressibility varies as a function of frame pressure, a single value will not adequately define rock compressibility when operating conditions show such a wide variance in pressure change.

4. Type of Samples: - One and one-half inch diameter cylindrical plugs are recommended for the hydraulic loading technique. One inch samples may suffice in hard, nonvuggy rocks and are required for the uniaxial loading system. Samples must be extracted prior to analysis. Pressure limitations are approximately 10,000 psi for uniaxial loading, and 10,000 psi overburden and 9,000 psi pore pressure for hydraulic loading.
5. Minimum Number of Samples Recommended: - Three to eight samples are needed so as to cover the porosity range exhibited.
6. Special Information Needed: - Data required are depth of the formation and the internal reservoir pressure. Information as to expected pressure drops to be encountered during the production history of the reservoir are helpful in designing the test program. Salinity of the formation brine is also helpful. The laboratory tests normally require saturation of the samples with a fresh to low salinity brine. This is an adequate procedure in essentially all cases but information on formation water is desirable.

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

7. Average Minimum Time Required: - Four to eight weeks depending upon the type and number of cores tested.
8. Data Reported: - Pore volume compressibilities, pore volume, bulk volume and porosity at various effective overburden pressures are reported in tabular form. Converted (reduced) compressibilities to reflect boundary conditions are also reported when the hydraulic loading technique has been used.
9. Key Equations: - Conversion of hydraulic load data to uniaxial loading is presented in the paper "Prediction of Formation Compaction from Laboratory Compressibility Data" by D. Teeuw, Society of Petroleum Engineers Journal, 1971, Volume XI, No. 3, pages 263-271.

M. WETTABILITY STUDIES

1. Use: - Wettability studies give an indication of the reservoir rock wettability at the time of test in the laboratory. This indication may or may not be representative of actual reservoir wettability. Special precautions must be observed during both the coring and transporting of the rock to optimize the chance of securing a reliable rock sample that will yield true reservoir wettability. The latter is what is desired in most tests of this nature.

Oil-wet rocks are often characterized by low connate water and poor water displacement. The normal capillary forces that attract water into small pores to displace oil are not operative in water flood of an oil-wet reservoir and the water tends to sweep the large pores first. High water cut may be experienced with low oil recovery. This means that oil-wet reservoirs are often poor prospects for water flood and this latter consideration is one factor that makes determination of wettability important.

A complex relationship exists between minerals comprising the rock, the oil composition and coring fluid additives. These common additives often reverse rock wettability in certain rock and fluid systems. Tests on rock of this altered wettability will yield performance non-representative of the reservoir. Use of water with no surface active additives or reservoir oil that has never been exposed to oxygen may yield a practical solution to the coring fluid.

Exposure of the core to air may cause a reversal in wettability, but more often has a less drastic effect that moves the rock surfaces from a strong water-wet condition to a neutral wettability. To circumvent this the cores should be plunged under de-gassed water immediately after removal from the core barrel. Another technique is to select samples, quickly wrap them in Saran and several layers of aluminum foil and wax them at the well site. This will assure their proper protection until received in the laboratory.

2. Method:

- (A) Imbibition at room conditions - A sample is drilled from the core using water as the lubricant. The core is then evacuated under water to reduce gas and flushed with water to residual oil. The plug is placed under oil processed to remove surface active agents and imbibition of the oil is monitored. Water displaced during imbibition is measured and is equal to oil imbibed.

After equilibrium has been obtained, which may take several weeks in low permeability core and is indicated by no further water displacement, the plug is flushed with oil to reduce the remaining water to an irreducible value. The sample is then placed under water and water imbibition is monitored by observing oil displaced. The fluid that imbibes into the sample is the wetting phase. At equilibrium conditions the core is removed and cleaned. Its porosity and permeability are determined.

In some cases two adjacent plugs are drilled and tested simultaneously. One prepared plug is placed under water and the second is placed under oil. This reduces total time of testing but requires additional core and offers the disadvantage the both oil and water wettability are not checked on the same piece of rock.

- (B) Imbibition at reservoir conditions - This test is requested on only rare occasions and varies widely depending on reservoir rock fluids and conditions. Test procedures must be designed for each situation. The following is presented as only a guide to procedure. Normally a cylindrical plug will be drilled from the preserved core using water as the lubricant. It will be evacuated under water and then flushed with oil to irreducible water. It is then placed in a special test apparatus that is brought to reservoir conditions of temperature and pressure. Live reservoir fluid (preferable a bottom hole sample) is used to fill the pore spaces not occupied by water. Water is then introduced to the face of the sample under a zero-to very slight pressure head and the volume of water imbibed into the core is monitored. This test is extremely complicated and the final technique selected will depend on the actual test conditions and fluid.
- (C) Other Methods - A simple drop test is often made as a check of wettability. This can be very misleading and is a qualitative measurement only. Drops of oil and water are placed on a fresh broken surface of the core. The fluid that is imbibed is a wetting

phase while the fluid that rolls off or forms a ball that does not wet the surface is the non-wetting phase. Drop test data that conflict with submersion imbibition test data may be obtained. When this occurs, the drop test data are believed invalid.

3. Type of Tests:

- (A) Imbibition type at room and reservoir conditions.
- (B) Drop tests on fresh broken surfaces of the core.

4. Type of Samples:

- (A) Imbibition tests at room and reservoir conditions can best be made on cylindrical plugs 1, or 1-1/2 inches in diameter. It is possible to make room condition imbibition tests on irregular shaped samples although this prohibits flushing of the cores as described above.
- (B) Drop tests require only enough rock to give a fresh break and adequate surface for drops of fluid.

5. Minimum Number of Samples:

- (A) Three to five samples for imbibition tests and these should cover lithology and depth interval as oil may vary with depth in reservoirs of large closure.
- (B) Drop tests should also cover lithology and depth.

6. Special Information Needed:

- (A) Imbibition tests at room conditions - No special information required.
- (B) Imbibition tests at reservoir conditions - Require

reservoir fluids, temperature and pressure
of reservoir.

(C) Drop tests - No special information required.

7. Average Minimum Time Required:

- (A) Imbibition at room condition - 6 - 8 weeks.
- (B) Imbibition at reservoir conditions - 8-10 weeks.
- (C) Drop tests - 1 week.

8. Data Reported:

- (A) Imbibition at room conditions - Total oil and total water imbibed as per cent of pore volume.
- (B) Imbibition at reservoir conditions - Fluid imbibed and other pertinent information will be furnished.
- (C) Drop tests - Fluids imbibed will be noted as well as others observations made during the test.

9. Key Equations - Not applicable.

N. ACOUSTIC VELOCITY

1. Use - These tests evaluate the relationship between porosity and acoustic velocity and thereby refine porosity values calculated from the down hole acoustic logging tool. Literature relationships presented for limestone and sandstones are average or representative values for these types of formation. In many cases a formation has a porosity-velocity relationship that varies from these average values. In some cases no correlation of acoustic velocity and porosity exists. Tests should be run to verify and/or replace literature average relationships.
2. Method: Direct measurement of acoustic travel time under overburden conditions through a vertical sample completely (or partially if desired) saturated with brine (or light oil). Samples should be saturated - even for cores from gas wells as the saturated condition approaches closely the condition in the vicinity of the bore hole.
3. Type of Tests - Acoustic tests are made under conditions of confining pressure. Tests have shown that the pressure difference between overburden pressure and fluid pore pressure is the pressure that controls acoustic velocity. Tests at various confining pressures are made to define the curve of acoustic velocity versus confining pressure. Maximum pressure used is equal to $1/2$ the depth. Equipment limitations are approximately 8000 psi for plugs and 20,000 psi for whole core tests.
4. Type of Samples - One inch diameter cylindrical plugs or selected whole core sizes. All tests samples should be vertical to simulate the down hole tool performance and

properly account for shale and/or other laminations.

5. Minimum Number of Samples Recommended: - Ten.
6. Special Information Needed: - Formation water sample, analysis, resistivity or chloride content. Depth of formation and current reservoir pressure.
7. Average minimum Time Required: - Six weeks
8. Data Reported: - Tabular presentation of acoustic velocity versus confining (net overburden) pressure for each sample. Composite plot of transit time versus porosity for all samples at one selected overburden pressure.
9. Key Equations: -
$$\frac{1}{V} = \frac{f}{V_L} + \frac{1-f}{V_m}$$

V = Velocity in saturated porous medium
(measured in laboratory)

f = Porosity, fractional

V_L = Velocity in liquid in pores

V_m = Velocity in matrix rock

0. SURFACE AND INTERFACIAL TENSION

1. Use:

Surface tension and interfacial tension data assist in understanding the recovery mechanism of additives that change rock wettability or alter fluid interfacial tensions. An example is caustic flooding where interfacial tension can be dropped to zero with greatly increased oil recovery in some oil-water systems. The amount of caustic required to yield this interfacial tension reduction can be found by interfacial tension measurements on solutions of various strength.

2. Method:

(A) Surface tension (atmospheric pressure only)

- (1) Room temperature-The fluid to be tested is placed in a clean dry beaker. A platinum ring is lowered into the fluid. It is then slowly raised and a DuNouy Tensiometer is used to determine the force required to break the ring free from the surface of the liquid.
- (2) Elevated Temperature - The same procedure is followed as for the room condition test except that the temperature of the fluid is elevated to the desired value prior to determination of surface tension.

(B) Interfacial tension (atmospheric pressure only)

- (1) Room temperature - The more dense of the two fluids to be tested is placed in a clean dry beaker. A platinum ring is lowered into the fluid. The second fluid is then poured over the first. The ring is slowly raised and a

DuNouy Tensiometer is used to measure the force required to pull the ring through the interface of the two fluids.

- (2) Elevated temperature - The same technique is used except temperature of the fluids is elevated to the desired value.

3. Type of Tests: - Not applicable.

4. Type of Samples:

(A) Surface Tension

Oil samples not contaminated by emulsion breakers or other additives and that have had a minimum exposure to oxygen are required. Water samples should be from a clean sampling point and free from chemical contaminants. Pit samples are not satisfactory.

(B) Interfacial Tensions - Same as Surface Tension

5. Minimum Number of Samples:

(A) Surface Tension

One test per fluid investigated per chemical additive is required.

(B) Interfacial Tension

One per set of fluids per additive if applicable.

DuNouy Tensiometer is used to measure the force required to pull the ring through the interface of the two fluids.

- (2) Elevated temperature - The same technique is used except temperature of the fluids is elevated to the desired value.

3. Type of Tests: - Not applicable

4. Type of Samples:

(A) Surface Tension

Oil samples not contaminated by emulsion breakers or other additives and that have had a minimum exposure to oxygen are required. Water samples should be from a clean sampling point and free from chemical contaminants. Pit samples are not satisfactory.

(B) Interfacial Tensions - Same as Surface Tension

5. Minimum Number of Samples:

(A) Surface Tension

One test per fluid investigated per chemical additive is required.

(B) Interfacial Tension

One per set of fluids per additive if applicable.

6. Special Information:

(A) Surface Tension - Temperature required if tests at elevated temperature.

(B) Interfacial Tension - Same as Surface Tension

7. Average Minimum Time Required:

(A) Surface Tension - One week

(B) Interfacial Tension - One week

8. Data Reported:

(A) Surface Tension - Value in dynes/centimeter.

(B) Interfacial Tension - Value in dynes/centimeter.

9. Key Equations: - Not applicable

P. SIEVE ANALYSIS

1. Use:

Sieve analysis data yield grain size distribution and can be used to gain insight into transportation prior to deposition. It is also used to assist in screen or slotted liner selection when completing poorly consolidated formations. The grain size found at the cumulative ten percentile point is normally used as the screen size.

2. Method:

A clean dry sample is reduced to grain size. This measurement should be restricted to friable cores since breaking up of hard formations may cause fines and/or larger pieces that do not represent a true grain size. The grains are then placed on the topmost (largest mesh) of a nest of screens. The screens are vibrated and the grains pass through the screen nests until they are caught on a mesh size slightly smaller than the grain. Grains that collect on each screen are weighed. The smallest size screen used is usually 350 mesh.

3. Type of Tests: - Not applicable

4. Type of Samples:

Normally restricted to friable sandstones. Fifty to 100 grams desirable.

5. Minimum Number of Samples:

This test may require one sample per foot or one per lithologic change depending upon the use. Samples should cover the cored interval.

6. Special Information: - Not required

7. Average Minimum Time:

One to two weeks

8. Data Reported:

Graphical and tabular data showing cumulative per cent of sample (by weight) for various grain (screen) sizes. A medium grain diameter is given as well as a calculated sorting coefficient.

9. Key Equations:

Sorting Coefficient = $\frac{A}{B}$ where A equals grain diameter @ 25 percentile and B equals grain diameter @ 75 percentile.

Company _____ Formation _____
Well _____ County _____
Field _____ State _____

Q. SAMPLE PREPARATION AND SELECTION

1. Use:

Testing of unconsolidated cores and heterogeneous carbonates now comprise a large segment of Special Core Analysis studies. These rock types require greater time and care for sample preparation than previously required for consolidated sandstones. A portion of the increased cost is passed on to the study that requires special techniques.

2. Methods and Types of Samples:

(A) Air permeability and porosity on cores prepared but not selected for further special tests.

(1) Overburden tests - In many cases a suite of samples of designated permeability and/or porosity are required to fit a statistical grouping made from the routine core analysis data. After samples have been prepared and permeability and porosity have been determined, certain samples that fit the permeability range are selected for further tests. In most cases no porosity or permeability charge is made if a single overburden pressure has been designated and the samples are selected for further tests. A charge is made for permeability and porosity measurement on those samples that do not fit the permeability or porosity range and consequently are not selected for additional testing.

(2) Room condition tests - As above, samples of designated permeability and/or porosity are often requested. When plug tests are made on core that has been analyzed by whole-core techniques many samples are often drilled to find a few of specified permeability. No charge for permeability or porosity is made for cores that fit the desired permeability and porosity range and are selected for special tests. Charges are made for prepared plugs that do not fit the requested ranges and are not needed further. A single page listing porosities and permeabilities of samples that were prepared but not selected will be given in a report.

(B) Mounting (friable or vuggy cores)

(1) Plug size cores

a. Metal jackets and screens are used to mount unconsolidated core. A hollow punch is inserted into a window cut in the rubber sleeve. When the punch is withdrawn a sample is trapped in the punch. This sample is then ejected from the punch by a plunger and forced into the metal jacket. Screens are placed over the ends of the sample and held in place by folding the thin lip of the jacket over the screen edge. These samples are subsequently squeezed under simulated overburden pressure to seat the jacket to

the sample. The cores are then cleaned and dried. Pore volume is measured by helium injection. Grain volume is measured in a matrix cup. Corrections are made to the measured pore volume by subtracting pore space in each screen. Corrections are made in grain volume calculations by subtracting the volume of the metal sleeve and the metal in the end screens. Bulk volume equals corrected pore volume plus corrected grain volume. Corrections in length are made for the screen and lip thickness of the metal jacket. Area is calculated by dividing bulk by length.

- b. Consolidated but friable plugs are often mounted in plastic. One inch or 1-1/4 inch cores are cast up to 1-1/2 inch diameter in epoxy mounting. Grain loss is minimized by this process. In preparation for mounting, cores are cleaned and dried and each core has its bulk volume and pore volume determined. Its length is also measured. The core is then placed on a clay base within a teflon mold. Epoxy is poured around the core. When the epoxy has set the core is removed and the ends are trimmed to remove any plastic and/or clay. Pore volume and length are again measured. It is assumed that porosity is the same in the trimmed core as was found originally. A new bulk volume is then calculated from the new pore

volume and from this and knowledge of the length an effective cross sectional area can be determined for flow tests.

(2) Whole Core

Whole core has often been slabbed prior to arrival and requires mounting to give a cylindrical shape suitable for testing. Vuggy cores must also be mounted. In some cases fiber glass is first bonded around the core to cover but not fill the vugs. The sample is then cast in epoxy to a larger cylindrical size. The plastic must be thick enough to prevent pressure imposed on the boot (to hold the core during testing) from breaking the plastic and flowing into the vugs. When this occurs the boot punctures and the test is ruined.

Mounting of whole cores in plastic is not an easy process. In many cases the thermal expansion of the plastic and of the rock is sufficiently different so that the sample and/or its mount pull apart during the heat curing process that is required. Cores that have been mounted also present problems in cleaning. Most cleaning processes work most efficiently when the entire circumference of the core is available for penetration by solvent. The impervious sheet surrounding the sample adds additional time to cleaning procedures.

(C) Special Handling Required Because of Rock Type or Texture

Special procedures such as hand shaping of plugs that are too friable to drill with water, oil or air, require excessive time and a premium is charged for this and other similar services. In those cases

where liquid nitrogen is required to drill plugs in a frozen state the cost of the nitrogen is charged to the study.

Rubber sleeve cores also pose special problems. When an analysis is made of this unconsolidated material a window is first cut into the sleeve and samples are extracted for permeability and porosity determination. If additional tests are being made on these cores, each window that has been cut into the sleeve must be taped to preserve the core. This is time consuming and in some cases additional charges are made to cover the cost of this extra handling. Use of windows to select samples is not a good process. In many of the reservoirs from which poorly consolidated sands come lithology varies within small intervals. If one only has a small window to observe the core these changes will not be noted. A much better process is to split the rubber sleeve such that the full core is revealed. In this manner representative samples can be secured. This presents problems, however, with unconsolidated rock which falls apart when the sleeve is split. Special waxing procedures must sometimes be employed and in many cases the rubber sleeve has been cast in a wooden box in wax, cut open, and samples removed. The cut portion is taped closed and wax is again used to seal the box. This is an excellent way to store the cores for a long period of time but is expensive and time consuming. In other cases samples must be pulled, wrapped in saran and aluminum foil and waxed.

R. PETROGRAPHIC STUDIES

1. Use:

Both mineral description of samples and diagenesis study require that thin sections of samples be made and studied under a petrographic microscope. The minerals present in the rock are identified and the texture of the sample is studied. The degree of rounding and sorting of the grains as well as the grain and pore sizes can give clues as to the depositional characteristics and also yield supporting data as to why permeability is reduced in water sensitive rock.

A diagenesis study includes a discussion of the changes in composition and texture that occur in a rock sample at relatively low temperatures after deposition has occurred. This study yields insight as to the type of environment in which the sediment was deposited and on the order of accumulation of minerals present in the sample. Examination of metamorphic rock for example, may reveal that the change in rock character was due to high pressures after deposition and not due to temperatures associated with an igneous mass. The latter of course would indicate that a well was near base rock and would have little chance of encountering a hydrocarbon pay.

2. Method:

Thin sections are made on each sample of rock to be analyzed and studied under a petrographic microscope. Optical techniques are available for identification of various minerals.

3. Type of Tests:

Mineral descriptions and diagenesis studies may be done independently of each other.

4. Type of Samples:

Representative samples should be secured for each foot of rock to be analyzed. Unlike other tests, a regular shaped plug is not required. Tests may be made on an irregular shaped sample although it is desirable to have the piece large enough so that the core may be oriented as it was in the reservoir. For example, thin sections can be made in both a horizontal and vertical plane and this difference in orientation could be very important in some cases. A 1" x 1" piece of rock would normally suffice for a test sample.

5. Minimum Number of Samples:

Rock character often changes with depth as varying depositional environment may have occurred during the time the sediments were deposited. For this reason samples should be taken throughout the vertical interval for these tests. A detailed study might require one sample per foot or in other cases one every ten feet might be adequate. The data have very little value unless sufficient samples are taken to establish a trend in changes that are occurring in the rock matrix.

6. Special Information Needed:

Orientation of the sample sent as to its horizontal and vertical position in the reservoir is required. Any supplementary information concerning possible injection problems or plugging of wells or other data that would indicate the presence of specific minerals expected would be helpful.

7. Average Minimum Time Required:

Time to make this study is a direct function of the number of samples to be tested. Thin sections can normally be made within a week. After a trend in any mineral changes occurring is established a minimum of two cores a day can be studied.

8. Data Reported:

- (A) Mineral description - The per cent and identification of minerals including cementing material is given. Textural properties of clastic samples such as estimated porosity, median grain diameter, degree of rounding and sorting, and other textural properties observed are presented. For chemical, biochemical, and biogenic rocks, a per cent estimate of porosity and the insitu characteristics of the rock as well as characteristics resulting from transportation are presented.

(B) Diagenesis - Data include a discussion of the type of environment into which the sediment was deposited, the order of accumulation of minerals present including order of cement, and discussion of the alteration processes to which the sample was exposed after deposition.

9. Key Equations: - Not applicable

S. DETERMINATION OF HYDRATABLE CLAY CONTENT

1. Use:

The primary value of these tests is the detection of water sensitive rock in petroleum reservoirs. These tests may also be used to supplement liquid permeability measurements where sensitivity has been indicated. Total swelling clay minerals can be separated and a quantitative measurement of weight per cent of the total clay can be determined. In addition, this total clay can be broken down into weight per cent of slightly swelling clays such as calcium-montmorillonite and highly swelling clay minerals such as sodium-montmorillonite. The actual clay type is not identified as to calcium or sodium but only as slightly swelling or highly swelling.

2. Method:

The test procedure is a centrifuge separation based on the hydrated grain densities of the swelling clay minerals. The samples to be tested are cleaned of all hydrocarbons and organic residues. The cores are dried at low temperature and then pulverized to separate the clay coatings from the sand grains. The samples are again dried and then treated with silicone to make the grains slightly oil wet and yet not impair water vapor transmission. The treated rock is then mixed with water which causes the swelling clay particles to expand. This in turn lowers their densities. Calcium-Montmorillonite and other slightly swelling clays have a grain density of less than 1.85 gms/cc and sodium-montmorillonite has a hydrated grain density of less

than 1.59 gms/cc. All non-swelling, water-insoluble minerals have grain densities of 1.9 or greater. It is this fact that makes it practical to separate the rock samples as to their swelling characteristics.

The rock-water slurry is centrifuged over a non-water miscible heavy liquid of selected density while stirring the mixture. This keeps the grains dispersed and allows individual sample grains to segregate by density difference. The hydrated clays remain in the water above the interface and these are decanted and dried to a constant weight. The swelling clay fraction is then calculated as a per cent of sample dry weight.

3. Type of Tests:

(A) Total swelling clay - Includes all swelling clay minerals.

(B) Highly swelling clay - An additional test is required to differentiate between total swelling clays and highly swelling clays. In some cases it is desirable to know the per cent of highly swelling clays as small volumes of these minerals can cause rather dramatic water sensitivity and permeability reduction problems. In some cases, small quantities of highly swelling materials in conjunction with large quantities of slightly swelling materials causes excessive permeability damage. The relationship of the highly and slightly swelling clays is very complex.

4. Type of Samples:

Irregular shaped samples can be used for these tests. The amount of sample required is roughly based on the per cent of swelling clay. In all cases 50 gms of sample will be adequate. This amount is required when small percentages of clay are present. When the clay content approaches 5 to 20 per cent only 5 gms of material are required.

5. Minimum Number of Samples:

Minimum of four to six samples should be tested for any given reservoir. If lithology changes greatly over the production interval, additional samples are required. Since clay content often varies with depth within a given formation, it is advantageous to select samples to cover the depth interval. Unless the minimum four samples are available, this analysis is not performed.

6. Special Information Needed: - None

7. Average Minimum Time Required:

This test requires the use of a centrifuge and the time to perform this type of analysis is therefore dependent upon the availability of the centrifugal equipment. Total time to complete and report the data is estimated at 4 weeks.

8. Data Reported:

- (A) Total swelling clay content as a per cent of dry weight of the core.

(B) Highly swelling clay content as a per cent of the dry weight of the core is given for this test. When both total and highly swelling clays are requested, the difference, which is equal to the slightly swelling clays, is also reported.

9. Key Equations - Not applicable

T. PICTURES

1. Use:

Color pictures furnish a permanent record of the test samples and in many cases aid in understanding test results when the actual rock is not available for study. They are of particular value in carbonates where vugs may dominate flow characteristics.

2. Method:

Color pictures are taken with a split frame camera so that two images (typically an end view and a side view) of the core are presented on a single print. These can be mounted in the back of the Special Core Analysis report. The size of the print (3-1/2" x 5") allows two prints to be placed on a single report page.

3. Type of Tests: - Not applicable

4. Type of Samples:

Whole core or permeability size plugs used in tests. Pictures have generally been restricted to whole core carbonate samples.

5. Minimum Number of Samples: - Not applicable

6. Special Information Needed: - Not applicable

7. Average Minimum Time Required:

Four weeks

8. Data Reported: - Not applicable

9. Key Equations: - Not applicable

U. PRODUCTION RESEARCH

Some labs offer fee cost facilities which are available to perform semi-research work on a variety of flow problems. These include evaluation of sodium hydroxide (caustic) floods, carbonated water, surfactants, polymers and other water flood or work-over additives.

Tests can be made under simulated conditions or reservoir temperature and pressure using live reservoir oil. The methods used will depend on the evaluation requested.

When possible, cost estimates are made by following quoted prices for more routine type studies to which a fee is added for unusual procedures, time factors or other precautions demanded for proper handling of the material. In other cases, a per hour or per diem rate may be quoted.

V. REFERENCES

1. Murphy, R.P. and Owens, W.W.: "The Use of Special Coring and Logging Procedures for Defining Reservoir Residual Oil Saturations," SPE Paper 3793, Improved Oil Recovery Conference, April 16, 1972, Tulsa, Oklahoma
2. Dalton, R.L., Deans, H.A., Shallenberger, L.K., and Tomich, J.F.: "Single-Well Tracer Method to Measure Residual Oil Saturations," SPE Paper 3792, Improved Oil Recovery Conference, April 16, 1972, Tulsa, Oklahoma.
3. Muskat, M.: Physical Principles of Oil Production, McGraw-Hill, (1949), 158-160.
4. Sewell, Ben W.: "The Carter Pressure Core Barrel," API Drilling & Production Practices (1939).
5. Mullane, J.J.: "Pressure Core Barrel," API Drilling & Production Practices (1941).
6. Hagedorn, A.R. and Blackwell, R.J.: "Summary of Experience with Pressure Coring," SPE Paper 2962, presented at 47th Annual Fall Meeting SPE-AIME, October 8-11, 1972, San Antonio, Texas.
7. Loomis Hydraulic Testing Company, P.O. Box 6408, Pasadena, Texas 77506.
8. Bobek, J.E., Mattax, C.C., and Denekas, M.O.: "Reservoir Rock Wettability -- Its Significance and Evaluation," J. Pet. Tech. (1958) No. 213, 213.

9. McCaffery, F.G.: "The Measurement of Interfacial Tensions and Contact Angles at High Temperature and Pressure," J. Can. Pet. Tech. (1972) 11, No. 3, 26.
10. Colpitts, G.P. and Hunter, D.E.: "Laboratory Displacement of Oil by Water Under Simulated Reservoir Conditions," J. Can. Pet. Tech. (1964) 3, No. 2, 66.
11. Odeh, A.S. and Cook, E.L.: "Discussion - Effect of Temperature on Waterflooding," J. Can. Pet. Tech. (1965) 4, No. 4, 242.
12. Edmondson, T.A.: "Effect of Temperature on Waterflooding," J. Can. Pet. Tech. (1965) 4, No. 4, 236.
13. Davidson, L.B.: "The Effect of Temperature on the Relative Permeability Ratio of Different Fluid Pairs in Two Phase Systems," J. Pet. Tech. (1969) No. 8, 1037.
14. Poston, S.W., Ysrael, S., Hossain, A.K.M.S., Montgomery, D. F., and Ramey, H.J., Jr.: "The Effect of Temperature on Relative Permeability of Unconsolidated Sands," Soc. Pet. Engineers J. (1970) 10, No. 2, 171.

APPENDIX B

PATENTS

SERIAL NO.	TITLE	INVENTOR	ASSIGNEE
1,952,170	Sample Taking Apparatus	G.A. Humason, et al	Reed Roller Bit Co.
2,146,263	Method of Coring to Preserve Fluid Content	N. Johnston	-
2,214,551	Method and Apparatus For Taking Samples	C.R. Edwards	-
2,216,962	Pressure Coring Device	B.W. Sewell	Standard Oil Devel. Co.
2,238,609	Pressure Coring Barrel	B.W. Sewell	Standard Oil Devel. Co.
2,256,552	Retrievable Formation Tester	H.E. Drake	-
2,264,449	Method and Apparatus For Coring	W.D. Mounce	Standard Oil Devel. Co.
2,343,805	Pressure Core Barrel	B.W. Sewell	Standard Oil Devel. Co.
2,347,726	Wire Line Pressure Retaining Core Barrel	D.W. Auld, et al	Phillips Pet. Co.
2,364,088	Core Drilling	H.C. Miller, et al	United States Government
2,373,323	Process and Apparatus For Pressure Core Drilling	G.A. Macredy	-
2,541,785	Coring Device	D.M. Smith	The Texas Co.
2,587,231	Boring Tool	W. Schierding	-
2,703,697	Process and Apparatus For Well Coring	R.D. Walker	-
2,830,667	Pressure-Operated Bottom-Hole Drill Stem Tester	J.E. Walstrom	California Research Corp.
2,862,691	Coring Bit Assembly	C.D. Cochran	Jersey Prod. Research Co.
2,880,969	Apparatus For Obtaining Unaltered	P.S. Williams	Jersey Prod. Research Co.
2,927,776	Coring Apparatus	A.B. Hildebrandt, et al	Jersey Prod. Research Co.
3,064,742	Obtaining Unaltered Core Samples	H.C. Bridwell	Jersey Prod. Research Co.
3,095,935	Coring Bit	A.B. Hildebrandt, et al	Jersey Prod. Research Co.
3,138,214	Bit Force Applicator	H.C. Bridwell	Jersey Prod. Research Co.

SERIAL NO.	TITLE	INVENTOR	ASSIGNEE
3,146,837	System For Obtaining True Core Samples	H.C. Bridwell	Jersey Prod. Research Co
3,329,220	Apparatus For Drilling Core Samples	R.K. Dyer	Sinclair Research Co.
3,635,295	Apparatus For Drilling A Small Borehole Downwardly From The Bottom of a Large Borehole	J.H. Cobbs	Fenix & Scisson, Inc.
3,804,184	Core Drilling Apparatus	M.T. Gusman, et al	-
3,837,412	Downhole Electrical Core Drilling System	W.B. Driver	-
3,839,899	Method and Apparatus For Determining Parameters of Core Samples	J.M. McMillen	Mobil Oil Corp.
3,898,815	Pressure and Volume Compensating System For Reciprocating Oil Field Drilling Tools	J.W. Young	Dresser Ind. Inc.
3,898,895	Method of Attaching Teeth To An Earth Drilling Tool	T.L. Taylor	-
3,921,733	Method of Drilling A Borehole Using Gelled Polymers	R.L. Clampit	Phillips Petro. Co.

APPENDIX C

LITERATURE SEARCH
ON
CORING EQUIPMENT

Petroleum Abstracts for the period January, 1965 to the present were searched for permanent literature on certain coring equipment. Approximately 120 references were located. Titles of these references are tabulated in the attached list which also includes the abstract number for that reference. Abstracts for each of these references are found in the following sections grouped as listed on the index tabs.

LITERATURE SEARCH

CORING EQUIPMENT

PETROLEUM ABSTRACTS NO.	TITLE	
67,640	EARTH BORING EQUIPMENT INCLUDING TWO PART ROTARY CUTTING HEAD	- U.S. Pat.
67,811	CORE DRILLING DEVICE	- Russia Pat.
68,506	PLASTIC-TUBE CORING TECHNIQUE FOR UNCONSOLIDATED WET SAND	
71,631	DEVICE TO TAKE CORES AT THE SEA-BOTTOM	- Neth. Appl.
72,242	CONTINUOUS-CORE RIG UNDERGOES FIELD TEST	-
72,625	FREE-FALL BEHAVIOR OF SMALL, LIGHT- WEIGHT GRAVITY CORERS	-
73,902	THE "SPHINCTER" CORER: A WIDE-DIAMETER CORER WITH WATER-TIGHT CORE-CATCHER	-
75,768	A MULTIPLE CORER	-
80,208	METHOD AND APPARATUS FOR DEEP SEA BOTTOM CORE SAMPLING	- U.S. Pat.
80,734	A DIVER-OPERATED PNEUMATIC CORE SAMPLER	-
82,076	EARTH CORING PUNCH AND DRIVE APPARATUS THEREFOR	- U.S. Pat.
82,882	DUAL CORE EQUIPMENT FOR SHOT DRILLING	-
83,315	UNDERWATER SAMPLING APPARATUS	- U.S. Pat.
85,840	METHOD OF AND APPARATUS FOR BOTTOM SAMPLING	- Canada Pat.
86,202	APPARATUS FOR DRILLING CORE SAMPLES	- U.S. Pat.
86,203	CORE DRILL	- Russia Pat.
87,976	CORE BARREL APPARATUS FOR CORING WHILE DRILLING	- French Pat.
89,795	APPARATUS FOR CORE DRILLING	- Russia Pat.

PETROLEUM
ABSTRACTS NO.

TITLE

89,796	A THRUST GRIPPING DEVICE FOR A CORE DRILL	- Russia Pat.
90,152	EARTH CORING DEVICE	- U.S. Pat.
91,900	A DOUBLE CORING UNIT FOR CORING WELLS IN HIGHLY FRACTURED ROCKS	-
95,097	APPARATUS FOR EARTH CORING	- Canada Pat.
95,427	PROBLEMS IN DESIGNING A DOUBLE CORE BARREL WITH A WATER-JET PUMP	-
96,749	APPARATUS FOR CORING SUBTERRANEAN FORMATIONS UNDER A BODY OF WATER	- U.S. Pat.
100,099	VACUUM CORE CATCHER	- Russia Pat.
100,830	DYNAMIC DEEP-OCEAN CORE SAMPLER	- U.S. Pat.
101,499	DRILLING EQUIPMENT FOR DIFFICULT CORING CONDITIONS--A NEW TYPE OF CORE LIFTER AND TRIPLE TUBE CORE BARREL	-
101,500	REMOVAL OF CORES FROM AND DETERMINATION OF LITHOLOGICAL-PETROGRAPHIC CHARACTERISTICS OF AN EXPERIMENTAL SECTION OF THE RESERVOIR CHOSEN FOR A FIREFLOOD	-
103,932	THE DEVELOPMENT OF THE BEDFORD INSTITUTE DEEP-SEA DRILL	-
104,037	TURBOCORER INSTRUMENTATION	-
106,350	APPARATUS FOR UNDERWATER DRILLING AND CORING LOOSE SEDIMENTS	-
108,068	THE LUBS, A LARGE UNDISTURBED BOTTOM SAMPLER	-
108,069	A SEDIMENT CORING DEVICE OF 21-CM DIAMETER WITH SPHINCTER CORE RETAINER	-
111,801	A SIMPLE CORER FOR SAMPLING SAND AND FINER SEDIMENTS IN SHALLOW WATER	-
111,802	BUOYANT CORING APPARATUS	- U.S. Pat.
113,855	CORING INSTRUMENT	- Russia Pat.
114,038	SEA BOTTOM CORING APPARATUS	- U.S. Pat.

PETROLEUM
ABSTRACTS NO.

TITLE

114,458	DESCRIPTION OF A DUAL CORER FOR OBTAINING PAIRED PISTON OR GRAVITY CORES	-
117,520	A NEW "SPHINCTER" CORER WITH A RECOILLESS PISTON	-
118,133	A DEVICE FOR RELEASING A PISTON CORER AND DEACTIVATING THE PISTON	-
118,728	RHEOLOGICAL STUDIES OF KAOLIN-CONTAINING DISPERSIONS, PART 1	-
118,730	IMPROVEMENTS IN BOREHOLE SURVEY MEANS AND CORE SAMPLE ORIENTATING MEANS	-
119,576	INSTALLATION TO TAKE BOTTOM SAMPLES	- Neth. Appl.
121,608	DRILL PIPE FOR CORE DRILLING APPARATUS	-
123,288	THE "MONO" CORER; A WIDE DIAMETER, GENERAL PURPOSE, GRAVITY CORING TOOL	-
124,372	A HYDRAULIC CORER FOR USE IN WATER SATURATED SEDIMENT	-
128,011	THE NPS ROCKET CORER; A FIRST GENERATION ROCKET POWERED CORING TOOL	-
128,390	AS SELF-DEACTIVATING PISTON FOR A PISTON CORER	-
128,791	UNDERWATER ELECTRIC TOOL BUILT TO CORE SEA FLOOR	-
129,653	A HYDRODYNAMICALLY ACTUATED DEEP SEA HARD ROCK CORER	-
130,830	IFP CUTS SUBSEA CORING COSTS WITH NEW ELECTRODRILL	-
131,388	AN AUTOMATIC-RELEASE PISTON FOR USE IN piston coring	-
132,135	ELECTRICALLY CONTROLLED AND POWERED SUBMARINE ROTARY CORER SYSTEM	- U.S. Pat.
133,070	EXPERIMENTAL USE OF EJECTING CORING TOOLS FOR INCREASING RECOVERY OF CORES	-
135,770	NEW DEVELOPMENT IN SEA-BOTTOM SAMPLING	-

PETROLEUM
ABSTRACTS NO.

TITLE

136,073	A NEW LARGE DIAMETER PISTON CORER AND CORE-LINER CUTTER	-
136,485	PISTON CORING APPARATUS WITHOUT RECOIL	- French Pat.
137,657	VIBRATING CORER COLLECTS HARD SAND SAMPLES	-
140,376	CORE DRILLING APPARATUS	- Germany Pat.
143,731	DESIGN OF AN AUTOMATIC MARINE CORER	-
145,083	DESIGN OF AN AUTOMATIC MARINE CORER	-
149,995	PRINCIPAL TRENDS IN CORE DRILLING	-
151,159	INFLUENCE OF LUBRICANTS AND POLYMER COATINGS ON PENETRATION OF OCEANOGRAPHIC CORING TOOLS	-
151,161	METHODS AND APPARATUS FOR DIRECTIONAL DRILLING	- U.S. Pat.
152,656	THE SACLANTCEN SPHINCTER CORER ASSEMBLY, PART 1. A WIDE-DIAMETER CORER WITH WATERPROOF CORE-CATCHER, PART 2. AN ELECTRICAL TRIGGERING SYSTEM	-
154,505	A SIMPLE CORER AND A METHOD FOR SAMPLING THE MUD-WATER INTERFACE	-
154,997	HYDRAULIC CORE DRILL FOR DRILLING OPERATIONS	- French Pat.
156,740	SOFT FORMATION CORE BARREL	- U.S. Pat.
156,741	APPARATUS FOR OBTAINING CORE SAMPLES IN UNCONSOLIDATED SOIL	- Germany Pat.
157,025	AIDS TO UTILIZATION OF A SHALLOW PENETRATION SEAFLOOR SITTING DRILL	-
158,204	APPARATUS FOR DRILLING A SMALL BOREHOLE DOWNWARDLY FROM THE BOTTOM OF A LARGE BOREHOLE	- U.S. Pat.
158,437	PERCUSSION CORING APPARATUS	- French Pat.
159,354	A METHOD OF AND APPARATUS FOR OBTAINING UNDERWATER CORES	- Gr. Brit. Pat.

PETROLEUM
ABSTRACTS NO.

TITLE

159,446	CORE DRILL, ESPECIALLY FOR UNDERWATER DRILLING	- French Pat.
159,551	DESIGN AND TEST OF A TORSIONAL VIBRATORY CORE SAMPLER FOR MARINE SEDIMENTS	-
159,772	DESIGN AND CONSTRUCTION OF A SHALLOW WATER SEDIMENT CORE SAMPLER	-
162,530	INSTALLATION FOR UNDER WATER CORE DRILLING	- Neth. Appl.
162,677	CORING APPARATUS FOR TAKING SAMPLES OF THE OCEAN FLOOR	- U.S. Pat.
163,041	UNDERWATER ROCK CORE SAMPLING DEVICE AND METHOD OF USE THEREOF	- U.S. Pat.
163,915	UNDERWATER CORING APPARATUS	- French Pat.
164,394	SPRING COUPLING FOR DRILL PIPE AND SAMPLING TUBES	- French Pat.
170,093	APPARATUS FOR LOWERING AND RETRIEVING A CORE BARREL	- U.S. Pat.
173,907	A VIBRATORY DEVICE FOR TAKING OCEAN FLOOR SEDIMENT CORES	- Gr. Brit. Pat.
174,452	VIBRO-PERCUSSION CORING APPARATUS	- French Pat.
176,416	A VIBRATORY CORING SYSTEM FOR CONTINENTAL MARGIN SEDIMENTS	-
178,119	CORE DRILLING APPARATUS FOR CABLE TOOL DRILLING	- Belgium Pat.
178,860	WIRELINER CORE BARREL WITH RESILIENT LATCH FINGERS	- U.S. Pat.
179,812	DOUBLE TUBE CORE BARREL WHICH IS LOWERED THROUGH DRILL PIPE	- U.S. Pat.
179,813	DEEP ROTARY CORE DRILLING IN ICE	-
181,624	IMPROVEMENTS IN AND RELATING TO APPARATUS FOR DRILLING ROCK	- Gr. Brit. Pat.
187,309	CORE TRAYS	- U.S. Pat.
188,791	AN IMPROVED CORE CATCHER FOR THE KIEL BOX CORER ("KASTENLOT")	-

PETROLEUM
ABSTRACTS NO.

TITLE

191,265	CORE DRILLING APPARATUS	- U.S. Pat.
193,555	APPARATUS FOR BOTTOMHOLE CORING	- U.S. Pat.
194,270	THE CBI POGO STICK CORER	-
195,649	CORE SAMPLING DEVICE AND METHOD	-
197,038	AN INEXPENSIVE HAND-OPERATED SEDIMENT CORER	-
198,557	CONCEPTUAL DESIGN OF A CORING SUBTERRENE GEOPROSECTOR	-
198,777	DOWNHOLE ELECTRICAL CORE DRILLING SYSTEM	- U.S. Pat.
199,308	CORING APPARATUS	- Belgium Pat.
199,647	DRILLING ASSEMBLY AND PROCESS FOR LIFTING IT TO THE SURFACE	- French Pat.
199,648	INSTALLATION TO TAKE SAMPLES IN LOOSE GROUND	- Neth. Appl.
202,045	DRILL INSTALLATION WITH REMOVABLE CORE BARREL AND CENTRAL PART	- Neth. Appl.
206,677	TECHNICAL AND ECONOMIC ADVANTAGES OF THE HYDRAULIC ANNULAR VIBRO-HAMMER FOR UNDERWATER SAMPLING AND GEOTECHNICAL IN-SITU INVESTIGATIONS	-
210,075	CORE DRILLING APPARATUS	- Canada Pat.
211,907	REMOTELY OPERATED SEAFLOOR CORING AND DRILLING METHOD AND SYSTEM	- U.S. Pat.
212,682	CORE DRILL FOR SOIL LAYERS	- French Pat.
214,772	UNDERWATER DRILLING APPARATUS, ESPECIALLY CORE DRILL	- German Pat.
214,773	CUTTER DEVICE FOR EARTH CORING	- Gr. Brit. Pat.

ABSTRACTS

EXPLORATORY DRILLING

67,640 ✓

EARTH BORING EQUIPMENT INCLUDING TWO PART ROTARY CUTTING HEAD - U. S. 3,241,624, c. 3/22/66, f. 1/24/63 (Appl. No. 253,626); C. L. Rassieur, asr.; (Central Mine Equipment Co)

This earth-boring equipment includes a 2-part rotary cutting head. The cutting head includes an outside part that is hollow, an inside part latched in place, and the necessary tools for removing and replacing the inside cutting head part while the cutting head is connected to the end of a hollow drill string such as a string of hollow auger sections detachably connected end-to-end and to the cutting head. The equipment can be used to depths of 200-300 ft. The equipment accommodates the passage of a sampling tool by removing one of the parts to provide for passage of the sample-taking tool. The closure plug can be unlatched and removed by a simple fishing operation performed through the hollow drill string. (6 claims)

CORING METHODS

68,506 ✓

PLASTIC-TUBE CORING TECHNIQUE FOR UNCONSOLIDATED WET SAND - D. E. Shier (Shell Oil Co) and R. W. Oaks, Jr. (Esso Production Res Co); J. SEDIMENT. PETROL. v. 36, No. 1, pp 241-244, March 1966

Cores of unconsolidated wet sand can be obtained by: (1) hammering plastic tubing into sand with a board; (2) filling the remainder of the tube with water and corking the tube to create a vacuum; and (3) pulling the tube, releasing the vacuum, and extruding the core. Depositional structures, concentrations of opaque minerals, differences in oxidation, orientation and preservation of shells, and stratigraphic contacts are strikingly well preserved in the resulting cores.

-326-

CORING EQUIPMENT

67,811 ✓

CORE DRILLING DEVICE - U.S.S.R. 178,323, f. 5/31/63; V. I. Maksimov, A. A. Volokitenkov, M. M. Rozin and V. M. Shvetsov; IZOBRET. PROM. OBRAZ. TOVARNYE ZNAKI v. 43, No. 3, pp 7-8, 1966 (In Russian)

A core drilling device consists of a tubular housing, a column of drill pipe, a drilling tip, an impeller pump, and a slurry-collecting pipe. In order to assure reliable operation of the pump during drilling, both in monolithic and in fractured rocks, the pump propeller is fixed in the drill string with its ring or band rigidly secured to the tool's housing. The apparatus is provided at the top with a bracing device, made in the form of one or more pairs of spring-activated levers.

CORING EQUIPMENT

71,631 ✓

DEVICE TO TAKE CORES AT THE SEA-BOTTOM - Neth. Appl. 6,515,742, f. 12/3/65 (pr. Fr. 12/4/64, Appl. 997,552); (Inst Francais du Petrole) (In Dutch)

A device to obtain cores on the sea-bottom can be lowered from a surface installation. It consists of a support frame with a large base surface, a lowering-hoisting cable, a coring bit including a coring motor connected to it, and flexible tubing wound on a storage drum. The system of the core motor and the instrumentation forms one rigid part of the coring device with the flexible tubing attached to its end. A motorized pump feeds the coring instrument with water under pressure, the discharge side being connected to the flexible tubing. The motorized pump is connected to the surface installation with electrical feeder leads. The coring instrument has electrical instrumentation to regulate the winding and unwinding of the flexible tubing on the drum. This instrumentation is remotely controlled from the surface installation. (6 claims)

CONTINUOUS-CORE RIG UNDERGOES FIELD TEST - PETROL. INTERAM.
v. 24, No. 7, pp 44-46, 48, July 1966

A new system of core drilling now being tested holds promise of increasing the efficiency and economy of exploration in shallow-to-medium depth formations. The new method cores continuously from the top of the hole to total depth. Core recovery and quality are amazingly high, and cost is only slightly higher than conventional drilling. Central feature of the system is a 2-tube drill string in which the freshly cut cores circulate to the surface with the return mud stream. Among the advantages claimed for the continuous core method are the following: (1) accurate determination of depth to key horizons; (2) measurement of dip, both for magnitude and direction; (3) detection of facies changes; and (4) accurate location of faults, pinchouts, sand lenses, porosity traps, overlaps, reefing, and minerals other than petroleum. Because the cores are pumped to the surface, recovery is virtually complete. Even cores of soft formation which cannot support their own weight in a conventional core tube are readily recovered by the new system. Because the core is exposed to the drilling fluid for a very short time compared to conventional coring, it arrives at the surface with less damage from mud flushing.

-327-

CORING EQUIPMENT

72,625 ✓

FREE-FALL BEHAVIOR OF SMALL, LIGHT-WEIGHT GRAVITY CORERS -
R. E. Burns (Washington Univ Seattle); MAR. GEOL. v. 4, No. 1, pp 1-9,
Feb. 1966 (Recd. Aug. 1966)

The increasing use of small, light-weight gravity corers equipped with free-fall devices, has raised the question of applicability of the optimum free-fall distance criteria originally established for large, heavy corers. Measurements have been made of the free-fall velocities of several devices representative of the class of small corers. These data indicate an optimum free-fall setting of 2-3 m, with general caution indicated on the minimum setting and specific caution indicated on the maximum for corers not fitted with stabilizing fins.

CORING EQUIPMENT

73,902 ✓

THE "SPHINCTER" CORER: A WIDE-DIAMETER CORER WITH WATER-TIGHT CORE-CATCHER - A. Kermabon, P. Blavier, V. Cortis (Saclant ASW Res Ctr Italy) and H. Delauze (Natl Sci Res Ctr Marseilles); MAR. GEOL. v. 4, No. 2, pp 149-162, April 1966 (Recd. Oct. 1966)

A long, wide-diameter corer with a watertight core-catcher is described. The main new features of this corer are: (1) a "Sphincter-type", nylon core-catcher, which seals the cores within a watertight container during retrieval; and (a) a split piston, which prevents suction of the core when the corer is retrieved from the sediments. This paper also describes an electrical release system which prevents accidental triggering due to sudden shocks, thereby making it safer than other systems when working in heavy seas. The design of this corer is close to those theoretically ideal proportions generally accepted as providing minimum sample disturbance. The equipment has worked successfully, and little or no disturbance has been observed in the cores taken with it. (10 refs.)

CORING EQUIPMENT

75,768 ✓

A MULTIPLE CORER - G. A. Fowler and L. D. Kulm (Oregon State Univ); LIMNOL. & OCEANOGR. v. 11, No. 4, pp 630-633, Oct. 1966

The multiple corer operates on the principle of the gravity corer and contains the same basic components: a weight, core barrel, plastic liner, cutting head, and one-way valve. The main core body is composed of 5 disk-shaped lead weights; 3 of them weigh approximately 110 kg each, and the other 2 weigh 55 kg each. Each weight was molded with 5 holes to accommodate the core barrels. The weights are held together with pieces of pipe with couplings screwed to each end. Steel plates are used at the top and bottom of the stack of weights to prevent the couplings from denting the soft lead. A corer is suspended by a chain and bale arrangement attached to the upper plate. The maximum size of the present model was determined by a desire to have the corer heavy enough to achieve adequate penetration and to be used by itself in deep water with a fairly large diameter cable. It can also be used as a trip weight for large-sized piston corers.

CORING EQUIPMENT

80,208 ✓

METHOD AND APPARATUS FOR DEEP SEA BOTTOM CORE SAMPLING - U.S. 3,301,336, c. 1/31/67, f. 3/24/64 (Appl. 354,400); W. W. Mount

This is a method and apparatus for deep sea bottom core sampling. The apparatus consists of a core tube with a weight at the end of a cable, suspended in part from the top of the core tube and in part from the ship, and attached for movement along the core tube. During operation, cable means raise the weight upward along the tube so that a force is produced urging the tube downward when it is positioned at the bottom of the sea. Near the lower end of the core tube but above the cutter sleeve, are located one or more holes to admit water. The holes are below the spring fingers of the core catcher so that water coursing down the annular space and entering the inside of the core tube at high pressures cannot directly jet against the sediment around which the core tube is falling, while its purpose is to provide a lubricant between the outside of the core sediment and the inside of the core tube. (20 claims)

CORING EQUIPMENT

80,734 ✓

A DIVER-OPERATED PNEUMATIC CORE SAMPLER - B. Walker (Freshwater Biol Assoc); LIMNOL, OCEANOGR. v. 12, No. 1, pp 144-146, Jan. 1967

A pneumatic sampler that can be handled by a diver has been designed. The anchor chamber is made of a steel cylinder closed at the upper end by a steel plate. Compressed air is carried in a cylinder of 750 liters capacity at 126 kg/cm² and mounted on the outer tube close to the operating valves. The cylinder holds enough air to take approximately 3 cores when using the 2.4-m corer or 2 using the 4.3-m corer in a water depth 0 to 9 m. From 9 to 25 m, 2 cores can be taken with the 2.4-m or one with the 4.3-m corer. The cylinder clamp on the outer tube accommodates larger cylinders if necessary, and a charging connection allows a spare cylinder to be used if the operating cylinder is emptied during the coring operation. The approximate weights of the corers, including the air cylinder, are 25 and 34 kg. A buoyancy pack enables the diver to maneuver the unit into any attitude when moving into position to take a core.

CORING EQUIPMENT

82,076 ✓

EARTH CORING PUNCH AND DRIVE APPARATUS THEREFOR - U.S. 3,308,897, c. 3/14/67, f. 4/6/64 (pr. Can. 11/6/63, Appl. 888,474); N. D. Becker, asr.; (Becker Drlg (Alberta) Ltd)

This is an earth coring punch for excavating holes for highway guard rails in earth or fill which contains coarse gravel or boulders. The apparatus is transportable and the punch has any desired cross section and length. The punch is suspended by its upper end from a high-energy percussion engine. The engine and punch are located on an adjustable framework on the vehicle and can be adjusted in position laterally and vertically. The punch is also independently pivoted about a horizontal axis adjacent to its upper end. Its lower end is fitted with an integral shoe with integral teeth aligned with the axis of the punch and spaced about the periphery of the shoe. A series of rock-breaker chisel-like teeth extend inward as well as below the cutting edge and project into the opening of the shoe to shatter or otherwise displace rocks in order that the fragments will move up through the shoe. (5 claims)

CORING EQUIPMENT

82,882 ✓

DUAL CORE EQUIPMENT FOR SHOT DRILLING - A. A. Grebeniuk, G. G. Moiseev and V. L. Khaustov; RAZVED OKHRANA NEDR No. 1, pp 27-32, Jan. 1967 (In Russian)

The construction and operation are described of the dual DKC-2 core drill, designed for shot drilling to a depth of about 500 m. Previous models of this type core drill had several disadvantages, the chief ones being that much of the core was lost in drilling fractured, shaly, and weakly consolidated sands. The DKC-2 drill recovers 60-80% core, continuously feeds shot to hole bottom while isolating shot from core, and breaks core and stores it in core barrel. The shot is transported through the core drill by the circulating drilling fluid. Under typical operating conditions the core drill rotates at 153 rpm, with a load of 650 kg, and drilling fluid circulation rate of 40-50 liters/min. Cast iron shot, 2-3 mm in diameter are circulated at rate of 75-100 g per 5 min. A schematic diagram of the core drill and typical performance data are given.

CORING EQUIPMENT

83,315 ✓

UNDERWATER SAMPLING APPARATUS - U.S. 3,313,357, c.4/11/67, f. 11/23/64 (Appl. 413,106); A.A. Venghiattis, asr.; (Dresser Industries Inc)

An apparatus for obtaining earth samples from submerged lands such as ocean, lake, and river beds is described. The apparatus includes an explosively operated coring device which can be lowered into the water by a cable and is actuated by contact with the ocean or lake bed. The gun includes an explosively dischargeable coring barrel, and is lowered through the water in a muzzle-down position. When the muzzle of the coring barrel contacts the bed, the core barrel is pushed back into the apparatus to actuate the explosive charge. Actuation of the charge drives the core barrel out of the gun and into the ocean bed. The core barrel remains connected to the gun by flexible cables, and thus when the gun is lifted to the surface the cables will carry the core barrel with it. (17 claims)

CORING

86,202 ✓

APPARATUS FOR DRILLING CORE SAMPLES - U.S. 3,329,220, c.7/4/67, f.7/10/64 (Appl. 381,820); R.K. Dyer, asr.; (Sinclair Research Inc)

An apparatus is provided for core drilling which consists of an elongated tubular housing and packing means disposed around the housing for sealing the well bore into which the apparatus can be inserted. The lower portion of the housing contains a core barrel. The barrel is connected to, and in fluid communication with, a hollow shaft above it. Hydraulic motors are used for reciprocating and rotating the shaft and core barrel. In addition, a mud pump circulates drilling fluid down through the shaft barrel and up around the outside the shaft. (14 claims)

-329-

CORING EQUIPMENT

85,840 ✓

METHOD OF AND APPARATUS FOR BOTTOM SAMPLING - Can. 763,300, c. 7/18/67, f. 9/25/64 (pr. Jap. 9/27/63, Appl. 50,816); N. Nasu, H. Yamazaki, H. Shinozaki and T. Yonekura, asrs.; (Asahi Kasei Kogyo KK) and (Tsurumi Seiki Kosak Co Ltd); CAN. PAT. OFFICE REC. v. 95, No. 29, pp 6195-6196, 7/18/67

This bottom sampler is operated by lowering it to the submarine floor and locating it at the desired position. The rockets which are mounted on the sampler are then ignited to push the core barrel downward. The sample is recovered by igniting rockets that exert an upward force. The number of rockets to be used can be varied in order to meet the requirement for a specific area. For instance, more rockets would be needed in areas where the bottom samples are harder to penetrate. (2 claims)

CORING

86,203

CORE DRILL - U.S.S.R. 185,807, f.7/2/65; V.I. Kot, N.F. Krivun, P.T. Sheshenya et al.; IZOBRET., PROM. OBRAZ., TOVARNYE ZNAKI v.43, No.18, p 15, 9/12/66 (In Russian)

A hydraulic cylinder is used to force a core drill through rock as it rotates. A hydraulic cylinder is pressurized to a desired level and the core drill is rotated. As the core penetrates the rock, the pressure is depleted. When this occurs, drilling is ceased and the cylinder is repressurized. This process is repeated until the desired length of core has been drilled.

CORE BARREL

87,976 ✓

CORE BARREL APPARATUS FOR CORING WHILE DRILLING -
Fr. 1,489,560, c. 6/12/67, f. 8/16/66 (pr. U.S. 8/27/65, Appl. 483,102);
L.A. Lindelof, asr.; (Longyear (EJ) Co); Abstr., BULL. OFFIC.
PROPRIETE IND. (FR.) v.8, No.29, p 10094, 7/21/67 (In French)

An apparatus for coring while drilling includes a core barrel with one end threaded, this end being connected to an extraction cap in which a core catcher is mounted. The core catcher consists of a ring transverse to the core barrel and which has internal grooves near the base, axially aligned with the core barrel axis. The ring is removable and is limited in axial displacement to a point near the core barrel, thus allowing cutting off the core by forcing it through the core catcher and into the core barrel.

CORING

89,796 ✓

A THRUST GRIPPING DEVICE FOR A CORE DRILL - U. S. S. R. 199,052, f. 12/29/65; S. N. Blinov, I. G. Komissarov, F. Z. Krasnovskii et al.; Abstr., IZOBRET., PROM. OBRAZ., TOVARNYE ZNAKI v. 44, No. 15, p 6, 7/13/67 (In Russian)

A thrust gripping device for a core drill includes the gripping section, rods, coil spring, reversible slip device, and a drilling platform. Essentially, the device provides a means of controlling the loss of the cutting instrument as related to its connection with the drilling column socket. The device has its ends in the form of hinged attachments, resembling yokes, on the drilling platform, with every yoke joined at one end of the cutter with the section clamps and the braces of the converter, and with the other end interacting with the pipe cap through a spring coil. In one aspect, the working surface of the section clamps is equipped with a frictional lining.

CORING

89,795 ✓

APPARATUS FOR CORE DRILLING - U. S. S. R. 198,269, f. 4/26/66;
V. I. Shilov and L. I. Shilov; Abstr., IZOBRET., PROM. OBRAZ., TOVARNYE ZNAKI v. 44, No. 14, p 6, 6/28/67 (In Russian)

This core drilling device is similar to U. S. S. R. Patent No. 137,855. The improvement consists in the core barrel having a greater reliability in the retention of cores from loose, unconsolidated rock. The lower part of the elastic core barrel is closed by means of elastic valves.

CORING EQUIPMENT

90,152 ✓

EARTH CORING DEVICE - U. S. 3,344,869, c. 10/3/67, f. 9/3/65 (Appl. 484,805); W. B. Tijmann and A. Cody

An explosively driven coring device is especially useful in taking soil cores for soil analysis, or for other purposes. The device has a threefold recoil system in which 3 separate and accumulative recoil mechanisms are able to absorb the recoil to the operator. A sealing assembly holds the expanding gas resulting from the explosive charge captive in a chamber at the head of the core sampling projectile in which the projectile forms one portion of the sealed chamber. The opposite portion is formed of a novel piston arrangement which functions to expand against a chamber wall under pressure and which further yields to absorb a substantial portion of the impact of the explosive charge so that the seal and the recoil absorption are accomplished in a single apparatus. The explosive gases are prohibited from entry into the recoil and sealing apparatus, thus preventing the mechanism from being contaminated by the charge gases. (13 claims)

CORING EQUIPMENT

91,900 ✓

A DOUBLE CORING UNIT FOR CORING WELLS IN HIGHLY FRACTURED ROCKS - S.S. Sulakshin; RAZVED. OKHRANA NEDR No. 8, pp 51-52, Aug. 1967 (In Russian)

Considerable difficulty is experienced in coring hard, highly fractured rocks. The main problem is trapping of cores in the core barrel. In this article a schematic drawing of a core drill, designed to drill and hole fractured cores, is described and presented. The core-holding and storage chamber is sealed by spring-actuated and hydraulically actuated mechanisms.

CORE BARREL

95,427 ✓

PROBLEMS IN DESIGNING A DOUBLE CORE BARREL WITH A WATER-JET PUMP-- G. I. Neudachin, A. V. Kolomoets, Yu. A. Polozov and B. Z. Sultanov; IZV. VYSSH. UCHEB. ZAVEDENII, NEFT GAZ No. 10, pp 27-30, 1967 (In Russian)

Operating efficiency of a double-barrel core drill was increased by installation of a water-jet pump in the core barrel. The water jet pump increased core recovery to 80 - 90%. Penetration rate of core drill with the pump was 15 - 20% higher than without the pump. A schematic diagram of the core barrel with the jet-pump is shown. Essentially, the water-jet pump is an arrangement of nozzles, tubes, and valves which circulate water or other drilling fluid upward through the core barrel, thereby aiding the recovery of core. Driving force for the water-jet pump comes from the mud pump. The relationship between dimensions of pump components, drilling fluid circulation rate, and operating efficiency of the core barrel are shown analytically.

-331-

CORING EQUIPMENT

95,097 ✓

APPARATUS FOR EARTH CORING-- Can. 779,148, c. 2/27/68, f. 2/19/66 (pr. Can. 4/5/65, Appl. 927,325); S.G. Atkins and S.B. Baillie; Abstr., CAN. PAT. OFFICE REC. v. 96, No. 9, p 1973, 2/27/68

A coring assembly consists, in combination, of a longitudinally extending body portion with a plurality of earth-plug segmenting fins secured around the body portion. These fins extend radially outward from the body portion and diagonally outward from one end of it toward the other end. A cutting ring is secured to the outer end of the fins, concentrically with the body portion. The ring is sharpened on its leading edge. The trailing edge and the portion of the ring adjacent to the trailing edge curves inward toward the body portion and forms an obtuse angle with the remainder of the ring. (5 claims)

CORING EQUIPMENT

96,749 ✓

APPARATUS FOR CORING SUBTERRANEAN FORMATIONS UNDER A BODY OF WATER-- U.S. 3,373,827, c. 3/19/68, f. 6/14/66 (Appl. 557,531); J.N. Biron, D.B. Jones and D.L. Sims, asrs.; (US Natl Sci Found)

This apparatus, for lowering on a flexible line, is used to core formations below a body of water. The core barrel of the apparatus is kept substantially vertically oriented while being lowered through the water and while cutting the core, even though the flexible line supporting the apparatus does not extend vertically to the surface of the water. A float is attached to the flexible line adjacent to the apparatus. By controlling its buoyant force, the float tends to nullify the effect on the attitude of the core barrel of the wire line extending upward from the apparatus at an angle. The buoyant force is less than the weight of the apparatus in the water so that the apparatus will sink. However, the float exerts a buoyant force sufficient to keep the short section of line between the float and the coring assembly taut. (1 claim)

CORE BARREL

100,099 ✓

VACUUM CORE CATCHER-- U.S.S.R. 209,356, f. 12/26/66; G.I. Potapov; Abstr., IZOBRET., PROM. OBRAZ., TOVARNYE ZNAKI v. 45, No. 5, p 9, 1968 (In Russian)

A vacuum core catcher consists of a housing with a core catching cup with a lid through which passes a shaft with the valve thereon, and having packing seals. In order to increase the tightness of the connection, the shaft is made in the form of a screw upon which is mounted the cover, the latter having threads.

CORE BARREL

101,499 ✓

DRILLING EQUIPMENT FOR DIFFICULT CORING CONDITIONS--A NEW TYPE OF CORE LIFTER AND TRIPLE TUBE CORE BARREL-- J.B. Robinson et al.; PROC. AUSTRALAS INST. MIN. MET. No. 224, pp 37-46, Dec. 1967; Abstr., No. L 52, IND. DIAMOND REV. v. 28, No. 333, p 378, Aug. 1968

Although considerable improvements in diamond drilling equipment have been made since the early 1950's, deficiencies in existing equipment led to the development of a new type core lifter and special 20 ft triple tube core barrel designed to operate in bad coring conditions. It is claimed that although developed essentially for coal drilling, the new equipment could be adapted to other fields of diamond drilling with the cost advantage of increased life of the core lifter.

-332-

CORING EQUIPMENT

100,830 ✓

DYNAMIC DEEP-OCEAN CORE SAMPLER-- U.S. 3,392,794, c. 7/16/68, f. 3/28/66 (Appl. 538,912); M. R. Kurillo, Jr. and L. R. Russel

The description discloses a deep-ocean core sampler which is self-supporting on the ocean bottom and will obtain vertical samples therefrom even though the ocean bottom may be inclined or has an irregular surface. The core sampler may include a sampling tube, a barrel which receives the sampling tube into the ocean bottom, and gimbals mounting the barrel and driving means to a support means which is adapted to rest on the ocean bottom. The barrel and driving means are free from restraint except for the gimbal connection to the support means. (8 claims)

CORE BARREL

101,500

REMOVAL OF CORES FROM AND DETERMINATION OF LITHOLOGICAL-PETROGRAPHIC CHARACTERISTICS OF AN EXPERIMENTAL SECTION OF THE RESERVOIR CHOSEN FOR A FIREFLOOD-- B. D. Panov and V. T. Malyshek; NEFT. KHOZ. No. 4, pp 57-61, April 1968 (In Russian)

Productive zones in injection and producing wells of Pavlova Gora field were completely cored, so that detailed information could be obtained concerning characteristics of the reservoir, chosen to be fireflooded. The construction of a core barrel, designed to remove large-diameter cores from unconsolidated sands and shales, is described. The cores gave information on textural characteristics of the reservoir, granular make-up, grain form of rock-forming minerals and petrographic composition of brecciated and cementing parts of the rocks. The reservoir was found to be heterogeneous. Sandstone is separated by shale stringers. The reservoir consists of sands and shales with various degrees of oil saturation. Granular analysis indicates that the middle part of the reservoir has the best properties. Reservoir properties are given by tabular data.

CORING EQUIPMENT

103,932 ✓

THE DEVELOPMENT OF THE BEDFORD INSTITUTE DEEP-SEA DRILL--
J. Brooke and R. L. G. Gilbert (Bedford Inst, Nova Scotia); DEEP-SEA RES.
v. 15, No. 4, pp 433-490, Aug. 1968

A new concept for drilling short cores of rock from the floor of the deep ocean is described. The power for operating the drill is obtained from water which moves from the normal ambient hydrostatic pressure into a low pressure void. A general description is given of the complete drill assembly and its method of operation. The results of 3 series of experiments at sea, and of a number of tests on land are given, from which the abilities and limitations of the drill in its present form may be inferred. The plans for future work are described and long-range objectives are outlined.

-333-

CORING EQUIPMENT

104,037 ✓

TURBOCORER INSTRUMENTATION-- Brown & Root, Inc. Staff; PB-178,836;
Approx. 90 pp, 7/5/67 (Recd. Oct. 1968)

The overall length of the turbocorer instrument depending upon the size of the core-barrel in use, ranges from 38 to 68 ft. In use, the instrument package with core-barrel assembly is lowered by the logging cable through the drill pipe and inside the turbocorer proper. When the package reaches its proper position, it is automatically locked into operation position by a mechanical latch. At this time, drilling can commence. To retrieve the core specimen, drilling is stopped; the logging-cable tension at the instrument-package head must be increased to 1,000 lb in order to disengage the latch from the latch body. The specific parameters measured are as follows: (1) core-bit speed; (2) the amount of core in the core-barrel; (3) pressure drop across the turbine and bit; (4) maximum allowable thrust-bearing wear; (5) inclination of the turbocorer; (6) cable tension at the instrument package head; (7) instrument package latch position; and (8) instrument package input voltage.

APPARATUS FOR UNDERWATER DRILLING AND CORING LOOSE SEDIMENTS-- S. Afr. 68/2,887, c. 10/18/68, f. 5/6/68 (pr. Fr. 5/8/67); J. Delacour, A. Castela and P. Moulin, asrs.; (Inst Français du Pétrole); Abstr., PATENTJOERNAAL (S. AFR.) v. 1, No. 11, p 165, Nov. 1968

An apparatus operable from a surface installation for driving into the underwater floor consists of a number of elements which are connected end to end and used for offshore drilling and coring operations. It consists essentially of a base member seated on bottom which is provided with a central well through which the pipe string passes. Rigid guide members extend in a direction parallel to the axis of the central well. Substantially parallel guide cables connect the surface installation to the tops of the guide columns. A drilling head with a submersible motor is slidable along the guide columns. A means is provided in the base to hold the pipe elements. Cables for power, for hoisting, and for lowering are provided. (5 claims)

CORING EQUIPMENT

108,068 L

THE LUBS, A LARGE UNDISTURBED BOTTOM SAMPLER-- R. J. Menzies (Florida State Univ) and G. T. Rowe (Duke Univ); LIMNOL. OCEANOGR. v. 13, No. 4, pp 708-714, Oct. 1968

A new benthic collecting device, the LUBS (large undisturbed benthos sampler), which satisfies many of the criteria for a successful soft-bottom quantitative sampler is described. The design is simple, inexpensive, and such that samples may be canned on retrieval. Stratified sediments can be collected in large diameters, so the device also should be useful to geologists. The LUBS recovers stratified sediments intact, impossible with the clam-shell grab. The volume of sediment captured by LUBS is known as soon as the sample arrives on deck and there is no need to dump the sample into a tray or can to measure its volume. A second advantage of LUBS is the capture of epifauna and of the in situ water overlying the sediment. A third advantage is that the sample is collected in its own container and may be preserved in toto for subsequent study of animal-sediment relationships, tracks, tubes, and so on. (12 refs.)

CORING EQUIPMENT

108,069 ✓

A SEDIMENT CORING DEVICE OF 21-CM DIAMETER WITH SPHINCTER CORE RETAINER-- J. C. Burke (Woods Hole Oceanogr Inst); LIMNOL. OCEANOGR. v. 13, No. 4, pp 714-718, Oct. 1968

A 21-cm-ID gravity corer of a new design was developed to provide large cross section core samples for analysis of fallout radionuclides in sediments of Crater Lake, Ore. The study of vertical profiles of the concentration of fallout radionuclides (which have been available for sedimentation only since the early 1950's in most places) also demands efficient sampling of the top-most layers of sediment and their recovery in situ. Some evidence from studies of more conventionally collected cores indicates that these upper layers are commonly lost, either by washout at the top of the core tube or by being swept away from the point of impact by the shock wave of rapidly falling corers. Another requirement is efficient retention of a variety of sediment types, ranging from very soft muds to coarse, sharp sands; loss of water through the usual core-retaining devices commonly flushes out such samples. The new coring device, combining large diameter with positive, watertight closing of both bottom and top of the core tube at the time of pullout, meets all these requirements.

CORING EQUIPMENT

111,801 ✓

A SIMPLE CORER FOR SAMPLING SAND AND FINER SEDIMENTS IN SHALLOW WATER-- P. S. Maitland; LIMNOL. OCEANOGR. v. 14, No. 1, pp 151-156, Jan. 1969

The main types of substrate found in aquatic environments can be divided into silts and finer sediments, sands, gravels, and coarser substrates. Each of these substrates presents its own difficulties for quantitative sampling, upon which are superimposed the variations in technique necessary with different depths of water. The sampler described is satisfactory for sands and finer sediments and for short-stalked macrophytes growing in such sediments. In practice, it is useful in depths less than 5 m.

CORING EQUIPMENT

111,802 ✓

BUOYANT CORING APPARATUS-- U.S. 3,434,551, c. 3/25/69, f. 6/26/67 (Appl. 649,438); A.M. Rosfelder, asr.; (US Navy)

A buoyant rig for supporting coring operations of an underwater coring barrel is described. The buoyant rig includes a float and a bottom-weighted stand which are interconnected by at least one guide wire. The core barrel slidably extends through the weighted stand and is positioned parallel to the guide wire and is slidable therealong by a guide means. When the core barrel is powered, the barrel will be guided along the guide wire as it penetrates the ocean bottom. A gimbal connection between the core barrel and the stand for uneven ocean bottoms and the guide wire may be separated from the stand after a sample is obtained so that the float will raise the core barrel and the remaining rigging apparatus to the ocean surface. (10 claims)

CORING EQUIPMENT

114,038 ✓

SEA BOTTOM CORING APPARATUS-- U.S. 3,442,339, c. 5/6/69, f. 2/17/67 (Appl. 616,893); T.N. Williamson, asr.; (Hughes Tool Co)

A marine bottom coring apparatus for drilling into and obtaining core samples from subsea formations is described. It is particularly useful for obtaining core samples from hard rock formations. The apparatus includes a frame having buoyancy, which has sufficient capacity to float the apparatus in the unballast condition. Ballasting means are also connected to the frame and having ballast capacity sufficient to overcome a buoyancy of the buoyancy means. Release means are provided for releasing the ballast at a predetermined time. The frame has the core drilling means attached to it and is supported on the sea bottom, whereby the apparatus may be sunk to the sea bottom by the ballast. a core sample drilled from the subsea formation, and the apparatus floated to the surface upon release of the ballast. (11 claims)

-335-

CORING BIT

113,855 ✓

CORING INSTRUMENT-- U.S.S.R. 232,880, f. 12/27/65; M.M. Rozin, N.M. Tsekhmistrenko and A.A. Volokitenkov; Abstr., OTKRYTIYA, IZOBRET., PROM. OBRAZIY, TOVARNYE ZNAKI v. 46, No. 2, p 9, 1969 (In Russian)

A coring instrument is designed to include a drilling head and a sub. The sub is equipped with spring-loaded plungers and lateral channels that communicate with the annulus of the core barrel during plunger displacement. (Abstract only - original not available)

CORING EQUIPMENT

114,458 ✓

DESCRIPTION OF A DUAL CORER FOR OBTAINING PAIRED PISTON OR GRAVITY CORES-- A. Blackman and R.S. Anderson (US Naval Oceanogr Office); MAR, TECHNOL, SOC, J., v. 3, No. 2, pp 73-74, March 1969

A simple method of obtaining paired cores spaced 3 m apart with known relative azimuth is described. A dual corer, fabricated from standard materials and available equipment, has been designed to take 2 long cores simultaneously. The advantage of working with paired cores is that it provides a means of studying sediment variability over a relatively short predetermined distance. An estimate of the direction of sedimentary processes is obtained by using a compass, which gives the relative orientation of the cores. The dual corer was used successfully in the field and 8 paired gravity cores were obtained in 8 lowerings in water depths of 4,000 m.

CORING EQUIPMENT

117,520

A NEW "SPHINCTER" CORER WITH A RECOILLESS PISTON-- A. Kermabon (Cie Maritime Expertises) and U. Curtis; MAR. GEOL. v. 7, No. 2, pp 147-159, April 1969

The Sphincter corer is an improvement over most of the existing piston corers. It includes a Sphincter-type nylon core catcher, which seals the cores within a watertight container during retrieval, and a split piston, which prevents suction of the core when the corer is retrieved from the sediments. A simple system for monitoring the piston relatively to a fixed platform lying on the sea floor is described. The device involves only cables and thin pulleys and can be adapted to any existing Sphincter corer. The equipment has worked successfully and little or no disturbance has been observed in the cores.

CLAY MUD

118,728

RHEOLOGICAL STUDIES OF KAOLIN-CONTAINING DISPERSIONS. PT. 1-- Z. Ceuros, J. Bozzay and B. Zsoldos; PERIOD. POLYTECH., CHEM. ENG. v. 12, No. 4, pp 381-394, 1969 (In German); EAST EUROPE. SCI. ABSTR. CHEM. No. 114, p 80, 9/2/69

The rheological properties of hydrolyzed starch and kaolin-dispersions, and dispersions containing both hydrolyzed starch and kaolin were investigated. Aqueous kaolin suspensions were pseudoplastic at low concentrations, plastic at higher concentrations. At higher concentrations, thixotropic effects became evident. Addition of dispersant reduces viscosity up to a certain concentration; thereafter, further additions of dispersant have no effect. The rheological properties of the dispersions change upon addition of dispersant. Increasing concentrations of hydrolyzed starch increase the viscosity of the dispersion. There is an inverse linear relation between apparent viscosity and absolute temperature. (Abstract only - original not available)

CORING EQUIPMENT

118,730 ✓

IMPROVEMENTS IN BOREHOLE SURVEY MEANS AND CORE SAMPLE ORIENTATING MEANS-- S. Afr. 69/0,260, c. 6/26/69, f. 1/14/69 (pr. Austral. 1/19/68); J. B. Robinson, asr.; (Joint Coal Board); Abstr., PATENTJOERNAAL (S. AFR.) v. 2, No. 8, p 189, Aug. 1969

A borehole survey means consists of a hollow cylinder adapted at its upper end to prevent substantially the escape of fluid from the upper end. It has holes through its wall near the lower end to admit drilling fluid so that air may be trapped in the upper end of the cylinder. A gel tube is provided to hold a gellable liquid. A receptacle is provided to hold a second liquid, that when mixed with the first liquid initiates gelling of it. A passage connects the gel tube and receptacle. A valve normally closes the passage but is designed, on sudden reduction of the pressure on the trapped air, to open and to allow the second liquid to flow into the gel tube and mix with the first liquid. (9 claims) (Abstract only - original not available)

118,133 ✓

A DEVICE FOR RELEASING A PISTON CORER AND DEACTIVATING THE PISTON-- J. L. Woodruff (Washington Univ, Seattle); DEEP-SEA RES. v. 14, No. 6, pp 809-810, 1 Pl., Dec. 1967 (Recd. Sept. 1969)

A device is described for releasing a piston corer, holding the piston cable during free fall and penetration, and deactivating the piston by dropping the piston cable. Combined in the instrument are a cocking and triggering device, a safety catch, and a closed-system timing cylinder with a needle valve that controls circulation of oil and thereby regulates the time the piston cable is held. The device eliminates the complexity, unreliability, and much of the time involved in the use of previous deactivators.

CORING EQUIPMENT

119,576 ✓

INSTALLATION TO TAKE BOTTOM SAMPLES-- Neth. Appl. 6,717,831, f. 12/29/67; B. P. Hageman, asr.; (Werf Conrad & St Hirsch NV) (In Dutch)

A drilling installation to take bottom samples consists of a hollow pipe which can be driven into the bottom by means of vibrations. A vacuum pump installed in the hollow pipe is activated by the vibration movement of the pipe. There is always an underpressure between the upper part of the core and the vacuum pump. The resistance of the core moving into the pipe barrel is thus decreased and the pipe can be driven deeper into the bottom, thus increasing the percentage of recovered core. (4 claims)

CORING EQUIPMENT

121,608 ✓

DRILL PIPE FOR CORE DRILLING APPARATUS-- Ger. 1,298,469, c. 7/3/69, f. 2/2/66 (Appl. 93,916); N. D. Becker and F. W. Becker, asrs.; (Becker Drig (Alberta) Ltd); Abstr., AUSZUEGE PAT. (GER.) v. 15, No. 27, p 2112, 7/3/69 (In German)

This drill pipe for impact core drilling with reverse circulation consists of double-walled pipe stands and suitable collars equipped with an annular space, so that a continuous flow path for the descending mud is provided between the walls of the pipe string. The lower end of the coupling is connected only to the outer pipe and contains an axially displaceable inner tube with radial holes; the upper end of the coupling is also connected to the outer tube only and has an inner cylindrical surface sealing against the inner pipe. The holes for the mud are drilled only in the upper part of the coupling and communicate with a sealed annular space through radial and axial grooves. (Abstract only - original not available)

CORING EQUIPMENT

123,288 ✓

THE "MONO" CORER; A WIDE DIAMETER, GENERAL PURPOSE, GRAVITY CORING TOOL-- R. P. Onorati; U.S. Naval Postgraduate Sch. MS Thesis, 56 pp, Dec. 1968; AD-694,912; Abstr., U.S. GOV. RES. DEVELOP. REP. v. 69, No. 23, p 135, 12/10/69

A gravity corer in its simplest form consists of a tube with a check-valve at the upper end which is driven into the sediment by encircling weights in order to obtain a sample. At many oceanographic institutions where a variety of research is undertaken relative to the ocean bottom, an efficient and reliable general purpose coring device is required. Such a device should enable the biologist, geologist, sedimentologist or engineer to obtain a sample which meets his particular requirements. A simple gravity corer fits many of these needs. The gravity corers in use at the present time have not significantly changed from the earlier corers. Even the most reliable of gravity corers are not without some drawbacks. An attempt is made to solve some of these problems and produce a reliable, easy to handle, general purpose, gravity coring tool useful for all phases of oceanographic research. (Abstract only - original not available)

CORING EQUIPMENT

128,011 ✓

THE NPS ROCKET CORER; A FIRST GENERATION ROCKET POWERED CORING TOOL-- G. E. Pierce and R. J. Smith (Naval Postgraduate Sch); Rept. No. NPS-58SJ70011A, 36 pp, 1/14/70; AD-700,707; Abstr., U.S. GOV. RES. DEVELOP. REP. v. 70, No. 7, p 82, 4/10/70

A rocket motor-powered corer has been designed and built. Limited tests of the rocket corer, conducted in a sand-silt-clay bottom at a depth of 100 ft off Pitas Point in Ventura County, showed promising results. It has been demonstrated that available rocket motors can be used to drive coring devices in relatively shallow water. Further tests are warranted to determine the maximum depth that rocket-powered instruments may be used. It presently appears possible that rocket motors may be used as a general source of power for varied underwater applications. (Abstract only - original not available)

CORING EQUIPMENT

128,390 ✓

ASSELF-DEACTIVATING PISTON FOR A PISTON CORER-- J. L. Woodruff (Hawaii Univ); OCEAN ENG. v. 1, No. 6, pp 597-599, Feb. 1970

Described is a piston containing an internal valve that is closed during penetration and open during extraction of the corer. It requires no cocking or other preparatory steps before use, and prevents liner collapse, core distortion, and consequent erroneous interpretation of the core materials as sometimes occurs when a conventional piston is used.

CORING EQUIPMENT

124,372 ✓

A HYDRAULIC CORER FOR USE IN WATER SATURATED SEDIMENT-- J. A. Gifford (Miami Univ, Florida); J. SEDIMENT. PETROLOGY v. 39, No. 4, pp 1619-1621, Dec. 1969

A suction corer utilizing an expendable plastic core liner was developed to sample sand strata in the tidal-flat environment. The device is lightweight, simple to operate, and contains a minimum number of moving parts. With it, continuous cores up to 10 ft in length and retaining sediment interstitial water were obtained. Nine cores averaging 10 ft in length were taken in 4 field days. Actual coring time averaged 30 min per core; transporting the equipment occupied the remaining time. Most of the cores taken with this device are composed of moderately coarse sand, but the corer successfully penetrated peat, compact silt strata, and shell debris. The problem of vacuuming in sediment not directly in the path of the corer did not prove serious. Careful measurements of barrel penetration vs. actual core length indicated a maximum of 5 to 8% elongation, a figure which may be substantially minimized by applying sufficient force to the corer before opening the vacuum tanks.

OFFSHORE DRILLING EQUIPMENT

128,791 ✓

UNDERWATER ELECTRIC TOOL BUILT TO CORE SEA FLOOR-- WORLD OIL v. 170, No. 6, pp 98-99, May 1970

An electric-powered underwater coring tool has been developed for sampling up to 130 ft of consolidated, ocean-bottom formations in as much as 1,000 ft of water. This assembly sits vertically on the sea floor and can retrieve cores below the ocean floor. Surface components are a power input of a 150 kVA, remote-control electric cable handled by an electrically powered winch and a testing and control panel. This device was developed by the Institut Francais du Petrole. The specification of the electric core drill are given. Drilling and coring cycles are minimized due to the power available for bit rotation and water circulation. Total operations time varies mostly with time required to lower, lift, and handle the assembly aboard ship.

-339-

CORING EQUIPMENT

129,653 ✓

A HYDRODYNAMICALLY ACTUATED DEEP SEA HARD ROCK CORER-- H. Frohlich and J. F. McNary (Miami Univ, Florida); MAR. TECHNOL. SOC. J. v. 3, No. 3, pp 53-60, May 1969 (Recd. May 1970)

The progress of several important geological studies is strongly handicapped by the lack of an efficient deep-sea hard-rock coring tool. A new, hydrodynamically actuated rock sampler has yielded promising results. Comparable in weight and in speed and ease of handling to regular gravity corers, the new instrument is capable of producing impact forces of several million newtons.

CORING EQUIPMENT

130,830 ✓

IFP CUTS SUBSEA CORING COSTS WITH NEW ELECTRODRILL-- J. Morrison; OIL GAS INT. v. 10, No. 4, pp 78, 81-82, April 1970

To reduce the high cost of sea-bed surveys to a minimum, Institut Francais du Petrole (IFP) has developed a system which allows prior selection of coring sites. This in turn is backed by a new subsea coring device designed to recover samples of consolidated formation down to 330 ft. Surface support for the IFP system is a dynamically positioned small tonnage vessel equipped with a sonic seismic device for recording sea-bottom profiles. These show the subsea formations down to several hundred feet. Since the profiles highlight the characteristics of the area scanned, coring site locations can be planned economically. Cores taken are 6-1/2 ft long and 3-1/2 in. diam. A complete geological profile of the first 330 ft of a subsea formation can be formulated by drilling holes to that depth and then taking successive 6-1/2-ft long cores. While the subsea corer can be operated from any vessel equipped with gear able to lift the 22,500-lb weight of the unit, the vessel must be provided with the means to hold itself almost vertical over the hole.

CORING EQUIPMENT

131,388 ✓

AN AUTOMATIC-RELEASE PISTON FOR USE IN PISTON CORING-- B. Winterhalter (Finland Geological Survey); MAR. GEOL. v. 8, No. 5, pp 371-375, May 1970

An automatic-release piston has been developed to replace the conventional fixed piston/wire combination used in Kullenberg-type corers. At the end of penetration of the corer into the sediment, this piston breaks into 2 parts. The actual piston is jammed in place by spring-actuated barbs that are pressed into the P. V. C. core liner. The released upper portion to which the piston wire is attached, is free to move up against the piston stop at the top of the barrel before the corer is pulled out and brought to the surface. In the case of incomplete penetration, core disturbances due to suction caused by the movement of a conventional piston during pull out are thus eliminated.

CORING EQUIPMENT

132, 135 ✓

ELECTRICALLY CONTROLLED AND POWERED SUBMARINE ROTARY CORER SYSTEM-- U.S. 3,516,503, c. 6/23/70, f. 12/23/68 (Appl. 785,918); E. F. Mayer, W. Brannon, E. S. Schaller, Jr. and F. C. Pickard, asrs.; (US Dept Interior)

A core-sample drilling apparatus is described which is made operable when stationed on a sea floor. A carriage guided for verticle displacement in the apparatus supports a self-contained pump and drill-drive mechanism governed by interrelated remote and internal control devices. Included is an internal control device for automatically connecting the drill drive to a carriage retracting mechanism at the end of the drilling stroke. (5 claims)

133, 070 ✓

CORING EQUIPMENT

EXPERIMENTAL USE OF EJECTING CORING TOOLS FOR INCREASING RECOVERY OF CORES-- B.I. Bykov, G. L. Lebedinskii, E. L. Katsnelson and I. Sh. Strelko; NAUCH.-TEKH. SB. SER. BURENIE No. 2, pp 12-15, 1970 (In Russian)

Core recovery from friable and fractured limestones is about 20% with ordinary core drills. Core recovery was greatly increased by development and use of specially designed ejector core drills. Construction and operation of 2 such core drills are described, and coring data are presented. The essential feature of this coring unit is a hydraulic system with which core is removed from well bottom, and placed in a core storing compartment. A schematic diagram and specifications of the unit are shown.

CORING EQUIPMENT

135, 770 ✓

NEW DEVELOPMENT IN SEA-BOTTOM SAMPLING-- OCEAN IND. v. 5, No. 10, p 32, Oct. 1970

Conrad-Stork and the Dutch Geological Survey Department have developed Geodoff II, the latest of their units designed for remote-control drilling of the upper 50 m of the sea floor and for recovering undisturbed samples. The new drilling method is a combination of 2 different penetration methods; i. e., pressure penetration and ordinary rotary drilling. The new unit has the advantage over other methods for obtaining undisturbed samples of being able to penetrate hard formations efficiently. The Geodoff II can operate at any water depth on the continental shelf completely independent of the ship. No assistance from skin divers is required. The main body with its 3 legs emplaced on the sea bottom, contains the rotary drilling device and a rotating supply disk on which the complete drill string is placed in 12 lengths of about 4 m each. The electric motor driving the hydraulic pumps, the computer, etc., are housed in the drums on the main body. An umbilical cord from the surface vessel supplies electric power, electric signals, and drilling mud. The filled core barrels are stored by mechanical arms after every pipe length of drilling progress. The tubes are placed on the supply disk in special clamps. By omitting the core barrels and connecting the rotary drilling device with the ship by means of a hose, a continuous flow of samples can be obtained by the counterflush system.

© The University of Tulsa - 1970

Printed in U.S.A.

CORING EQUIPMENT

136, 073 ✓

A NEW LARGE-DIAMETER PISTON CORER AND CORE-LINER CUTTER-- A. Langford, J. C. McDougall and N. Robertson; NEW ZEAL. J. MAR. FRESHWATER RES. v. 3, No. 4, pp 595-601, 1969; DEEP-SEA RES. OCEANOGR. ABSTR. v. 17, No. 4, p A433, Aug. 1970

A newly developed piston sediment corer utilizing a neat-fitting piston operating within a 2-7/8-in. -diam plastic liner has successfully cored heavy gravel, coarse shell, and sandy sediments. A quick fit and release junction for pipe lengths and cutter has been devised. (Abstract only - original not available)

CORING EQUIPMENT

136,485 ✓

PISTON CORING APPARATUS WITHOUT RECOIL-- Fr. 1,597,431, c. 6/29/7
f. 8/7/68 (Appl. 22,360); A. Kermabon; Abstr., BULL. OFFIC. PROPRIETE
IND. (FR.) v. 11, No. 32, p 14772, 8/7/70 (In French)

A coring apparatus has a set of sheaves attached to the upper end of the core tube, and a second, symmetrical set of sheaves attached to the exterior of the penetrating nose. A platform across which the core tube can freely move in the vertical direction is attached in 2 symmetrical points to a steel cable passing over the sheaves and ending inside the coring apparatus over the sheave attached to the sealed piston. (Abstract only - original not available)

-341-

CORING EQUIPMENT

137,657 ✓

VIBRATING CORER COLLECTS HARD SAND SAMPLES-- L. Purrett;
UIR/RES. NEWSLETTER v. 5, No. 1, p 7, Spring 1970

A coring device that vibrates its way into lake and ocean sediments may enable oceanographers to obtain core samples from types of sediments that are impenetrable to present tools. The corer is designed especially for obtaining cores from hard sand. When agitated in the presence of water, sand forms a fluid. The device takes advantage of this so-called thixotropic effect. A small turbine vibrates the core tube about its vertical axis. As it enters the sand, this vibration creates a thin layer of liquid around the outer surface of the tube, which enables it to slip easily. The same process takes place along the tube's inner walls, resulting in minimum disturbance of the sample.

CORING EQUIPMENT

140,376 ✓

CORE DRILLING APPARATUS-- Ger. 1,963,239, c. 12/17/70, f. 12/17/69 (Appl. 1,963,239); W. Schulz, W. Mager and H. Gause, asrs.; (Salzgitter Maschinen AG); Abstr., AUSZUEGE PAT. (GER.) v. 16, No. 51, p 2555, 12/17/70 (In German)

This core-drilling apparatus consists of a drill pipe and an inner tool, which receives the core and which can be either brought into rigid connection with the drill pipe or pulled out by means of a cable. The rigid connection between the inner tool and drill pipe is achieved by a tongue and groove arrangement. (Abstract only - original not available)

CORING EQUIPMENT

145,083 ✓

DESIGN OF AN AUTOMATIC MARINE CORER-- E. I. Bailey and H. O. Henderson (Texas A&M Univ) and G. L. Davis (Cameron Iron Works Inc); 3RD ANNU. OFFSHORE TECHNOL. CONF. (Houston, 4/19-21/71) PREPRINT No. OTC-1365, pp 1-397 - 1-416, 1971 (v. 1)

A program was initiated at Texas A&M University under the Sea Grant Program to design a self-contained automatic sea-floor setting corer which will (1) extract up to 50 ft of continuous undisturbed core, (2) operate in depths up to 1,000 ft of water, (3) core in hard as well as soft material, and (4) be as compact as possible to facilitate shipboard handling. The Seacore 50 will extract a 3-in. diameter core 49.5 ft long in 11 sections. The unit is octagonal in cross section measuring 6 ft side to side and is 12 ft in height. When the unit reaches the sea floor, 4 legs fold down and level the unit on slopes of up to 15°. The unit weighs 10,000 lb dry, 8,000 lb in water, and is lowered to the sea floor by a single power-tension cable. An automatic control system is contained in the unit with shipside manual control available at any time.

CORING EQUIPMENT

149,995 ✓

PRINCIPAL TRENDS IN CORE DRILLING-- L. P. Konstantinov, I. I. Barabashkin and S. F. Alekseeva; NEFT. KHOZ. No. 5, pp 27-30, May 1971 (In Russian)

The principal trend in developing core drilling is to design and introduce equipment which would allow obtaining cores of bigger diameter and maximum possible ratio between diameters of the core and the drilling head. It is suggested that for rotary core drilling, there should be 3 types of core devices specially designed for groups or rocks characterized similar coring problems. For dense and monolithic rocks, core barrels which rotate during drilling can be used. In fissured and alternating with respect to hardness rocks, the core assembly must have a nonrotating core carrel suspended on bearings, smaller outer diameter of the assembly body, a system of core breakers to completely cover the core entrance, and means to flush the core barrel before setting it on the hole bottom. Assemblies for collecting cores from loose, easily drillable rocks must have elastic core containers. For turbo-core drilling, assemblies with bigger diameter core containers can be used. However, the use of rotary core drilling is preferable, in most cases. The optimum ratio of core diameter and diameter of drilling head is 0.37 to 0.42 for non-retrievable and 0.21 to 0.28 for retrievable core barrels. Recommendations for designing core bits are given.

CORING EQUIPMENT

143,731 ✓

DESIGN OF AN AUTOMATIC MARINE CORER-- E. I. Bailey and G. L. Davis (Texas A&M Univ); Rept. No. TAMU-SG-71-202, 93 pp, Nov. 1970; PB-195,984; Abstr., U.S. GOV. RES. DEVELOP. REP. v. 71, No. 3, p 121, 2/10/71

A self-contained automatic seafloor setting corer which will: (1) extract up to 50 ft of continuous undisturbed core, (2) operated in depths up to 1,000 ft of water, (3) core in hard as well as soft material, and (4) be as compact as possible to facilitate shipboard handling was designed. The Seacore 50 is described. (Abstract only - original not available)

CORING EQUIPMENT

151, 159 ✓

INFLUENCE OF LUBRICANTS AND POLYMER COATINGS ON PENETRATION OF OCEANOGRAPHIC CORING TOOLS-- R.A. Erchul; AD-845, 189, 59 pp, Dec. 1968; Abstr., GOV. REP. ANNOUNCE. v. 71, No. 13, 7/10/71

The friction developed on the inner and outer faces of oceanographic coring tubes tends to decrease penetration and gross recovered length and to increase sample disturbance. An effort was made to decrease this friction through use of lubricants and polymer coatings and to thereby increase the penetration of smooth steel surfaces into fine-grained sediments. Tests were conducted in the laboratory using steel plates and an Atwood test apparatus, and at sea using gravity corers. In the laboratory tests, the lubricants STP, CRC, zinc grease, and lithium grease increased penetration 46, 25, 24, and 20% respectively. Tests at sea showed that use of STP lubricant increased corer penetration 18 and 35% and gross recovery length of cores 16%. Statistical analysis indicated that the above increases were highly significant. (Abstract only - original article not available from T. U.)

DIRECTIONAL DRILLING

151, 161

METHODS AND APPARATUS FOR DIRECTIONAL DRILLING-- U.S. 3,593,810, c. 7/20/71, f. 10/13/69 (Appl. 865,884); R.Q. Fields, asr.; (Schlumberger Technol Corp)

A tool carrying a drill bit is dependently coupled from a drill string and lowered into a borehole which is to be excavated in a desired direction. First and second sets of wall-engaging members are operatively arranged around the tool in such a manner that as the weight of the rotating tool is successively supported by each of the first members, commensurate outwardly directed forces will be successively imposed on each of the second members for urging the drill bit in a desired lateral direction. Various controls adapted for operation from the surface of the earth are disclosed for selectively interconnecting the first and second wall-engaging members so as to either maintain the course of the drill bit along a vertical axis or else to direct the drill bit in a selected azimuthal direction and inclination. (37 refs.)

CORING EQUIPMENT

152, 656 ←

THE SACLANTCEN SPHINCTER CORER ASSEMBLY. PT. 1. A WIDE-DIAMETER CORER WITH WATERPROOF CORE-CATCHER. PT. 2. AN ELECTRICAL TRIGGERING SYSTEM-- A. Kermabon, P. Blavter and U. Cortis; Rept. No. SACLANTCEN-TR-34, 29 pp, 3/1/65; AD-808,766; Abstr., GOV. REP. ANNOUNCE. v. 71, No. 16, pp 100-101, 8/25/71

A long, wide-diameter corer with a waterproof corecatcher is described. Its design is closer to theoretically ideal proportions than most oceanographic corers, and the cores it provides appear to be unmodified samples of the sediments. A sphincter-type, nylon-sleeve core-catcher seals the cores within a waterproof container during retrieval. An electric triggering system for this and other heavy corers, is described. The use of a mercury switch instead of counterweights prevents accidental triggering by sudden shocks, thereby making it much safer than other systems when working in heavy seas. (Abstract only - original article not available from T. U.)

CORE BARREL

154, 505 ✓

A SIMPLE CORER AND A METHOD FOR SAMPLING THE MUD-WATER INTERFACE-- A. L. W. Kemp, H. A. Saville, C. B. Gray and A. Mudrochova; LIMNOL. OCEANOGR. v. 16, No. 4, pp 689-694, July 1971

A triple corer has been designed, based on a modification of the Benthos corer. Satisfactory cores have been taken in clay muds, silty clay muds, silts, and glacio-lacustrine clays at depths up to 250 m. The sediment is extruded layer by layer on a simple screw thread piston device. Results show that extrusion of each tube separately is reproducible and that it is possible to subsample the cores at close intervals. Bottom water for analysis also is collected by the corer.

DRILLING

CORING EQUIPMENT

154,997 ✓

HYDRAULIC CORE DRILL FOR DRILLING OPERATIONS-- Fr. 2,066,895,
c. 8/13/71, f. 10/28/69 (Appl. 36,849); (Craelius Diabor); Abstr., BULL.
OFFIC. PROPRIETE IND. (FR.) v. 12, No. 37, Pt. 2 (No. 32), p 20032,
9/17/71 (In French)

This core drill consists essentially of a rotating exterior tube and an interior tube which is not driven in rotation. The internal tube receives the core and can be raised to the surface. The control elements are hydraulically actuated and consist of a head in a thrust sleeve with corresponding surfaces, subjected to the action of the drilling mud. This core drill is particularly applicable to coring operations in petroleum exploration. (Abstract only - original article not available from T. U.)

**DRILLING
CORE BARREL**

156,740

SOFT FORMATION CORE BARREL-- U.S. 3,621,924, c. 11/23/71, f. 3/24/70 (Appl. 22,251); M.P. Lebourg

A core barrel device for producing and retrieving subterranean cores, particularly from soft or unconsolidated formations, utilizes a fluid-pressure collapsible sleeve above the corer to receive and hold the core material and permit its retrieval in its original subterranean condition. Pressure responsive valves maintain a fluid pressure behind the collapsible sleeve to retain it in the collapsed position until the core is received in the sleeve and also permit fluid behind the sleeve to exhaust as the core enters the sleeve while the sleeve continues to offer lateral pressure support for the core and also remains collapsed above the core. When the coring device is withdrawn, a small amount of core material falls from the lower portion of the core barrel and the lower portion of the sleeve collapses to retain the remainder of the core within the core barrel. (27 claims)

-345-

CORING EQUIPMENT

156,741

APPARATUS FOR OBTAINING CORE SAMPLES IN UNCONSOLIDATED SOIL-- Ger. 2,104,442, c. 12/16/71, f. 1/30/71 (Appl. 2,104,442); M. Reichling and H. Dombrowski, asrs.; (Woma App Maasberg Co GmbH); Abstr., AUSZUEGE PAT. (GER.) v. 17, No. 51, p 3554, 12/16/71 (In German)

An apparatus for obtaining core samples in unconsolidated soil consists basically of 2 concentric tubes, with the drilling mud flowing downward in the annular space, a drilling bit attached to the lower end and equipped with means for reversing the direction of flow of the mud, and suitable means for removing the soil sample from the inner tube which acts as a core barrel. An annular space above the drilling bit is provided for radial distribution of the high pressure drilling fluid to jets. The jets facilitate the penetration of the core barrel into the bottom of the hole being drilled; the core barrel and the drilling bit are under the influence of a percussion device. (Abstract only - original article not available from T. U.)

CORING EQUIPMENT

157,025 ✓

AIDS TO UTILIZATION OF A SHALLOW PENETRATION SEAFLOOR SITTING DRILL-- R.D.O'Brien and E.J. Duley (Marine Minerals Technol Center); Rept. No. NOAA-TM-ERL-MMTC-1, 16 pp, Sept. 1971; COM-71-01011; Abstr., GOV. REP. ANNOUNCE. v. 71, No. 24, pp 69-70, 12/25/71

Drilling and sampling in the marine environment present a number of problems unique to the ocean-oriented investigators. This study is concerned with one of these problems. The initial penetration of a marine sediment to a depth of 10 ft deep is the most difficult in which to obtain reliable, relatively undisturbed samples, rapidly. Suspending a drilling tool over the side of a ship and under water, where visibility often is zero, raises problems relating to assuring that the penetration into the marine sediments is perpendicular to the sea floor. One way to solve this problem is presented in the description of a break-away tripod, which provides support for the initial penetration, and then collapses to allow further penetration. The drilling/sampling tool described can be suspended over the side of a small ship by a cable, with an air hose from the ship as an umbilical connection for operation. (Abstract only - original article not available from T. U.)

CORING EQUIPMENT

158,204 ✓

APPARATUS FOR DRILLING A SMALL BOREHOLE DOWNWARDLY FROM THE BOTTOM OF A LARGE BOREHOLE-- U.S. 3,635,295, c. 1/18/72, f. 12/2/69 (Appl. 881,394); J.H. Cobbs, asr.; (Fenix & Scisson Inc)

An apparatus is provided for drilling a small diameter borehole extension to a large diameter borehole. Generally, the apparatus consists of a hollow splined drill shaft which terminates on the lower end with a bit. Coaxially connected to the upper end of the drill shaft is a drive drum having driving lugs on the outer periphery which engage flutes on the inner wall of a tubular large borehole drilling or coring tool affixed to the lower end of a rotatable drill string in a large borehole. Rotation of the large borehole drilling tool causes rotation of the small borehole drilling tool. Extending upwardly from the drive drum is a hollow neck having an annular sealing means which forms in cooperation with the neck and the inner wall of the large borehole drill string a fluid chamber such that fluid pumped into the interior of the large borehole drilling tool creates a downwardly acting hydraulic thrust force to cause the rotating small borehole drilling tool to penetrate the earth. (7 claims)

CORING EQUIPMENT

158,437 ✓

PERCUSSION CORING APPARATUS-- Fr. 2,081,149, c. 12/3/70, f. 3/10/70 (Appl. 8,542); J. Liautaud, asr.; (ERAP); Abstr., BULL. OFFIC. PROPRIETE IND. (FR.) v. 13, No. 1, Pt. 2 (No. 48), pp 296-297, 1/7/72 (In French)

This addition to Fr. 183,118, issued 12/31/68, covers improvements in underwater coring apparatus of the percussion type, consisting of a housing which can be attached and detached from an exterior pipe. An interior core tube receives the core and is equipped with means for cutting and holding the core. At the upper end, directional guidance fins and conduits for circulating water are provided. The improvement consists in providing valves in the conduits, the closing of which is actuated by the coring apparatus arriving at the end of its course. This prevents the core being leached during retrieval of the core from the bottom of the sea. (Abstract only - original article not available from T. U.)

-346-

CORE BARREL

159,354 ✓

A METHOD OF AND APPARATUS FOR OBTAINING UNDERWATER CORES-- Gr. Brit. 1,268,629, c. 3/29/72, f. 7/25/68 (Appl. 35,432); J. L. Abrahams, asr.; (Rock Fall Co Ltd)

A method of and apparatus for obtaining underwater cores are described. The method consists of embedding one end of a heavy hollow cylindrical outer casing in a bed of material from which the core is to be taken, so that the outer casing stands substantially rigidly in an upright position. A relatively lighter coring casing is inserted down the outer casing, embedding one end of the casing in the bed of material. A drill string is then inserted down the coring casing to obtain the core from the bed of material. The outer casing, coring casing, and coring rods are sequentially connectible by connecting means to the chuck of standard-size drilling equipment. Preferably, the connecting means is provided with a central action water flushing and is compressed. (8 claims)

CORING EQUIPMENT

159,446 ✓

CORE DRILL, ESPECIALLY FOR UNDERWATER DRILLING-- Fr. 2,085,365, c. 12/24/71, f. 4/17/70 (Appl. 13,380); (COCEAN); Abstr., BULL. OFFIC. PROPRIETE IND. (FR.) v. 13, No. 4, Pt. 2 (No. 51), p 2541, 1/28/72 (In French)

This core drill is of the type containing a vertically vibrating core tube and a concentric coring bit which cuts the core in the formation. The vibrating core tube is displaced axially with respect to the coring bit during the coring operation. The 2 movements--vibration and displacement of the core tube, and rotation and advancement of the coring bit--are controlled separately and independently, simultaneously or not. This apparatus permits drilling of large diameter cores in mixed formations. (Abstract only - original article not available from T. U.)

CORING EQUIPMENT

159,551 ✓

DESIGN AND TEST OF A TORSIONAL VIBRATORY CORE SAMPLER FOR MARINE SEDIMENTS-- R. J. Harker and R. M. Shah (Wisconsin Univ); INT. UNESCO ET AL. ENG. PROPERTIES OF SEA FLOOR SOILS GEOPHYS. IDENTIFICATION SYMP. (Seattle, 7/25/71) PROC. pp 37-48, 1971

Studies of marine sediments for geological, biological or engineering purposes is an area of increasing importance as more investigations are directed toward surveys of submerged bottoms of oceans, lakes, and rivers. This paper summarizes a project initiated in Jan. 1969, to design, develop, and test prototype coring equipment for marine environments. The torsional system of vibration offers several specific advantages with respect to penetration of a marine sediment probe: (1) shear stresses, for inducing thixotropic transformation in the sediment, are obtained without involving the preload mass in the vibratory system, by swivel mounting; (2) a sawing action is provided at the leading edge of the probe; and (3) a square tube in torsion generates an envelope by soil compression, both outside and within the tube. The square tube has further advantages in facilitating construction of a core retainer and in allowing transverse sampling for daughter cores through ports in the sidewall.

CORING EQUIPMENT

159,772 ✓

DESIGN AND CONSTRUCTION OF A SHALLOW WATER SEDIMENT CORE SAMPLER-- T. C. Daniel and G. Chesters (Wisconsin Univ); ENVIRON. LETT. v. 1, No. 3, pp 225-228, 1971; Abstr. No. W72-01738, SELEC. WATER RESOURCES ABSTR. v. 5, No. 4, p 53, 2/15/72

A shallow-water core sampler was constructed from plumbing materials and extruded Plexiglas tubing. Construction of the sampler is simple and the total cost of materials is approx. \$35. The sampler is capable of taking cores at water depths up to 6 m and by modification at greater depths. The total weight of the sampler is 12 kg; it is easy to operate and can be used for sediments ranging from sand to highly organic clayey material. Core samples varying in length and cross-sectional area can be obtained by changing the dimensions of the Plexiglas tube. (Abstract only - original article not available from T. U.)

CORING EQUIPMENT

162,530 ✓

INSTALLATION FOR UNDER WATER CORE DRILLING-- Neth. Appl. 7,111,812, f. 8/27/71 (pr. Fr. 9/24/70, Appl. 34,727); (Inst Francais du Pétrole) (In Dutch)

The invention relates to underwater core drilling as described in Neth. Appl. 6,515,742, but has the following specifics. The foot section of the installation consists of a rigid frame having 2 feet. This frame forms a first plane. One foot is hinged to one of the tops of the frame and can move through a plane mainly perpendicular to the first plane. This movable foot is removed from the plane in a first position, thereby forming a 3-legged construction which can rest stably on the bottom. The movable leg has a second position closer to the frame to reduce its size, thereby making the transportation of the foot section easier. (4 claims)

CORING EQUIPMENT

162,677 ✓

CORING APPARATUS FOR TAKING SAMPLES OF THE OCEAN FLOOR-- U.S. 3,666,028, c. 5/30/72, f. 9/25/70 (Appl. 75,519); M. L. Greene, asr.; (US Navy)

An apparatus for extracting a core from the ocean floor includes a core tube that is held in a cocked position, and can be driven into the ocean floor by a set of elastic bands when the restraining cord is cut. An extracting collar, also held in a cocked position and powered by elastic bands is used to extract the core tube, with its core, from the ocean floor when collar's restraining cord is cut. The invention relates to the use of a coring system suitable for use by a manned deep submersible so that bottom samples may be taken at locations selected by the crew of the manned submersible without endangering the crew. Some of the prior coring systems used one set of rockets mounted on the coring tube to drive the coring tube into the bottom and then a second set of rockets to withdraw the tube. (3 claims)

CORING EQUIPMENT

163,041 ✓

UNDERWATER ROCK CORE SAMPLING DEVICE AND METHOD OF USE THEREOF-- U.S. 3,664,438, c. 5/23/72, f. 8/26/70 (Appl. 66,935); C. L. Winget, G. W. Gibson and W. S. Shultz, asrs.; (US Navy)

A rotary diamond rock core drill capable of obtaining a 3/4 in. diam core 4 in. long at any depth down to 6,000 ft is provided. The drill is adapted to be used with manned deep submersibles and is operated by the submersible's power supply. The drive motor is encased in an oil-filled pressure-compensated chamber. A water pump in the drill maintains a steady low pressure flow of water against the sample during drilling operations, washing away rock chips and mud. The water flow may be reversed after the core has been cut, holding the specimen within the core tube as the drill is extracted from the rock outcrop. The sample is then ejected by again reversing the drive motor and pump, forcing the water flow down through the core tube, and expelling the specimen. (10 claims)

CORING EQUIPMENT

163,915 ✓

UNDERWATER CORING APPARATUS-- Fr. 2,102,709, c. 4/7/72, t. 8/17/70 (Appl. 30,229); P. Grolet and Y. Castel, asrs.; (Inst Français du Pétrole); Abstr., BULL. OFFIC. PROPRIÉTÉ IND. (FR.) v. 13, No. 19, Pt. 3 (No. 14), p 12414, 5/12/72 (In French)

This addition to Fr. 1,463,801 issued 12/4/64 presents an improvement in an underwater coring apparatus. The means for controlling the winding on, or the unwinding from, the storage drum of the flexible conduit include a reversible hydraulic apparatus. This apparatus is used in coring under water. (Abstract only - original article not available from T. U.)

-348-

CORING EQUIPMENT

164,394 ✓

SPRING COUPLING FOR DRILL PIPE AND SAMPLING TUBES--

Fr. 2,105,013, c. 4/28/72, t. 9/16/70 (Appl. 33,503); (Acker Drill Co Inc); Abstr., BULL. OFFIC. PROPRIÉTÉ IND. (FR.) v. 13, No. 22, Pt. 2 (No. 17), p 13921, 6/2/72 (In French)

The sample tube is fed water from the string of drill pipe. The water flow is regulated by a spring-loaded piston which acts as a flow regulator and reduces or even completely interrupts the flow of water when a soft formation is encountered. This apparatus is especially useful in prospecting for soft coal and for copper minerals. (Abstract only - original article not available from T. U.)

CORE BARREL

170,093

✓ APPARATUS FOR LOWERING AND RETRIEVING A CORE BARREL-- U.S. 3,704,756, c. 12/5/72, f. 7/19/71 (Appl. 163,640); T.O. Wolda, asr.; (Boyles Industries Ltd)

A lowering and retrieving system is described that may be used when core drilling, either up or down, including drilling at any inclination. A flexible seal element is mounted around the periphery of the lowering and retrieving device and looped over a pin on a movable actuator element. The flexible seal element forms a fluid seal with a hollow drill string allowing the lowering and retrieving device to be pumped through the drill string. An elongated spear head on a retractable core barrel contacts and moves the movable actuator element thereby changing the position of the flexible seal element and a fluid channel around the lowering and retrieving device is opened. (11 claims)

CORE BARREL

173,907

A VIBRATORY DEVICE FOR TAKING OCEAN FLOOR SEDIMENT CORES-- Gr. Brit. 1,312,120, c. 4/4/73, f. 8/4/70 (Appl. 37,654); Z. P. Edigariav, E. I. Kudinov and V. E. Sukhov, asrs.; (USSR Agency)

The present invention relates to devices for taking sediment cores from the ocean floor. It consists in a vibratory device, comprising a string of pipe, a vibrator disposed on the string of pipe for sinking the pipe into the ocean floor, an arrangement for providing for periodical engagement and disengagement of the vibrator with the string of pipe, a hoist providing for periodical displacement of the vibrator, which is originally disposed on the lower portion of the string of pipe, up the string as the latter is being sunk into the ocean floor, and operatively coupled with the engaging arrangement. A piston is freely displaceable in the string of pipe and fixed relative to the ocean floor when the pipe is being sunk, to retain the ocean floor sediments in the pipe. The core of sediment is pressed against the piston under the action of hydrostatic and atmospheric pressures. A system is provided for stabilizing the device consisting of a load platform, a float, and guide cables. (6 claims)

CORING EQUIPMENT

174,452 ✓

VIBRO-PERCUSSION CORING APPARATUS-- Fr. 2,133,132, c. 11/24/72, f. 4/8/71 (Appl. 12,554); Sondages Inject Forages SA; Abstr., BULL. OFFIC. PROPRIETE IND. (FR.) v. 13, No. 52, Pt. 3 (No. 47), p 30154, 12/29/72 (In French)

The core tube is associated with a bottomhole-type pneumatic hammer. This apparatus is used mainly in civil engineering work. (No more information) (Abstract only - original article not available from T. U.)

CORING EQUIPMENT

176,416 ✓

A VIBRATORY CORING SYSTEM FOR CONTINENTAL MARGIN SEDIMENTS-- R. L. McMaster and C. E. McClennen (Rhode Island Univ); J. SEDIMENT. PETROLOGY v. 43, No. 2, pp 550-552, June 1973

A vibratory coring system has been developed specifically to sample sands on continental margins for more detailed data concerning sedimentary processes. It consists of 3 vibration mechanisms with attached 2 m coring tubes, a battery powered energy source, and a locking compass for orientation. Coring units, 2 m apart, are located at the apices of a triangular platform. Field tests indicate that the system is operational at all depths on the continental shelf.

CABLE TOOL DRILLING

178,119

✓ CORE DRILLING APPARATUS FOR CABLE TOOL DRILLING-- Belg. 732,032, f. 4/24/69; (Diamant Boart SA); Abstr., REC. BREV. INVENT. (BELG.) v. 1969, No. 4, p 1594, 3/16/73 (In French)

This core drill consists of a set of exterior tubes, a drilling bit, and means of retrieval by cable. The drilling head carries the drilling bit and is equipped with means for breaking off the core, a set of inner core tubes, and means for locking and unlocking the apparatus. The means for retrieval consist of sleeves sliding within each other. The drilling head and the means of retrieval can slide within the exterior set of tubes under the action of a pressurized fluid or of a cable. (Abstract only - original article not available from T. U.)

CORE BARREL

178,860

WIRELINE CORE BARREL WITH RESILIENT LATCH FINGERS-- U.S. 3,739,865, c. 6/19/73, f. 6/7/71 (Appl. 150,485); T.O. Wolda, asr.; (Boyles Industries Ltd)

This wireline core barrel system may be used when drilling up or down, including drilling at various inclinations. Latch fingers that are flexible and resilient are rigidly connected to the core barrel body. The latch fingers are moved into and retracted from a latch seat by a movable actuator that bends the latch fingers in a first actuator position and allows them to spring back into shape in a second actuator position. The core barrel system provides a predetermined pressure signal indicating latching and blocks fluid flow until the core barrel is properly latched. (17 claims)

CORING

179,813

DEEP ROTARY CORE DRILLING IN ICE-- G. R. Lange; COLD REG. RES. & ENG. LAB. TECH. REP. No. 94, 46 pp, Feb. 1973; Abstr. No. W73-09079, SELEC. WATER RESOURCES ABSTR. v. 6, No. 14, pp 5-6, 7/15/73

A method of drilling holes and obtaining core to depths of 1,500 ft in high polar glaciers was required for International Geophysical Year (IGY) glaciological investigations. Rotary drilling equipment was modified and sent to Greenland and the Antarctic. Principal modifications included the use of chilled compressed air as a circulating fluid and specially designed coring bits. During initial trials in NW. Greenland in 1956 nearly continuous core was obtained to 970 ft, but the core was badly cracked at depth. A second season in Greenland produced much more continuous core to 1,000 ft, and single coring runs at the 1,100-, 1,200- and 1,300-ft levels produced usable core. Core cracking at depth persisted although it was less severe. During the Antarctic field season of 1957-1958 similar equipment was used to take continuous core to 1,000 ft at Byrd Station for the IGY glaciological program. The use of a special constant rate of feed device for coring and improved techniques based on experience gained in Greenland resulted in further improvements in core condition and rate of recovery. (Abstract only - original article not available from T. U.)

CORE BARREL

179,812

DOUBLE TUBE CORE BARREL WHICH IS LOWERED THROUGH DRILL PIPE-- U.S. 3,741,323, c. 6/26/73, f. 3/19/71 (Appl. 126,029); D. Constantinescu, S. Cruceanu, E. Spataru and N. Mereanu, asrs.; (Inst Proiec Cerc Util Petr)

A double tube core barrel, which is to be lowered through a drill pipe, has a locking system between inner and outer tubular parts thereof which is particularly characterized by its sturdy and simple construction. The locking system has 2 free, unlinked oscillating locking plates, the closing of the plates for releasing the locking system being accomplished by means of a sliding sleeve of special construction. This system eliminates every kind of failure of the locking system due to accidental deflection of the locking parts of classical systems provided with links. The core barrel of the invention also preferably has a novel system for breaking the core. Such core breaking system is provided with 2 core retainers. The supplementary core retainer is mounted on the outside tube; this allows the avoidance of traction overloading of the inner tube by reason of the taking over of these stresses by the outside tube. The system of the invention can be applied to core barrels with large sizes. When coring in soft rocks, the supplementary core retainer can be omitted. (1 claim)

MARINE EXPLORATION EQUIPMENT

181,624

IMPROVEMENTS IN AND RELATING TO APPARATUS FOR DRILLING ROCK-- Gr. Brit. 1,334,651, c. 10/24/73, f. 11/25/69 (Appl. 57,554); D. Flinn and E. Harrison

An apparatus is described for drilling rock under water as on the sea floor. Such a relatively small and transportable rock drilling or sampling apparatus is intended principally for securing small rock samples. When the drilling tool has cut a sample core, the latter may be snapped off cleanly from the parent rock by operation of the wedge member and continued rotation of the tool until the drilling operation has been interrupted. It is preferred that the tool driving means is an electric motor which may, conveniently, be carried by the support, and may be energized from storage batteries. (11 claims)

CORE HANDLING
187,309
CORE TRAYS-- U.S. 3,786,932, c. 1/22/74, l. 10/8/71 (Appl. 187,757); C.M. Smith, asr.; (Schlegel Co Canada Ltd)

The invention relates to a plastic drill core tray of the type having a number of longitudinally extending channels disposed in a side by side relationship which are dished in cross-section to contain a drill core. The effective contained angle of the cross-section at the dished bottom of the channels is greater than 90°. The plastic tray is reinforced with elongated metal reinforcing ribs having a U-shaped cross-section. The ribs are adhered to adjacent longitudinally extending marginal areas of adjacent channels to provide longitudinally extending reinforcing means, and the contained angle of the cross-section of the tray at the adjacent longitudinally extending areas is less than 90°. (2 claims) (Continuation-in-part of U.S. Appl. 42,770, l. 6/21/70)

CORE BARREL
188,791

AN IMPROVED CORE CATCHER FOR THE KIEL BOX CORER ("KASTENLOT")-- F. Warner; MAR. GEOL. v. 15, No. 5, pp M59-M65, Dec. 1973

The optimum efficiency of the Kiel box corer (Kastenlot) is dependent upon certain mechanical properties of the sediments. To avoid this limitation, a new core catcher was constructed and has been tested for several years in both shallow and deep-water sediments. The essential part of this catcher is a reinforced canvas curtain which is pulled slantwise through the core before the corer is pulled out of the sediment.

CORE BARREL
191,265

CORE DRILLING APPARATUS-- U.S. 3,804,184, c. 4/16/74, l. 3/8/73 (Appl. 339,052); M.T. Gussman, L.P. Konstantinov, B.D. Malkin et al.

Mounted on the exterior of a nonrotatable core barrel is an end of a resilient tape, the other end of which extends inward into the barrel and is connected to a device for pulling the tape inward into the barrel. The apparatus also is provided with an arrangement which forms a sleeve from the tape as this is being pulled into the core barrel. During the coring operation, the tape is being pulled inward into the barrel and a sleeve is formed from the tape with the aid of the arrangement to encase and protect the core from disturbance. The coring apparatus is intended for core drilling in soft, unconsolidated, and fractured formations. (3 claims)

WIRE LINE CORE BARREL
193,555

APPARATUS FOR BOTTOM-HOLE CORING-- U.S. 3,807,511, c. 4/30/74, l. 11/17/72 (Appl. 307,687); D.L. Oliver, asr.; (Cities Service Oil Co)

An apparatus for the bottom-hole coring of formations during drilling consists of a core bullet holder having a core bullet and positioned within an aperture of a ballie plate located in a drill string. The core bullet holder is also positioned with an aperture of a drill bit to allow exposure of the core bullet to an undrilled sample of the formation. A cartridge is positioned within a cartridge chamber in proximity to the core bullet. A firing pin is located above the cartridge chamber and is driven into the cartridge to fire the core bullet into the formation by a piston slidably positioned within a piston chamber located in the upper portion of the core bullet holder. The piston is engaged by a trigger member which extends through an aperture in the core bullet holder. The trigger member releases the piston when contacted by the ballie plate as the core bullet holder passes through the aperture. (11 claims) (Continuation-in-part of U.S. Appl. 129,493, l. 3/30/71)

CORING EQUIPMENT
194,270

THE CBI POGO STICK CORER-- J.B. Schubel and E.W. Schiemer; JOHNS HOPKINS UNIV. SPEC. REP. No. 34 (Rel. 73-13), 8 pp, Nov. 1973; Abstr. No. W74-06923, SELEC. WATER RESOURCES ABSTR. v. 7, No. 13, p 90, 7/1/74

The Chesapeake Bay Institute Pogo Stick Corer is a novel and useful device for collecting short, relatively undisturbed cores of fine-grained sediments in waters up to about 3 m deep. The corer is patterned after a child's pogo stick. The operator thrusts the corer into the bottom by hand, then mounts the device and jumps it into the sediment. (Abstract only - original article not available from T.U.)

FARY CORE BARREL

195,649

CORE SAMPLING DEVICE AND METHOD-- S. Afr. 73/3,751, c. 3/19/74, f. 6/4/73 (pr. Austral. 6/9/72, Appl. 9,290); P.R. Dobson, asr.; (Gray (G) & Co Pty Ltd); Abstr., PATENTJOERNAAL (S. AFR.) v. 7, No. 4, p 218, April 1974

A method for obtaining a core sample consists of:

- (1) drilling to a specified sample taking depth; (2) passing a core tube casing containing an open core sample tube into the material below the depth to receive a core sample, such that the core sample tube is maintained in fixed relation to the casing, and the casing and sample tube extend into the material from within a hollow auger or bore; (3) motioning the core sample tube toward the sample taking depth, thereby actuating closure means to seal the sample tube adjacent its innermost end; and (4) withdrawing the sample tube, containing the sample. (14 claims) (Abstract only - original patent not available from T. U.)

CORING EQUIPMENT

197,038

AN INEXPENSIVE HAND-OPERATED SEDIMENT CORER--

R. G. Sutton (Rochester Univ); J. SEDIMENT. PETROLOGY v. 44, No. 3, pp 928-930, Sept. 1974

A piston corer has been developed that permits sampling of shallow-water and dry beach sands. It is simple, light weight, easily operated and inexpensive. The piston head consists of a piece of cellulose sponge that permits a partial vacuum to be created providing space for the core tube penetration as well as allowing water to soak the sediments that reduces friction and facilitates extrusion.

CORING EQUIPMENT

197,039

THE CBI POGO STICK CORER-- J. R. Schubel and E. W. Schiemer (Johns Hopkins Univ); J. SEDIMENT. PETROLOGY v. 44, No. 3, pp 936-938, Sept. 1974

The CBI Pogo Stick Corer is a novel and useful device for collecting short, relatively undisturbed cores of fine-grained sediments in water up to about 3 m deep. The corer is patterned after a child's pogo stick. The operator thrusts the corer into the sediment by hand, then mounts the device and forces it into the sediment with a jumping motion.

CORING

198,557 ✓

CONCEPTUAL DESIGN OF A CORING SUBTERRANE

GEOPROSPECTOR-- J. W. Neudecker; Los Alamos Scientific Lab. Rep. No. LA-5517-MS, 14 pp, Feb. 1974; Abstr. No. 26788, NUCL. SCI. ABSTR. v. 29, No. 11, p 2591, 6/15/74

A rock-melting Subterranean system is described that can obtain a continuous core along the projected route of a tunnel. System specifications, individual component functions, preliminary design concepts, and design alternatives are included; and subcomponents that can be assembled from commercially available hardware are indicated. The device requires 150 kw of electric power to melt an accurate 300-mm (1-ft)-diam glass-lined hole and removes a 200-mm (8-in.)-diam glass-cased core at an advance rate of 0.4 mm/sec (5 ft/hr). The accurate hole diameter and stable hole lining allow the use of a packer-thruster located at the heated hole-melting and hole-forming penetrator assembly. An orientation sensor and a guidance unit can also be located in this assembly. A hollow, flexible stem trailing behind the assembly contains the electric-power, coolant, and instrumentation lines, and provides a passage for debris removal. Core sections are removed through the flexible stem intermittently with wire-line core-retrieval hardware. (Abstract only - original article not available from T. U.)

CORING EQUIPMENT

198,777 ✓

DOWNHOLE ELECTRICAL CORE DRILLING SYSTEM--

U.S. 3,837,412, c. 9/24/74, f. 12/6/72 (Appl. 312,629); W. B. Driver

A downhole electric core drilling system is described that is lowered into a well hole by an electric cable to drill a core sample or to drill a well hole. The system consists of a core bit, core barrel, and a reduction transmission powered by an electric motor. This assembly is attached to the downhole end of a drill collar, which has its up hole end attached to the electric cable, which is used to raise and lower the system in a well hole and provide electric power to the system. The core barrel contains a mechanism, which when activated by a drilled core, cuts the drilled core from the formation from which it was drilled, and holds the drilled core in the core barrel while the system is hoisted to the top of a well hole. (7 claims)

CORING

199,308

CORING APPARATUS-- Belg. 772,340, f. 9/8/71
(Appl. 772,340); (Diamant Boart SA); Abstr., REC. BREV. INVENT. (BELG.) v. 1974, No. 22, p 333, 8/12/74
(In French)

This invention describes a coring apparatus with an extractor spring having a longitudinal slot and equipped with teeth on its internal surface. Grooves on the internal surface defined by rows of teeth are arranged symmetrically with respect to the axial plane through the center of the longitudinal slot. This arrangement imparts a rigidity to the extractor spring which is proportional to the flexing moment, between the rows of teeth and on each side of the plane of symmetry. (Abstract only - original patent not available from T. U.)

CORING

199,647

DRILLING ASSEMBLY AND PROCESS FOR LIFTING IT TO THE SURFACE-- Fr. 2,203,016, c. 5/10/74,
f. 10/16/73 (pr. Japan 10/16/72, Appl. 102,734);
(Sumitomo Metal Mining Co); Abstr., BULL. OFFIC. PROPRIETE IND. (FR.) v. 15, No. 24, Pt. 2 (No. 19),
p 9382, 6/14/74 (In French)

This drilling apparatus intended for great depths consists of a drill pipe and a cutting element which can be inserted into the pipe, including a locking mechanism. This locking mechanism is attached to a pulling device which is engaged in the pulling mechanism of the lifting apparatus, so that when the pulling device is activated, an interior pipe and an exterior pipe which are part of the locking mechanism move with respect to each other and thus unlock the drill pipe and the cutting element. This is accomplished faster and easier than by the conventional technique. This apparatus is used in particular for obtaining geologic samples. (Also related to Japan 11/20/72 (Appl. 132,752), Japan 7/28/73 (Appl. 84,594), Japan 8/8/73 (Appl. 88,520), Japan 8/10/73 (Appl. 93,640) and Japan 8/21/73 (Appl. 97,233)) (Abstract only - original patent not available from T. J.)

CORING

199,648

INSTALLATION TO TAKE SAMPLES IN LOOSE GROUND--
Neth. Appl. 7,402,346, f. 2/20/74 (pr. Fr. 2/20/73,
Appl. 6,000); (Inst Francais du Petrole) (In Dutch)

The invention relates to an installation to take samples in loose ground. It contains a rigid, tube-shaped body in which a sample carrier tube can be moved under the influence of remote-control means. The sample tube can move from a first position in which the tube is secured in the body to a second position wherein the tube extends from the body and penetrates into the loose ground. The body is connected to a source of drilling fluid and to driving means for rotation. The body has a drilling crown having a bore through which the sample tube can move into the second position. There are means to close off the end of the sample tube. (18 claims)

CORING EQUIPMENT

202,045

DRILL INSTALLATION WITH REMOVABLE CORE BARREL AND CENTRAL PART-- Neth. Appl. 7,405,173,
f. 4/17/74 (pr. Fr. 4/17/73, Appl. 13,967); (Cie Francaise Petroles) (In Dutch)

The invention relates to a core drilling apparatus with an interchangeable core barrel and central part. The core barrel and removable part of the tool each contain a carrying pipe in which the mechanisms are installed. The pipe is kept vertical by a seat on a receiver tube which rotates with the tool. The carrying pipe is isolated at its upper part from the drilling fluid by an element containing a closeoff, which is installed against the fastening pipe, rotating with the tool. The core barrel and removable central part contain passages to circulate the drilling fluid at a pressure which is lower than the pressure of the drilling fluid above the closeoff element. (10 claims)

CORING EQUIPMENT

206,677

TECHNICAL AND ECONOMIC ADVANTAGES OF THE HYDRAULIC ANNULAR VIBRO-HAMMER FOR UNDER-WATER SAMPLING AND GEOTECHNICAL IN-SITU INVESTIGATIONS-- L. Menard; 11TH INT. ACOBOR EXPLOIT. OF THE OCEANS COLLOQ. (Bordeaux; Fr., 10/1-4/74) TRANS. v. 2, 17 pp, 1974 (Bx 117) (In French)

The Vibro-Hammer is a hydraulic underwater coring tool with 4 double action unbalanced weights with an incorporated hammer. Its rotary action extends sampling possibilities from sediments to rocks. It can work in 200 m of water and recover up to 100 m of samples. It can be worked from a supply vessel. The maximum weight is about one ton. It is used for anchoring of oil platform piling, prospecting for ore deposits, sample-taking for geological purposes, etc.

CORING

210,075

CORE DRILLING APPARATUS-- Can. 971,550, c. 7/22/75, f. 2/15/73 (Appl. 163,829); M. T. Gusman,

L. P. Konstantinov, B. D. Malkin, G. M. Nikitin et al., asrs.; (USSR Agency); Abstr., CAN. PAT. OFFICE REC. v. 103, No. 29, p 29-54, 7/22/75

The present invention provides a coring apparatus for core drilling consisting of a splined telescopic joint to adapted to be connected to a drill string. A housing is attached to the splined telescopic joint at its upper end and connected to a core bit at its lower end. A core barrel is arranged inside the housing and suspended from the housing by means of bearing. A sleeve, insuring producing and retrieval of core in undisturbed condition is formed of a tape made of resilient material. One end of the tape is mounted on the exterior of the core barrel. The other end extends inward into the barrel, and the longitudinal edges of tape are adapted to be joined one with another so as to form the sleeve which encases the core as it is produced and enters the core barrel. Means for pulling the tape inward into the core are provided. A clamping device is connected to the end of the tape extending inward into the core barrel and to the means for pulling the tape inward into the core barrel. Means for joining the longitudinal edges of the tape and forming the sleeve from the tape are provided. (3 claims) (Abstract only - original patent not available from T.U.)

CORING EQUIPMENT

211,907

REMOTELY OPERATED SEAFLOOR CORING AND DRILLING METHOD AND SYSTEM-- U.S. 3,891,037, c. 6/24/75, f. 12/26/72 (Appl. 318,114); D. E. Well and K. C. Marley

A method and apparatus are described for emplacing a structure such as a casing, piling or core barrel into the floor of a body of water. The structure is mounted on a towable and submersible vessel which includes a number of ballast tanks. Means are provided to selectively vary the ballast in certain tanks in a

manner to cause the vessel to have selectively controllable negative or positive buoyancy for descent or ascent. A support device on the vessel moves the structure between a horizontal orientation for towing and descent and an upright position for drilling. The vessel descends with a positive metacenter to maintain the established orientation until it reaches the sea floor, after which it is anchored and leveled for the drilling operation. (3 claims)

CORING

212,682

CORE DRILL FOR SOIL LAYERS-- Fr. 2,240,346, c. 3/7/75, f. 8/8/73 (Appl. 29,050); (Armadillo Holdings Ltd); Abstr., BULL. OFFIC. PROPRIETE IND. (FR.) v. 16, No. 15, Pt. 2 (No. 10), p 4617, 4/11/75 (In French)

This core drill with back-and-forth movement consists of a central shaft and a circular shield surrounding the shaft, maintained concentric with the shaft by 4 cutting blades. The shield decreases in diameter from fore to aft so as to slightly compress the core being drilled. The back edges of the cutting blades are equipped with alternately bent teeth which help in pushing out the core when it is extracted from the core drill. (Abstract only - original patent not available from T.U.)

CORING EQUIPMENT 214,772
UNDERWATER DRILLING APPARATUS, ESPECIALLY
CORE DRILL-- Ger. 2,121,007, c. 6/19/75, f. 4/29/71
 (Appl. 2,121,007); R. Stock, A. Tiemon and H. Bertele,
 asrs.; (Dornier System GmbH); Abstr., AUSZUEGE
AUSLEGESCHRIFTEN (GER.) v. 21, No. 25, p 1813,
 6/19/75 (in German)

This underwater core drilling apparatus consists of a supporting frame carrying the drive and at least one drill string with a bit. The frame also carries a magazine containing at least 2 drill strings with their own bits, in an axially parallel arrangement. (Abstract only - original patent not available from T. U.)

CORING EQUIPMENT 214,773
CUTTER DEVICE FOR EARTH CORING--
Gr. Brit. 1,412,542, c. 11/5/75, f. 7/27/73
 (Appl. 36,000); S. G. Atkins and S. B. Ballie, asrs.;
 (Armadillo Holdings Ltd)

A cutter device is described, for use in push-pull earth coring, consisting of a shaft for attaching the device to a push-pull driving means. A shell surrounds the shaft, and knife means extend between the shaft and the shell to maintain the shell concentrically spaced from the shaft. The shell is in the form of a truncated cone, with the narrower end adjacent to one end of the shaft and the wider end adjacent to the other end of the shaft. The knife means is edge-sharpened on the edge adjacent to the wider diameter end. (6 claims)