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FIELD AND LABORATORY PROCEDURES FOR ORIENTED CORE ANALYSIS OF DEVONIAN SHALES

Prepared

by

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FIELD AND LABORATORY PROCEDURES FOR ORIENTED CORE ANALYSIS OF DEVONIAN SHALES

by

C. W. Byrer[1/] and C. A. Komar[2/]

ABSTRACT

Field and laboratory procedures for handling, performing a lithologic description, marking azimuth directions, mapping the native fractures and measuring directional physical properties of oriented cores are described. In the fulfillment thereof, directional properties of tensile strength, and sonic velocity are correlated with preferred planes of weakness and orientation of visible fractures in the core to ascertain the preferred direction of fracture orientation that should occur in the hydraulic fracturing process. Characterization of the lithology is required to identify intervals for stimulation. Measurements of hardness are conducted to identify containment barriers to fracture growth vertically. All information is required to assist in the design and the development of a pattern of fractured wells for commercialization. Definition and description of the activities required to extract and characterize the oriented cores should serve as the standard methodology for all Devonian Shale core analysis.

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INTRODUCTION

The task description and procedural summary of the field and laboratory procedures for oriented core analysis is divided into five STAGES. The initial phase is the planning of cored wells and the preparation of personnel and equipment for field work. The second phase of the core handling involves the field procedures at the core well site. Once the core is in the oriented core laboratory, the third phase entails actual laboratory tasks and tests. The fourth phase includes compiling, correlating, and summarizing all the data gathered in the laboratory. The final stage is to properly store/archive the remaining core sections for possible additional sampling.

Task No.	Task Description	Task Procedure
	I. Planning and Preparation	
1.	Preparation of field personnel	Initially, the core well site is located on a regional map. Specific directions to the well site are obtained from the drilling contractor and these directions are relayed to all interested parties. Information normally acquired is the distance to the well location, the amount of core to be taken, and the equipment needed. Communications with the coring and directional survey companies, and involved private and government agencies/labs along with other interested organizations are then completed as a tentative coring date is scheduled.
2	Equipment requirement	A. FIELD EQUIPMENT NEEDED 1. Adquate vehicles for the field requirements 2. Cardboard boxes (3' x 4¼" x 4¼") 3. Plastic bags (3' and 1½' lengths--.006 ml thickness) 4. Magic markers (medium and wide tip) 5. Tape measure (30') 6. Wooden boxes (3' x 7" x 7") at least 4 boxes are needed 7. Strip charts (lithologic description) 8. Staple pliers (½" staples) 9. Lights or lanterns

Task No.	Task Description	Task Procedure
		10. Tarpaulin (12' x 12') 11. Sheet plastic (.006 ml) 12. Portable canner and cans (2 qt. capacity) 13. Camera (35 mm with flash) 14. Sponges and buckets B. SAFETY EQUIPMENT NEEDED 1. Hardhat 2. Hardtoed Boots 3. Safety Glasses 4. Cotton Gloves 5. Raincoat and Rain Pants 6 First Aid Kit 7. Flashlight 8. Adequate Seasonal Clothing
	II. <u>Field Work</u>	
3.	Retrieval of core	The field work at the well site is divided into several phases. The first phase is the retrieval of the core which requires removing it from the 60' core barrel. The length of the core in the barrel is only 58 feet in order to keep the core from jamming in the barrel. At times a 30' core barrel will be utilized if core has a tendency to jam in the core barrel. The smaller barrel may also be used if only a small amount of core is to be taken. Actual coring time per core barrel varies depending upon the zones being cored. The time required to bring the barrel to the surface is usually 1-2 hours. The retrieval of the core from the barrel is the most critical phase in the field. Care is exercised in handling the core on the rig floor and in keeping one's hands out of the area directly beneath the core barrel. At times the core will slip down from the core barrel when retrieving the core. The core is transported from the barrel on the rig floor in wooden 3' boxes or sleeves and

Task No.	Task Description	Task Procedure
		reassembled on casing or troughs of angle iron near the drilling rig. The core is initially reassembled as accurately as time allows while the core is being retrieved. Arrows are placed on the wooden boxes showing which direction is down-hole. Attention is required so that the core sections are not upside down when reassembled.
4.	Reassembling core	The placing of 3' sections of core on a core trough is the preferred procedure. The core is lined up by the three orientation grooves which are on the core. Shear fractures, vertical fractures, and broken pieces of the core usually will occur throughout the entire cored section.
5.	Removing drilling mud	The next phase is to clean the drilling mud from the core section. This is necessary to mark the depth and describe the core lithologically. A damp sponge is used to wipe the drilling mud off.
6.	Marking depth of core	This phase includes marking the core every foot and putting down-hole arrows on the core. The core must be dry before marking the core. Care should be taken not to duplicate or omit any depth. A record of depth will then be correlated with the drillers log/geolograph.
7.	Lithologic description	A general lithologic description of the core is recorded on a strip chart along with visible fractures. The scale shall be 1" = 1'. All gas and oil shows are recorded along with other significant characteristics.
8.	Photographing core	Those sections of the core of immediate significance to research personnel are photographed. Necessary photographic accessories are available for night operations. Close up photographs with a 35 mm camera suffice for the quality of photographs needed.

Task No.	Task Description	Task Procedure
9.	Sample selection	The samples used for geochemical analysis, outgassing, and other tests are extracted and recorded. These samples do not exceed 5 inches in length and are canned as soon as possible. The time of the actual coring of a particular section containing the selected sample is noted. The time of canning is also noted so that the exposure time before sealing is known.
10.	Placement of core in boxes	The core specimens are now ready to be placed in boxes. The boxes (3' x 4¼" x 4¼") should be assembled with staples placed so that they point in, and the boxes marked before each core barrel is emptied. The name of the cooperating company, well number, and box number is marked on top of the box as it is assembled. The core is placed in clear plastic which has been draped in each core box and then the core is wrapped tightly with the plastic and taped. Plastic bags could also be used. The depth of the core (interval) is then added to the other information on the box top. The core is stacked and covered properly for future transport back to the laboratory. Each foot of shale core weighs approximately 10 pounds. An adequate vehicle is required to haul the core to the designated laboratory.
11.	Time allotment of field work	The above sequence from retrieving core in the barrel to boxing the core takes between 3-4 hours with four personnel. The crew can anticipate when the next barrel will be ready after boxing the last sections of the previous core. This time interval may be shortened if the next core jams in the barrel. Coring rates when drilling with mud (aquagel, water, barite mixtures) will be considerably longer than the air-soap (foam) mixture.

Task No.	Task Description	Task Procedure
III.	Core Laboratory Procedures	
12.	Labeling core boxes for storage	After the core has been transported back to the laboratory, the first step is to properly label one end of the box for storage on shelves. The company name, well number, box number, and depth interval must be transferred clearly and legibly to the end of the core box. A four-man crew could label boxes containing 250'/day.

Sample:

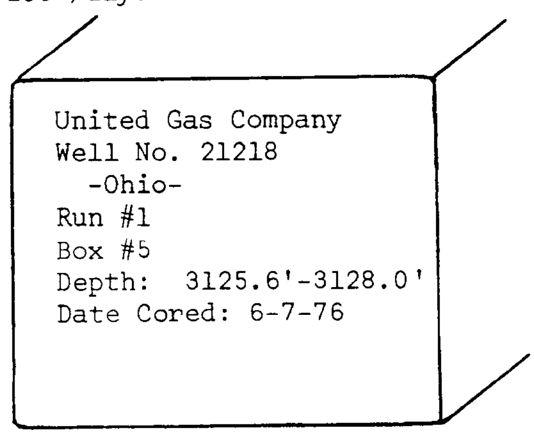


Figure 1. - Typical Documentation

Task No.	Task Description	Task Procedure
13.	Placing of core in shelving	The boxes are then placed in the storage shelves in descending sequential order beginning with the first box of the first run and ending with the last box of the last run. Shelving should be constructed in order to accomodate as many boxes as possible.
14.	Hardness test	The core is now ready to be processed and examined by various tests in the laboratory. A four man crew is necessary to efficiently process the core samples. The first test performed is the hardness test. This test gives a quick analysis of the relative hardness of the core sections. The test is performed with a scleroscope which uses the Shore scale of hardness as the standard.

Task No.	Task Description	Task Procedure
		Tests are made taking 10 readings per foot on either the side of the core or the flat surface of a bedding plane. Whichever surface is used, it must be used consistently throughout. These 10 readings are added together, divided by 10, and an average hardness reading is obtained for each foot. Two personnel operate two scleroscopes simultaneously and read the values from the instruments while two personnel record the figures, take averages, and place them on a composite sheet in descending well order. A four-man team can test an average of 100'/day. These data are used in conjunction with the well logs to determine depth intervals of varying strength characteristics which can be interpreted as barriers to fracture growth vertically.

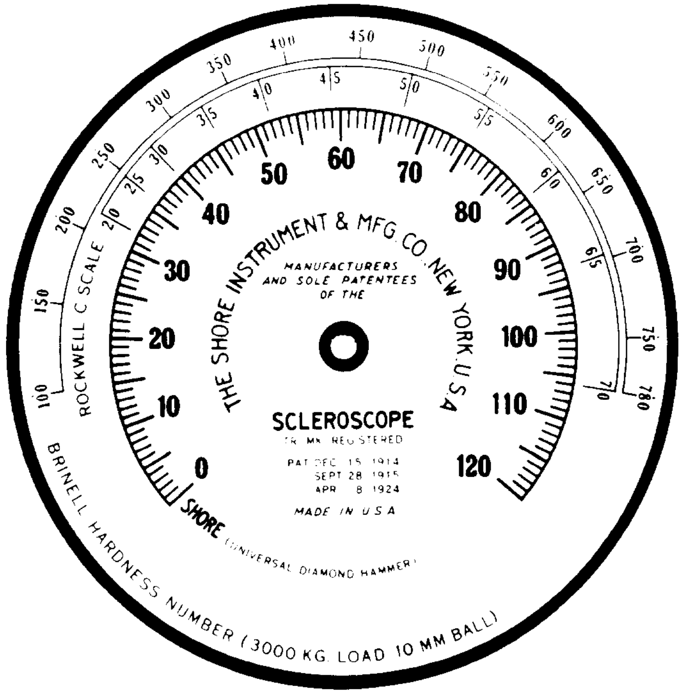


Figure 2. - Scleroscope Scale

Task No.	Task Description	Task Procedure
15.	Reassembling core	Two boxes of core (approximately six feet of core) are placed on a core holder (wooden tray) and reassembled. The core is wiped clean with a damp sponge if drilling mud is evident on the outer surfaces. Down-core arrows and depth marks are then retraced if necessary. This stage may be time consuming if the core sections are highly fractured.

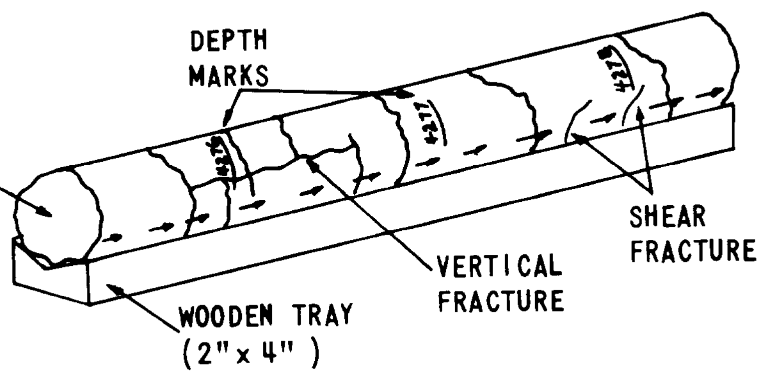


Figure 3. - Reassembled Core in Laboratory

16.	Orientation of core	The next step is to orient the core by coordinating the grooves on the oriented core with the compass on the goniometer. The grooves on the core have been previously set according to the core orienting log. The orientation log of the cored section shows the drift and orientation of the core every two feet. The reference groove column on the log is the most significant for orienting purposes. This phase allows the core to be labeled in its natural orientation. After orienting the core every two feet, all

Task No.	Task Description	Task Procedure
		of the core can be marked by use of a straight edge and the four major compass points can then be marked on the core. The marking pen should have a medium-size point.
17.	Recording of core fractures	The next phase of the core analysis is to record all visible natural and induced fractures in the core according to the fracture format (Table 1). All fractures are numbered, described according to depth, type, length, strike, and dip. Additional descriptive features may be present such as slickensides, mineral fillings and face marks. Additional interpretation may include natural or induced fracture, lithology in which fracture occurs, and any additional comments which would aid in describing each fracture. The natural fracture is given particular attention when this data is recorded because it could represent highly fractured zones. Data are expressed in plots of fracture frequency and orientation over the entire cored interval as a qualitative interpretation of potentially productive intervals.
18.	Lithologic description of core	The lithologic description of the core follows a certain sequence to keep everything uniform. The description of the core takes place in a well-lighted area with a table or bench large enough for maneuvering and inspecting the core sections. After each 6 foot core section is reassembled, it is described lithologically. The grain size, texture (silt, sand, shale, etc.), color (G.S.A. Color Chart), percentage of the different colors, and additional minerals found in the core are noted.

TABLE 1. -- Fracture Data Format

Well Number 20336 Run Number 4 Date 11/15/76

Fracture No.	Depth	Type	Upper Extent	Lower Extent	Total Length	Strike	Dip	Slickensides	Fillings	Face Marks	Interpretation	Lithology Intersected	Comments
01	2757'	PCF	FS	BP	5.3	N60E	Vert.	Yes	Dol.	Yes	Nat.	Lam Sh.	1/32" Fx Width
02	2757'	Inc.	FS	BP	.20	N50E	45SE	-	-	Yes	I.	SAA	
03	2759'	Inc.	FS	BP	.10	N40E	60NW	-	Cal.	-	Nat.	Mass. Sh.	1/16" Width

Legend

PCF--Petal-Center Line Fracture
FS --Free Surface
BP --Bedding Plane
Mass. Sh.--Massive Shale

I --Induced Fracture
Inc.--Inclined Fracture
Nat.--Natural Fracture
SAA --Same as above

Lam. Sh.--Laminated Shale
Dol. --Dolomite
Cal. --Calcite
Fx. --Fracture

Task No.	Task Description	Task Procedure
		Hydrochloric acid is added as a test for the presence of calcite, dolomite, or other effervescing minerals. Additional features such as spores, spore casts, worm burrows, pyrite, cross-bedding, iron-stains, slickensides, and mineralized fractures are also noted. Organic zones (dark grey-black) and kerogen-type odors are recorded. It should be noted whether the core is whole, highly fractured, or impossible to orient or reassemble. The equipment used in describing the core includes: (1) a binocular microscope with μ scale, (2) an examining probe, (3) an aluminum engineering 6' rule (marked in tenths of a foot), (4) hydrochloric acid (10%), (5) a geological color chart, and (6) various laboratory trays, beakers, tweezers, and brushes.

TABLE 2. -- Sample Lithologic Description

Top-Bottom (Interval, ft)	
3551-3553.6 (2.6)	Shale, brownish black 5YR 2/1, interbedded with silty shale (olive grey). 5Y 4/1, slightly calcareous is some silty shale beds, pyrite nodules, carbonaceous fragments and pyritic replacement of spores (Tasmanites). 5YR 2/1, 60%, 5Y 4/1, 20%, and 5Y 6/1, 20%.

Task No.	Task Description	Task Procedure
19.	Photographic log	As the core is being oriented and described, all of the core should be photographed. The photographing of all the core ensures an accurate permanent record of the core before samples for testing and analysis destroy much of the original core. It is best to have adequate light and background in order to record the shale core for its true color as well as possible. Three-foot core sections should be the maximum photographed in any one picture. Color slide film is the easiest and least expensive film to use for this purpose.

Task No.	Task Description	Task Procedure
		Any outstanding or unusual characteristic should also be listed according to box number and depth. Later, these particular sections or unusual qualities may be photographed by a professional photographer for black and white prints, color prints, and color slides.
20.	Cutting and marking core for test samples	A. The next phase of core processing involves the selection of core samples to be used in various tests. Initially, selected core sections from every tenth of a foot along the North reference line are re-marked.
		B. The selection of Ultrasonic Velocity Test Samples is next. A 4-8 inch specimen is selected every 5 feet (if possible) and cut into a perfect cylinder. These specimens may be difficult to locate in some core sections because of the high frequency of fractures. The ends of the cylinder are sanded if rough edges or surfaces are evident.
		C. The next phase is to select and cut 2" diameter x 1" thick specimens to be used for Line Load Directional Tensile Strength Tests and Point Load Tests. Six 2" specimens per 10' core section are required for the Tensile Strength Test and six to ten 2" specimens per 10' core section are required for the Point Load Test. The ends of each sample are sanded so that a smooth surface shows the frequency and alignment of microfractures.
		D. As the samples are being prepared, the finished samples are grouped into ten foot intervals. This allows the laboratory personnel to know how many samples are being prepared in each ten foot interval.

Task No.	Task Description	Task Procedure
21.	Marking of microfractures	The next phase is to mark all microfractures on the cut surfaces. Each fracture is recorded in red pencil on the surface of the core. The length of the microfractures (in millimeters) and the quadrant (either northeast or northwest) in which they occur are recorded. All microfractures in each degree range (every 5°) of each quadrant are recorded on a composite sheet.

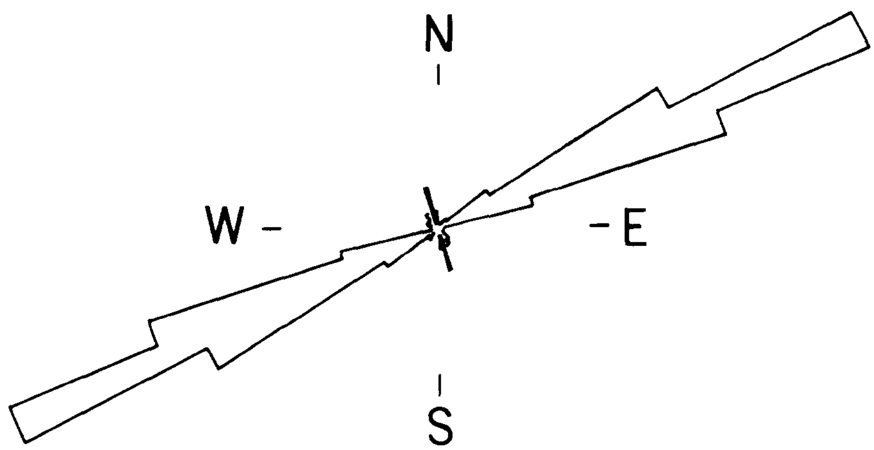


Figure 4. - Rose diagram showing average vertical fracture (Petal Center-Line Fracture) trend (N72E) of a Shale Core Well.

22.	Selection of other samples	The selection of samples for other tests performed by various laboratories may be conducted after the physical property samples are removed. The physical property samples are to be tested and then saved for additional testing/analyses which include elemental analysis, X-ray diffraction, pore size distribution, porosity-permeability, mineralogical, and others.

Task No.	Task Description	Task Procedure
23.	Directional tensile strength test	At intervals of 10 feet, six samples (2" x 1") are selected for Line Load Tensile Strength Tests. Each sample is placed horizontally between the two platens in the instrument and compressed in the manner shown in the accompanying illustration.

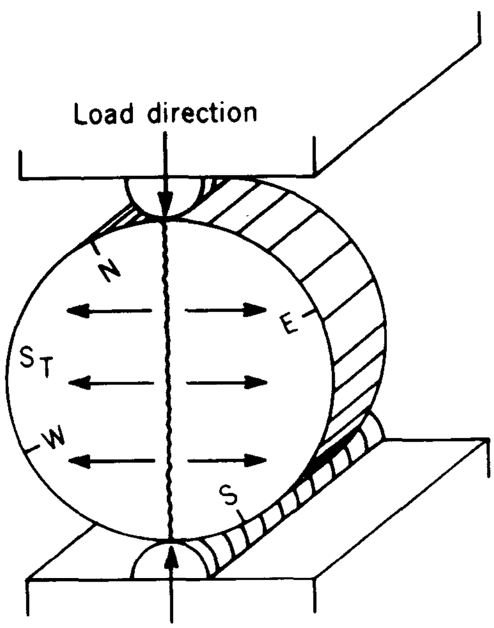


Figure 5. - Method of showing tensile strength test

Tensile strength normal to the axes of loading is determined from the magnitude of the applied load at failure by the formula (1):

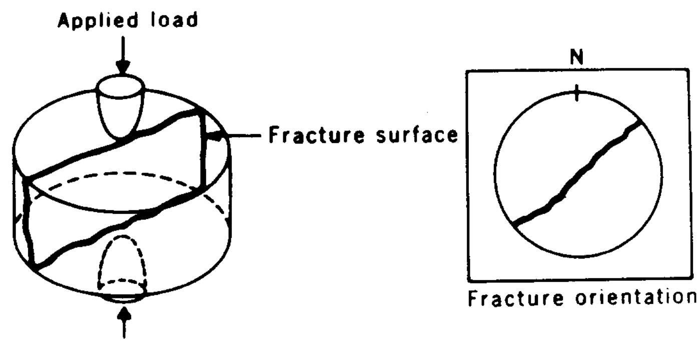
$$S_T = \frac{2P}{\pi d t}$$

where S_T = tensile strength, psi
P = applied load of failure, lb
d = diameter of disk, in
t = thickness of disk, in

1. Each sample is broken in one of six directions, 30° apart. For example, one sample is broken at N 60° W, one at N 30° W, and one at N 0°. The remaining samples are broken at N 30° E, N 60° E, and N 90° E, respectively.

Task No.	Task Description	Task Procedure
		2. The breaking load of each sample is recorded in pounds per square inch on a large circular scale (0-60,000 lbs.). The breaking point is then recorded on a composite sheet. This test usually requires two personnel: one breaking samples and the other recording the breaking point (in lbs.) on a composite sheet.
		3. In the last phase of this test, the induced fractures on the sample are numbered according to the sample number and then the fractures are traced on paper. This gives an accurate visual record of all samples. This step also requires two personnel.
24.	Point load test	The next test requires samples which do not require being grouped as in the previous test. The remaining samples are to be used in the Point Load Test. These samples should have masking tape around their circumference in order to preserve the fractures after the point load test is performed.
		1. These samples are compressed in a vertical direction by loading them directly in the center on both the top and bottom sides. Hemispherical platens are used in this test for both the top and bottom, as seen in the illustrations.

Task No.	Task Description	Task Procedure



Fracture direction at random unless a "preferred direction" of failure exists.

Figure 6. - Method of Showing Inherent Rock Weakness

Task No.	Task Description	Task Procedure
		2. The breaking point load is then read on the Tinius Olsen Scale and recorded on a composite sheet in pounds.
		3. In the last phase of the Point Load Test, the induced fractures on the sample are numbered according to the sample number and then the fractures are traced on paper.
25.	Directional ultrasonic velocity test	Once the 4-8" samples for the Ultrasonic Velocity Test have been selected, the orientation in 30° increments is recorded on one end of the sample, using a circular template. The orientations of the core to be tested are N 0° , N 30° E, N 60° E, N 90° E, N 60° W, and N 30° W. The diameter of the core is measured in each of the above directions using a

Task No.	Task Description	Task Procedure
		vernier micrometer. The sample is then wrapped with black plastic tape so that the tape just touches itself but does not overlap, and no exposed core is found. The area taped is directly in the middle of the sample, and three widths of the tape are used yielding a taped area with a width of approximately two inches. The taped area of the sample is then coated with a di-electric silicon lubricant and the sample is then placed in the sonic velocity apparatus. The ultrasonic velocity is then measured in the six directions mentioned above and an average of ten values for each direction is used as the final measurement. One technician is required to operate and record the average of the sonic impulse.

Basic Design for Ultrasonic Velocity Equipment

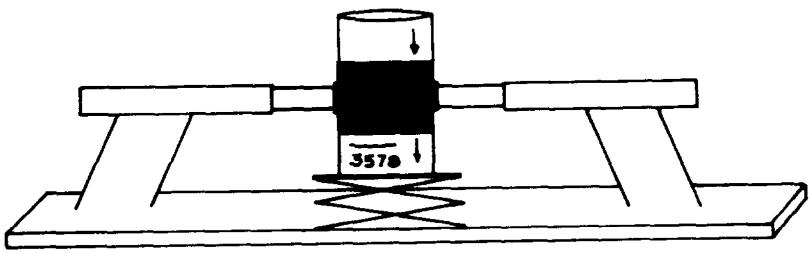


Figure 7. - Proper Alignment of Core Sample for Testing in the Ultrasonic Velocity Apparatus

Task No.		Task Description	Task Procedure
	IV.	Summarizing Data and Archiving Core	
26.		Compiling all data in oriented core lab	Several Xeroxed copies should be made of all data recorded. These copies may be distributed to all concerned personnel. All data from every test are compiled in order from the first to the last test. The data will be used for various phases of the core characterization. The lithologic description will be used as background information for the various tests on the core. The description will also be used as correlative data in locating zones of high hydrocarbon content on a regional scale. Fracture data will be used for the planning of directionally deviated wells and hydraulically induced fractures. The hardness, directional tensile strength, point load, and ultrasonic velocity tests will be utilized to characterize the rock mechanics of each core section. All the data collected in the oriented core laboratory will be used as support data in related characterization studies. Results of correlative data that are consistent enough for prediction of fracture orientation are shown in the accompanying figure. Usually statistical minimums of sonic velocity and tensile strength occur normal to the greatest occurrence of microfractures and preferred planes of weakness (2, 3, 4).

Task No.	Task Description	Task Procedure

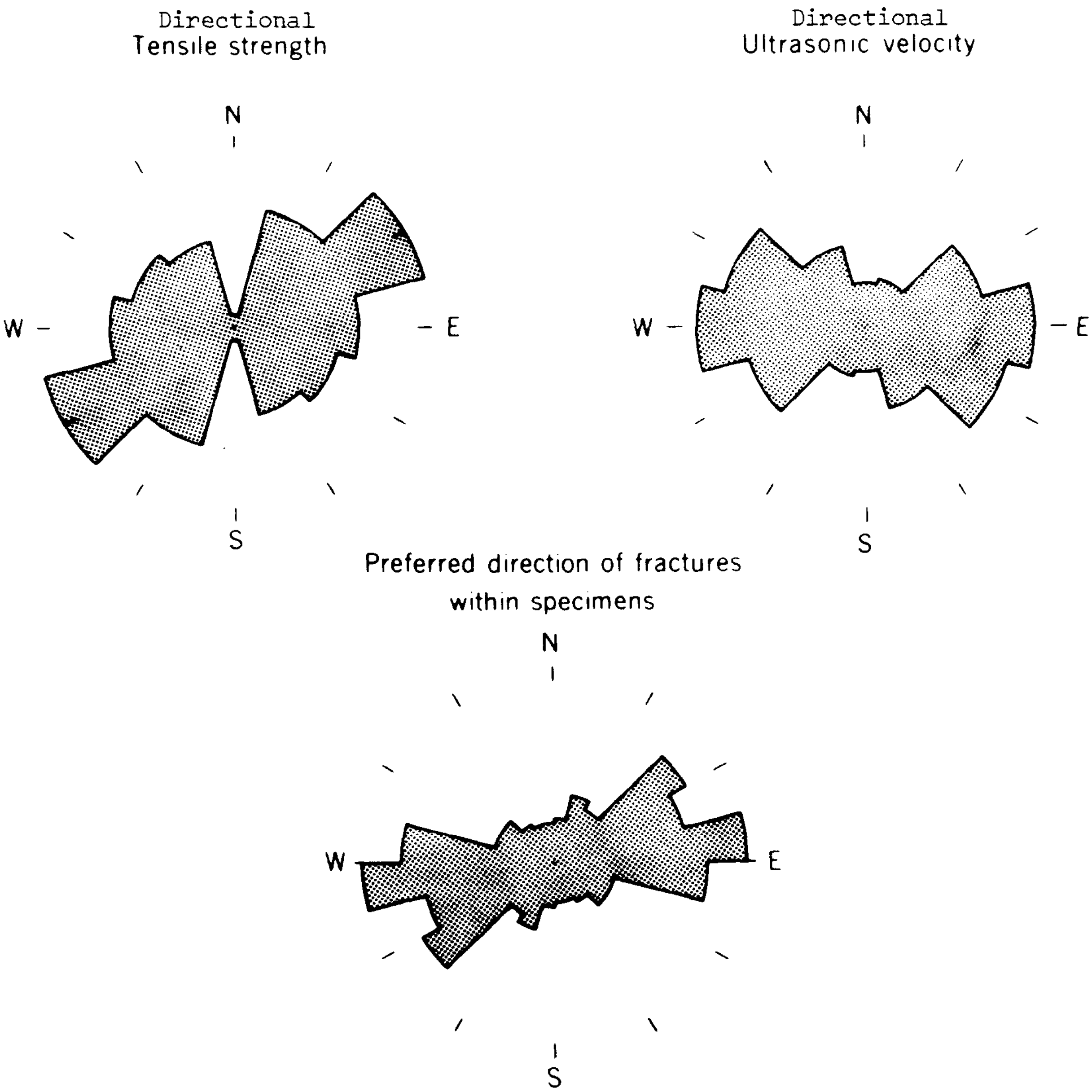


Figure 8. - Statistical Polar Frequency Diagrams of Sonic Velocity and Tensile Strength Compared to Planes of Weakness

Task No.	Task Description	Task Procedure
27.	Summarizing core well data	All data obtained in the oriented core laboratory are compiled for possible publication. Lithologic data will be published as background information for additional tests and characterization studies on the shale core. Each well cored will have pertinent geographic and geologic information related to its particular locality. A location map is constructed showing the exact location of the cored well. A general geologic column is also drafted showing the specific lithologies in the cored well locality. Additional illustrations showing the well logs, hardness test, and any of the rock mechanics results displaying significant correlations should be included in the final report, (5, 6).

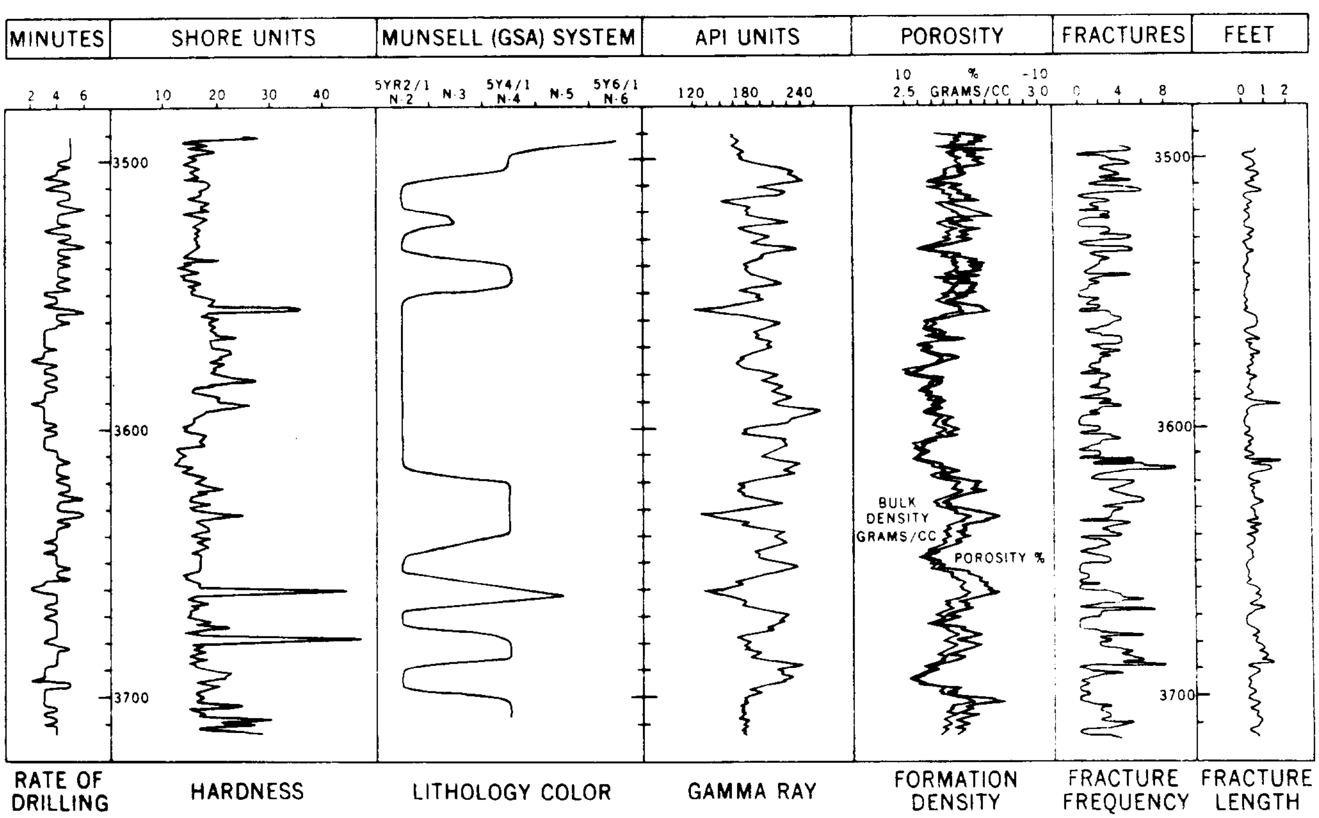


Figure 9. - Correlation Effort with Shale Core Data

Task No.	Task Description	Task Procedure
	V. Archiving Core	
28.	Archiving and proper storage of core	The final stage in the core handling procedure is proper storage of the remaining core specimens. All test samples are placed back in their proper sequence in the core boxes before the core is taken out of the laboratory. The core is stored in a building where it will be easily accessible if samples are later required. Excessive dampness, heat, and cold should be avoided in the core storage area. A record of the storage location of each cored well will be kept and updated in the oriented core laboratory files.
29.	Sampling of core	Sampling of Devonian Shale Core in the Storage/Archive Area Additional sampling may occur on the remaining core sections for more chemical, geological or physical analyses. A few suggestions for sampling the stored shale core are listed here. 1. Prior arrangements should be made for sampling a particular core at the state survey, government facility or commercial laboratory where the core is stored. 2. The storage area should have adequate heat, light, and ventilation for a proper working environment. 3. An adequate working area and a large table for sample selection should be prepared by the storage facility. 4. An accurate log of all samples removed (size and depth) should be recorded and a copy provided for the storage facility records.

Task No.	Task Description	Task Procedure
		5. A tentative list of tests/ analyses could also be provided for the storage facility record.

ACKNOWLEDGMENTS

The field and laboratory procedures in this manual have been implemented and refined by several MERC personnel over the last three years. The authors thank the following people for their suggestions and expertise: David B. Trumbo, geologist, Cities Service Oil Company; Stewart J. Rhoades, Michael K. Vickers, and Brian G. Easterday, geologists, West Virginia Geological Survey; Royal J. Watts, geophysicist, MERC, Dr. Claude S. Dean, geologist, MERC, Clyde I. Pierce, physicist, MERC, and William K. Overbey, Jr., geologist, MERC.

Task No.	Task Description	Task Procedure

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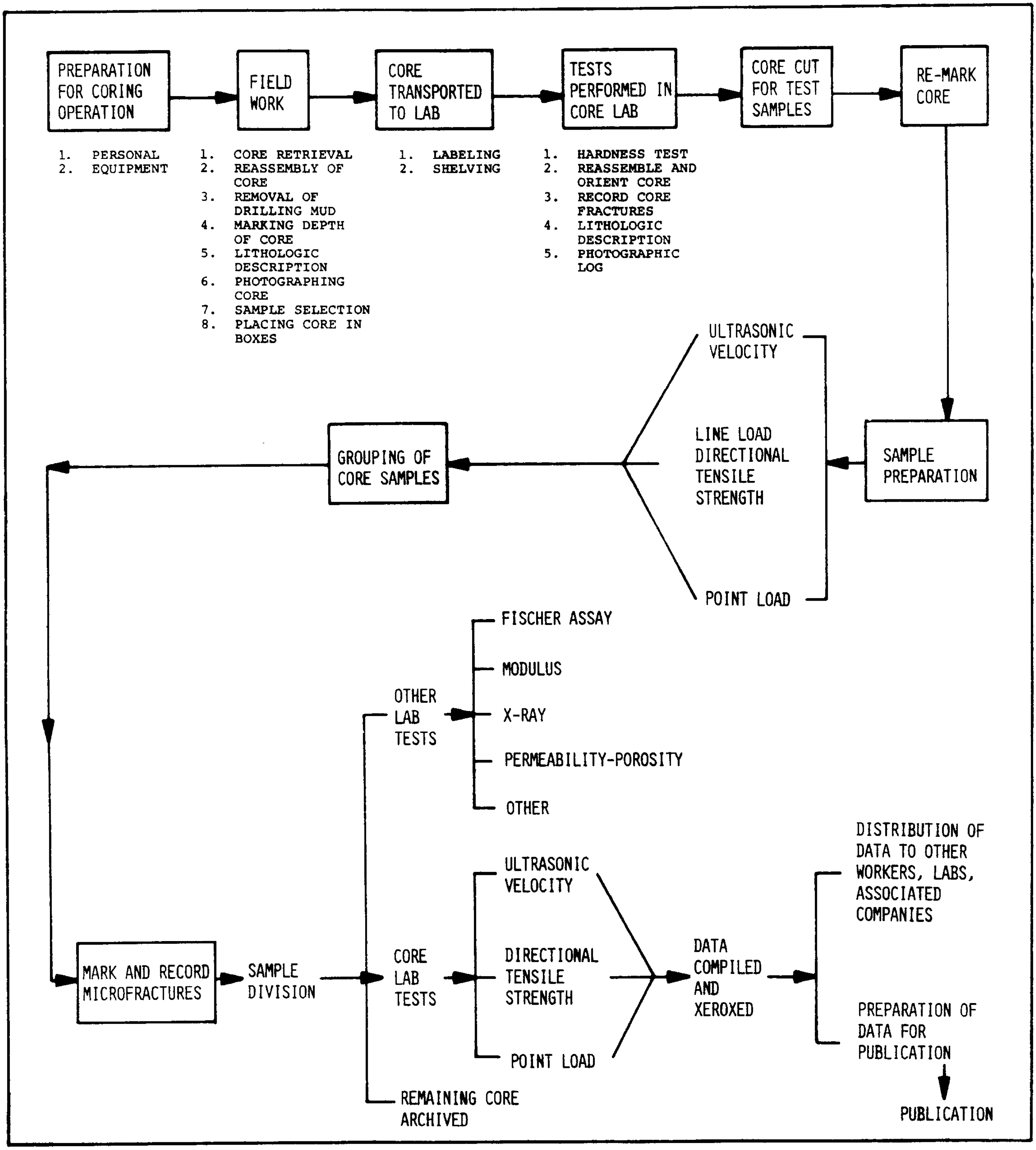
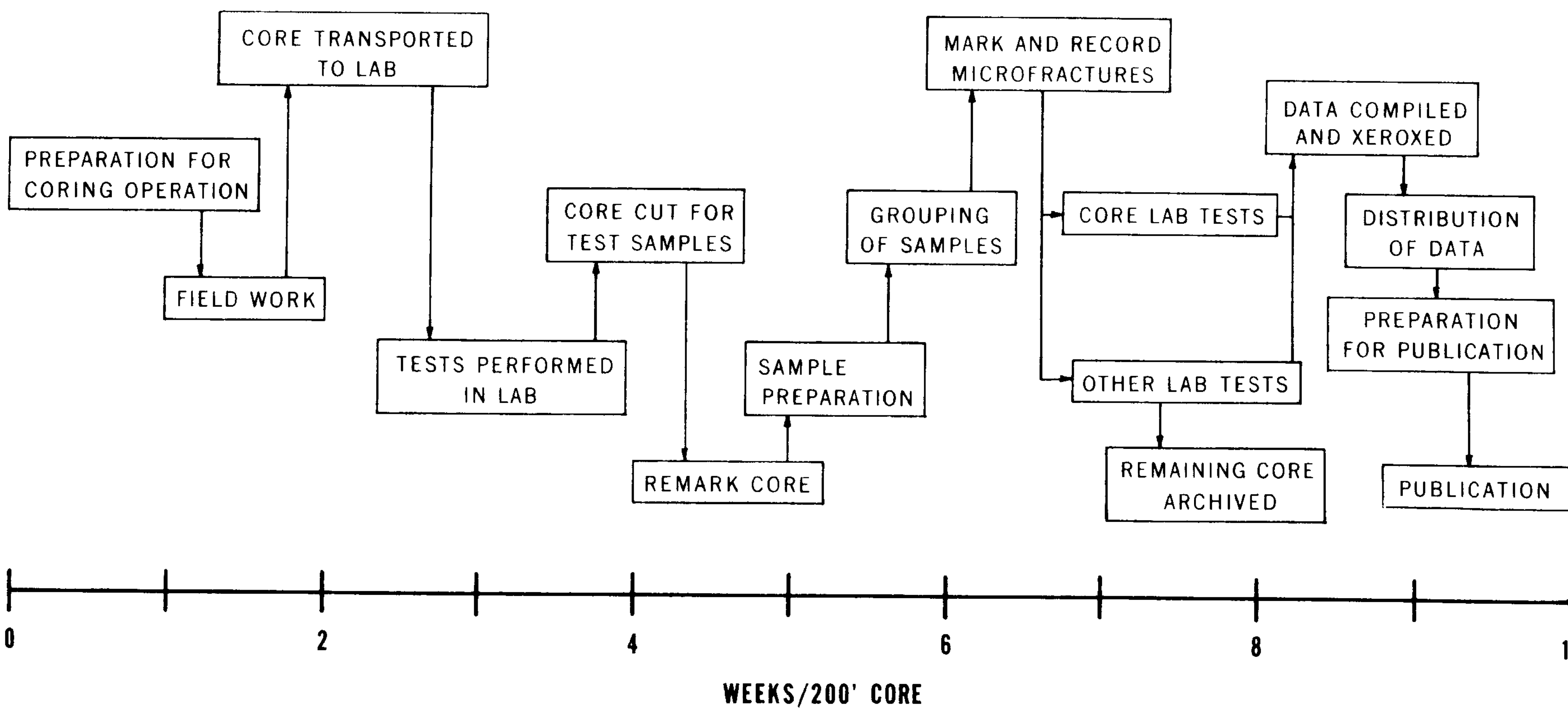
APPENDIX

FIELD AND LABORATORY PROCEDURES FOR ORIENTED CORE ANALYSIS OF DEVONIAN SHALES



FIELD AND LABORATORY PROCEDURES FOR ORIENTED CORE ANALYSIS

PERT DIAGRAM



FOUR PERSONNEL/LAB AND FIELD

Field and Laboratory Safety Procedures

Field Work

The field work at the well site should stress safety at all times. The various activities associated with drilling and coring warrant a keen awareness of the work being performed by all individuals at the well site. The necessary safety equipment should be utilized by all the individuals involved in the field operations.

The retrieval of the core from the core barrel (Task #3) is the most difficult and dangerous task performed in the field. Care should be taken in following the procedures involved in the retrieval of the core while on the drilling rig floor.

Tasks #4 through #9 involve reassembling, describing, and sampling the core. The work area should have adequate light and space for properly performing these tasks. Task #10 requires careful handling and lifting of the core sections.

Laboratory

Safety shoes are worn at all times by personnel working in the laboratory. Safety glasses, goggles, and ear protection are supplied and worn when necessary.

Tasks #12 and #13 (Labeling and Shelving Boxes) do not require safety glasses, but correct lifting and handling procedures should be observed.

During task #14, (Hardness Test), safety glasses are worn to prevent possible eye injury.

Tasks #15 through #19 involve reassembling the core, recording data, and describing it lithologically which requires no safety glasses.

Task #20 (Cutting and Marking Core) involves selection and preparation of samples for various tests performed in the lab. Slab saws, drill presses, and sanders are used to prepare these samples. During operation of this equipment, safety glasses and/or goggles are worn. Ear protection is available for personnel. Care should also be taken to keep hands and clothing away from rotating blades, belts, gears, etc.

Tasks #21 and #22 (Marking Microfractures and Selection of Samples) do not require safety glasses. Correct lifting and handling procedures should also be observed.

The Tinius Olsen Press is used in task #23 and #24 (the Line Load Tensile Strength Test and the Point Load Test). Safety glasses are worn while performing these tests. Care is also taken to keep hands away from the press when in operation.

In task #25, (Ultrasonic Velocity Test), there is no hazard involved and no safety glasses are worn.