Acoustical Imaging and Mechanical Properties of Soft Rock and Marine Sediments (Technical Progress Report #15302R01)

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ABSTRACT

The oil and gas industry has encountered significant problems in the production of oil and gas from weak rocks (such as chalks and limestones) and from unconsolidated sand formations. Problems include subsidence, compaction, sand production, and catastrophic shallow water sand flows during deep water drilling. Together these cost the petroleum industry hundreds of millions of dollars annually. The goals of this first quarterly report is to document the progress on the project to provide data on the acoustic imaging and mechanical properties of soft rock and marine sediments. The project is intended to determine the geophysical (acoustic velocities) rock properties of weak, poorly cemented rocks and unconsolidated sands. In some cases these weak formations can create problems for reservoir engineers. For example, it cost Phillips Petroleum 1 billion dollars to repair of offshore production facilities damaged during the unexpected subsidence and compaction of the Ekofisk Field in the North Sea (Sulak 1991). Another example is the problem of shallow water flows (SWF) occurring in sands just below the seafloor encountered during deep water drilling operations. In these cases the unconsolidated sands uncontrollably flow up around the annulus of the borehole resulting in loss of the drill casing. The $150 million dollar loss of the Ursa development project in the U.S. Gulf Coast resulted from an uncontrolled SWF (Furlow 1998a,b; 1999a,b).

The first three tasks outlined in the work plan are: (1) obtain rock samples, (2) construct new acoustic platens, (3) calibrate and test the equipment. These have been completed as scheduled. Rock Mechanics Institute researchers at the University of Oklahoma have obtained eight different types of samples for the experimental program. These include: (a) Danian Chalk, (b) Cordoba Cream Limestone, (c) Indiana Limestone, (d) Ekofisk Chalk, (e) Oil Creek Sandstone, (f) unconsolidated Oil Creek sand, and (g) unconsolidated Brazos river sand. These weak rocks and sands are intended to represent analogs to the formations that present oil and gas engineers with problems during oil and gas production and drilling operations.

A series of new axial acoustic sensors have been constructed (and tested) to allow measurement of compressional and shear wave velocities during high pressure triaxial tests on these weak rock and sand samples. In addition, equipment to be utilized over the next 18 months of the project have tested and calibrated. These include the load frames, triaxial pressure cells, pressure sensors, load cells, extensometers, and oscilloscopes have been calibrated and tested. The multichannel acoustic emission and acoustic pulse transmission systems have also been tested. Graduate research assistant, research faculty, and the laboratory technician have begun Tasks 4 and 5 which involve preparing the sand samples and rock samples for testing. The construction of the lateral acoustic sensors has also been started during this quarter as outlined in the project timeline.

With the equipment having been tested and calibrated, and the samples now being prepared, the experiments are on schedule to be started in April, 2001.

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INTRODUCTION

Oil and gas companies are increasingly seeking production in reservoirs that have tremendous reserves but are associated with rock formations in which one can encounter costly problems such as subsidence, compaction, sand production, or shallow water flows. For example, the unpredicted subsidence of the Ekofisk Chalk reservoir during production cost Phillips Petroleum Company one billion dollars to repair and rebuild offshore production facilities. Another example is the occurrence of shallow water flows (SWF) during deepwater production where unconsolidated, weak sands shallow below the seafloor begin to uncontrollably flow during deepwater drilling operations.

All of these problems occur in soft rock formations (such as chalks, weak sandstones, and high porosity limestones) or in unconsolidated marine sediments. Engineers have studied the mechanical and deformation properties of these types of cases over the last 30 years and developed a knowledge base of how they occur. However, pre-drill prediction or detection of these problems, if they are induced during oil and gas operations, is problematic.

Geophysical seismic surveying is traditionally utilized in the petroleum industry to image the structure, geometry, and nature of subsurface rock types to identify potential targets for oil and gas production. Recently, the industry has started to use repeat 3-D seismic surveys to time-lapse image reservoir operations such as water floods, firefloods, or the migration of oil-gas-water contacts. The remarkable advances in geophysical subsurface imaging technology have lead to some interesting questions. First, can seismic techniques, such as seismic hazard surveying, be used for the predetection of potential problematic unconsolidated sand units that could lead to shallow water flows (SWF)? Second, can time-lapse (i.e., 4-D) seismic surveys on established reservoirs be utilized to image weak, high porosity rocks as they undergo damage; such as subsidence and compaction? In order to use geophysical seismic surveys to image rock damage (or its potential to cause damage) a laboratory correlation of the acoustic signatures of weak rocks is required during deformation. Traditionally, the deformational and mechanical properties of rock samples are researched by petroleum engineers and geologists. The geophysical (or rock physics) properties of rocks are traditionally the domain of geophysicists. The goal of this research project is to combine those techniques, concepts, and technologies such that geophysicists can provide drilling and reservoir engineers (and geologists) an idea of the problems that can occur or have occurred within an oil and gas reservoir.

The project is divided into 12 tasks (see Table1) spanning a two-year period. The ultimate aim is to acquire advanced compressional and shear wave velocity data on rocks and sand samples deformed under triaxial conditions at high pressures. This data will then be used to make a series of deformation/velocity maps outlining the acoustic signatures of problematic rock types. The first quarter of the project (i.e., current report period) involves obtaining the rock and sand samples for the study, calibrating and testing the equipment, constructing the acoustic sensors, and starting to prepare the samples for experimentation. The next 17 months of the project will involve laboratory experiments to acquire data on the deformational mechanisms, compressional and shear wave velocities, acoustic emission events, and ultrasonic tomography that occur in rock and unconsolidated sand samples under simulated reservoir production scenarios. The final four months of the project will be utilized to make correlations between the rock physical and rock mechanical properties.

This report briefly reviews accomplishments in the first quarter of the research project.

EXECUTIVE SUMMARY

This report represents the initial quarterly report for the project "Acoustic Imaging and Mechanical Properties of Soft Rocks and Marine Sediments." The project has been started in the Rock Mechanics Institute at the University of Oklahoma with involvement of three faculty members, two graduate student research assistants, and a laboratory technician. The goal of the project is to correlate specific acoustic velocity signatures to damaging deformational mechanisms in soft rock and unconsolidated sands. These mechanisms include pore collapse, compaction (normal consolidation), dilatancy, and shear failure. Four tasks were outlined in the work plan for the first quarter of the project. These include: Task 1 - Obtain the rock and unconsolidated sand samples; Task 2 - Construct new axial acoustic velocity platens; Task 3 - Calibrate equipment; Task 4 - Prepare sandstone and chalk samples; and Task 5 – Construct lateral acoustic velocity sensors. Tasks 1, 2, and 3 have been completed and Tasks 4 and 5 were initiated and are continuing. (The latter two tasks overlap into the second quarter of the project.)

During Task 1 a total of 6 rock samples and 2 unconsolidated sand samples were obtained. The soft, high porosity weakly cemented rock samples obtained for the study include the (1) Danian Chalk, (2) Cordoba Cream Limestone, (3) Ekofisk Chalk, (4) a high porosity variant of the Indiana Limestone, (5) Antler Sandstone, and (6) Oil Creek Sandstone. Two unconsolidated sand samples were obtained for experimentation also. These include disaggregated Oil Creek sandstone and sand from the Brazos River. These sands are quite different from one another with the Oil Creek sand being extremely well sorted, clean, and with well rounded grains. The Brazos sand has a higher content of clays and volcaniclastic fragments and the grains are more angular (and more typical of marine sediments).

All these rocks and sands were collected because they are considered to be analogs for subsurface formations which lead to: (1) reservoir production problems such as compaction or subsidence, or (2) problems associated with drilling leading to damage such as shallow subsurface water flows during deep water drilling operations. All eight of the collected samples are thought to be weak enough to result in compaction and subsidence during production operations. The unconsolidated sand samples represent analogs to formations that would yield uncontrollable shallow water flows that would not occur in the more competent lithified rock in the study.

Two different types of axial platens have been constructed for the project (Task 2). These include steel platens containing 600 KHz compressional and shear wave ultrasonic piezoelectric elements for use during experiments on the weak soft rocks and platens for the unconsolidated sediments which also contain bender elements which are traditionally used for measuring shear wave propagation in soils. These are currently being tested. Researchers have also started constructing the sensors for lateral acoustic emission measurements and lateral compressional/shear wave velocity measurements. The Laboratory equipment has been setup, calibrated, and tested. The computer command and control programs for acquisition of stress-strain data, acoustic emission hypocentral location data, and ultrasonic velocity waveform data have also been tested. Samples of the above listed rock types are also being prepared to start the experiments outlined in Tasks 6 and 7.

EXPERIMENTAL

The first quarter of this project encompassed five tasks as outlined on the project timeline (see Table 1). These include:

Task 1: Obtaining the rock samples to be used in the laboratory testing program
Task 2: Constructing new acoustic platens
Task 3: Calibrating laboratory equipment
Task 4: Preparing sandstone and chalk samples for testing
Task 5: Constructing lateral acoustic emission and acoustic velocity sensors

Tasks 1, 2, and 3 were completed as scheduled in the first two months of the project and Tasks 4 and 5 were started. The researchers in the project also:

1. Compiled a detailed scientific literature survey of important topics to be covered during the course of the research.
2. Developed computer programs for data reduction of laboratory data.
3. Developed an experimental method and data reduction procedure for determining the full dynamic tensor for the rock samples to be tested later in Tasks 7 and 8 (in the second half of the first year of the project).

Task 1: *Obtaining the rock samples*

Researchers in the Rock Mechanics Institute have selected and acquired six different blocks of rock and two unconsolidated sand samples to be tested in the experimental program: (1) Danian outcrop chalk, (2) Cordoba Cream (Austin) Chalk, (3) Indiana Limestone, (4) Ekofisk Chalk, (5) Oil Creek Sandstone, (6) Antlers Sandstone, (7) unconsolidated Oil Creek sand, and (8) unconsolidated Brazos River sand.

The blocks of rock include:

<u>Danian Chalk</u>. This is a clean, white outcrop chalk obtained from Denmark. It has a porosity of 35% and is equilivalent in strength and character to the Ekofisk Chalk of the North Sea and will therefore represent a superb analog for the Ekofisk Reservoir. The Ekofisk Reservoir represents a reservoir which has undergone severe subsidence and compaction (over 30 feet) in the last 30 years. The Danian Chalk samples will be used in experiments to simulate this process. A limited series of dry reconnaissance tests have been conducted to outline the tensile strength and failure properties of this block of rock to prepare for the more detailed acoustic tests to be conducted later in Task 6.

<u>Cordoba Cream Limestone</u>. This is the generic name given to the soft, buff colored Austin chalk quarried in Texas. It has a lower porosity (25%) than either the Danian or Ekofisk Chalk rocks. This rock type has been previously studied in the RMI laboratory; and hence, a previous set of data from Azeemuddin et al. (1994) will be used as a starting point for RMI researchers who will be conducting more detailed experiments on the acoustic properties of this rock. This limestone is primarily calcite (85%) but has a large percentage of clays (10-13%) which significantly weakens the strength of rock. It is medium-to-coarse grained, has calcite cement, and contains small fossils.

Ekofisk Chalk. The Ekofisk Chalk is buff colored, high porosity (35%), highly fractured limestone from the North Sea. Researchers in the Rock Mechanics Institute have retained a few samples of the Ekofisk reservoir from a previous study (Scott et al. 1998b) and these samples will be tested in the new research program. The Ekofisk Chalk is Danian (Paleocene) age with low matrix permeability (1 to 10 md) but with an overall higher permeability (150 md) due to natural fractures (Teufel et al. 1991). These chalk samples are from a depth of approximately 10,000 feet and are from the reservoir horizon directly responsible for the large amounts of compaction in the Ekofisk reservoir in the North Sea.

Indiana Limestone. A block of high porosity Indiana Limestone was also obtained for the research program. This rock type was not listed in the original proposal submitted to DOE. Recent reconnaissance tests conducted by RMI personnel indicate that high porosity variation of this limestone might be very suitable for testing in this DOE project. The reconnaissance experiments indicate that this block had a brittle-to-ductile transition around 7,000 psi. The preliminary experiments also indicate that the block of rock was very uniform. It is stronger than the other rocks to be tested in the experimental program and therefore represents the high strength end of samples that will be analyzed in the study. As a reservoir analog this rock type would be expected to generate damaging compaction and subsidence only in the most severe cases (i.e., at high effective confining pressures near depletion of the reservoir). But, the preliminary experiments were so intriguing it was added to the list of rocks to be tested.

Antler (Paluxy) Sandstone. The Antler Sandstone is a weakly cemented, poorly consolidated sandstone that has a porosity of approximately 37% (Boldt 1992). This sandstone is a quartz arenite but it also has approximately 2-3% illite clay coating the quartz grains. The grains in this sandstone are rounded to subangular. In the original proposal researchers planned to utilize the weakly cemented Paluxy Sandstone as one of the rock types to be tested. However, no quarries in central Texas had suitable material that could be readied for the testing program. We discovered that this particular rock (Cretaceous age) formation extends over a wide region of central Texas and Southern Oklahoma (where it is locally known as the Antler Sandstone). Blocks of this sandstone were recovered from some riverbank outcrops in southern Oklahoma.

Oil Creek Sandstone. This sandstone is a very clean quartz arenite (99.9% quartz) from Mill Creek, Oklahoma in the Oil Creek Formation (Middle Ordovician Simpson Group). Porosities average around 33-35%. This sandstone is very friable and is composed of well rounded grains. The blocks of Oil Creek were hand cut from a glass sand quarry operated by U.S. Silica. Both the Antler and the Oil Creek weakly cemented sandstones are friable enough so that the cores can be cut with a special hand coring device developed in the Rock Mechanics Institute for preparing soft rock samples.

Oil Creek (unconsolidated) Sand. Disaggregated Oil Creek Sandstone is sold for use as a proppant in hydraulic fracture treatments and is locally known as Oklahoma #2. It has been washed, cleaned, and sieved. As such, this sand makes excellent material for the unconsolidated sand packs for the research program.

Brazos River Sand. Marine sediments in the U.S. Gulf Coast are rarely clean quartz arenites or have well rounded grains (like the Oil Creek mentioned above). Typically they are relatively immature and have some angularity and a high percentage of volcaniclastic grains. A lot of the marine sands in the U.S. Gulf are reworked river sands (like the Mississippi, Brazos, Red, and Colorado rivers). So researchers have collected some Brazos River sand as a representative example of the sands that might be deposited in the offshore U.S. Gulf Coast region. Again, experiments on this sand are intended to present a more realistic data base than experiments on the Oil Creek might provide.

Task 2: *Constructing new acoustic platens*

Four different sets of axial acoustic platens have been machined and assembled for the research project. These correlate to the different sample sizes to be tested during the experimental program. Sample diameters are 1.5, 2.125, 3, and 4 inches. The sample length-to-diameter ratios will be 2 to 1 as outlined in the ASTM rock testing procedures. The platens contain pore pressure ports and three piezoelectric elements (one compressional and two orthogonally oriented shears) with a nominal center frequency of 600 KHz. The 2.125-inch diameter platens had been previously developed and described by Scott et al. (1993) and the other platens were made specifically for this research project. The smaller 1.5-inch acoustic platens are to be used only on reconnaissance research tests in Task 6. The 2.125- and 3- inch samples are to be used during the deformational pathway experiments in Task 6. Both the 3- and 4-inch diameter platens will be utilized during the acoustic emission experiments (Task 7), tests to determine the full dynamic tensor (Task 8), and acoustic tomography imaging experiments (Task 10). The 1.5-, 2.125-, and 3-inch platens have been tested in both an acoustic emission (passive mode) and pulse transmission (active mode). The 4-inch platens have been machined and will be tested at the beginning of May 2001.

The above mentioned acoustic platens are well suited for testing weakly cemented rock samples or competent, lithified rock samples (see Scott et al. 1993, 1998a,b for examples). However, one goal of the research program is to examine the acoustic properties of unconsolidated sands, since these are the problematic formations that lead to catastrophic shallow water flows. These are not only problematic for drilling and production engineers but represent challenges for laboratory researchers as well. A new type of platen is being designed for this study, and is based on a modification of the type used to study the acoustic properties of soils undergoing mechanical deformation testing. These platens contain the same 600 KHz compressional and shear wave piezoelectric elements in the standard loading platen (outlined in the above paragraph) but also have a piezoeletric bender element embedded in them. Bender elements project up into the unconsolidated sand and provide a high energy, low frequency, shear wave pulse through the poorly consolidated sample (Gohl and Finn 1991; de Alba and Baldwin 1991; Arulnathan et al. 1998). Standard 600 KHz plate type piezoelectric elements do not yield very discernable shear waves at low effective confining pressures due to the loss of coupling between the grains. (Shear waves propagate only through the solid grain-to-grain framework.) The high amplitude pulse generated by bender elements can even propagate a shear wave through loose, unpressured sand packs.

The platens developed in this study are designed for use in triaxial pressure cells with much higher confining pressures (up to 20,000 psi) than what is traditionally used in soil mechanics experiments (generally less than 600 psi). Preliminary tests with the new platens have been successful in obtaining shear wave velocities in unconsolidated, unstressed sand samples during benchtop tests as low as 40 m/sec. Figure 1 shows a photograph of the two different types of axial acoustic platens designed and constructed in the first phase of this research.

Task 3: *Calibrating and testing laboratory equipment*

The testing program will utilize a variety of systems in the Geomechanical Acoustic Imaging System (GAIS). Figure 2 is a photograph of the completed GAIS as it now stands in the O.U. Geomechanical Acoustic Laboratory. Figure 3 is a schematic of the technologies in the GAIS. Figures 4 - 7 are schematics of the equipment modules for some parts of the GAIS that will be used in the study. Figure 4 shows the data acquisition system and the command and control system for the load frame and triaxial pressure cell of the GAIS. Figure 5 illustrates the equipment to be used in the acoustic emission research phase of the project. Figure 6 shows the 20-channel acoustic velocity system for acquisition of multi-channel compressional and shear wave velocities and acquisition of data for the ultrasonic full dynamic tensor of the deforming samples. The pore fluid system (with the capability of permeability measurements) is shown in Figure 7. All of these systems have been tested and are ready for use in the later tasks outlined in the research plan.

RMI researchers have tested and/or calibrated the following equipment items to be used in the research program. These include:

1. A TerraTek 3,000,000 lb. load frame and 138 MPa triaxial cell used for the dynamic tensor, ultrasonic velocity, acoustic emission hypocentral location experiments in Tasks 7 –10.
2. An MTS 600,000 lb. load frame and 138 MPa triaxial cell to be used in the reconnaissance experiments of Task 6.
3. The 15 channel Vallen Systeme for acoustic emission full waveform acquisition.
4. The 24 channel Physical Acoustics Corporation (PAC) Mistras System for both AE event parametric and full waveform acquisition.
5. The 8 channel Spartan Acoustic Emission system from PAC.
6. Two Tektronix TDS420 digital storage oscilloscopes (for acoustic velocity measurements.
7. An HP3488 VHF switchbox for switching high voltage pulses and acquired acoustic velocity waveforms.
8. An HP3852 data acquisition system (used for both command and control, and data acquisition of the Geomechanical Acoustic Imaging System).
9. An MTS TestStar II controller for control of the load frames and triaxial pressure cells.
10. An MTS extensometer (Model 632.92B-05) for axial strain measurements.
11. An MTS extensometer (Model 632.90B-04) for circumferential strain measurements.
12. 1.5-, 2.125-, 3-, and 4-inch diameter acoustic compressional and shear wave velocity platens.
13. 3-inch acoustic velocity platens with shear wave piezoelectic bender elements installed.
14. Internal load cells rated to 20,000, 200,000, and 300,000 lbs. for both the MTS 319 and the TerraTek load frame.

The calibrations are carried out using primary or secondary calibrations depending on the type of equipment available. A visit by MTS Systems Corporation is also scheduled for mid-May for calibrations on the high capacity 600,000 lb. load cell.

The programs for the command and control computers for both the Geomechanical Acoustic Imaging System and the MTS 319 (described in the next section) have been written and tested. These include those for a variety of deformational pathways including: triaxial deformation, uniaxial strain, hydrostatic compression, and K-ratio tests.

A final check-out on one component of the Ultrasonic Tomography System has not yet been accomplished. As this piece of equipment is not slated for use until a full year from now (in Task 10) the RMI staff decided to leave setup, testing, and final calibration to later this summer. This does not impact the timeline as currently scheduled.

Task 4: *Preparing sandstone and chalk samples for testing*

The graduate research assistants and the laboratory technician involved in the project have already started preparing the rock and sediment samples for testing. The sample sizes are 1.5- and 2.125-inch diameter cores for reconnaissance tests (Task 6) and 3- and 4-inch diameter cores for the acoustic emission and acoustic velocity tests (for the full dynamic tensor). The rocks are cored as right circular cylinders and are being surface ground plane parallel to within .0001 inch.

Task 5: *Constructing lateral acoustic emission and acoustic velocity sensors*

A series of lateral acoustic sensors have been made for the project. The design has been successfully used by Scott et al. (1993) in previous research. Two different types of lateral sensors have been made for this research project. They include: (1) single element acoustic emission sensors, and (2) three component sensors with one compressional and two orthogonally mounted shear wave elements (see Figure 8). The single element sensors are designed for acoustic emission hypocentral location experiments. Typically, an acoustic emission location experiment (in Task 7 scheduled for later this year) will utilize a minimum of 12 of these sensors. The sensors with three elements are to be used in acoustic velocity experiments. All acoustic piezoelectric elements are .25 inch in diameter and have a nominal center frequency of 600 KHz. In the single component model these are mounted (cast) in an epoxy shell with a diameter of .35 inch. In the three component model the elements are mounted in an in-line housing 1 inch in length and .35 inch in width. These are glued to the jacket (of a soil sample) or directly to the rock sample with a silver conductive epoxy.

RESULTS AND DISCUSSIONS

Scientific Literature Search

A detailed review of the scientific literature has been initiated by the faculty researchers and graduate research assistants. A complete bibliography incorporating the previous scientific literature survey will be provided in the second quarterly report. The review of the preexisting scientific literature for this project presents some interesting challenges. First, as noted in the original research proposal, there is very little research combining simultaneous measurements of both geophysical rock properties with mechanical strength properties. A correlation of these properties during the research in this proposal represents the crux of the problem to be investigated; i.e., as to whether geophysical 3-D and 4-D surveys can be used to image reservoir deformation. As such, the initial literature search for the project has been extensive and wide ranging. A collection of papers has been assembled to assist researchers and students involved in preparation for the laboratory experiments, a later analysis of the results, and to assist in later publication of the data. This DOE project is unique in that it involves multidisciplinary research that crosses the traditional boundaries of geoscience and engineering. The searches have been carried out in journals for geophysics, soil mechanics, rock mechanics, structural geology, geotechnical engineering, petroleum engineering, and geology. The topics have been subdivided into three areas:

1. Laboratory techniques and technologies to be used in the research project

   Laboratory techniques and testing technologies include: (1) acoustic velocities (determined by the time of flight method), (2) acoustic emission (single channel methods), (3) acoustic emission hypocentral location methods, (4) rock and soil permeabilities, (5) shear wave bender element measurements, (6) ultrasonic tomography, and (7) dynamic elastic tensor measurements

2. Papers related to the field problems to be examined (i.e., compaction, subsidence, shallow water flows)

   Research papers on the following topics related to field research in the petroleum industry have been collected for review: (1) subsidence and compaction, (2) shallow water flows, (3) induced seismicity during reservoir production, (4) seismic anisotropy, and (5) in-situ stresses. The first two topics represent literature searches on the main thrust of the research project---analyzing damage induced by production from oil and gas reservoirs (i.e., compaction and subsidence) and during drilling (i.e., shallow water flows). The third topic, production induced seismicity in oil and gas reservoirs, was incorporated as a literature research topic because it is indicative that there is damage occurring to a reservoir during production. The fourth topic, seismic anisotropy of petroleum reservoirs, is important since the proposed testing program will be to acquire acoustic velocities in both the axial and lateral directions of weakly cemented rocks and unconsolidated sand samples; thereby providing data on both the inherent and stress-induced acoustic anisotropy. The fifth topic, measurements of in-situ stresses in oil and gas reservoirs, will provide data on the evolution of stress and pressure changes during production operations. This data will be used to plan some of the deformational pathway experiments in this study which are intended to directly simulate the changes that occur during production and drilling.

3. Papers about rock acoustic, deformational mechanisms, or mechanical properties

   The papers collected on rock mechanical, acoustical, and deformational properties represent the most difficult aspect of the preliminary literature review. Researchers engaged in the project have subdivided these into various topics based on the diagram submitted in the original DOE proposal (see Figure 9). Previous research work has been subdivided into several subtopics. The first involves separation of papers into categories related to one of the four deformational mechanisms (i.e., elastic, dilatant, pore collapse, and normal consolidation). The papers include both those on rock mechanics and soil mechanics research.

   Since one of the goals during the experiments in the testing program is to determine the static and dynamic elastic moduli, a search has been conducted for previous research measuring rock and soil moduli, such as Young's modulus, Poisson's ratio, bulk modulus, and poroelastic parameters; e.g., Biot's coefficient and Skempton's parameter.

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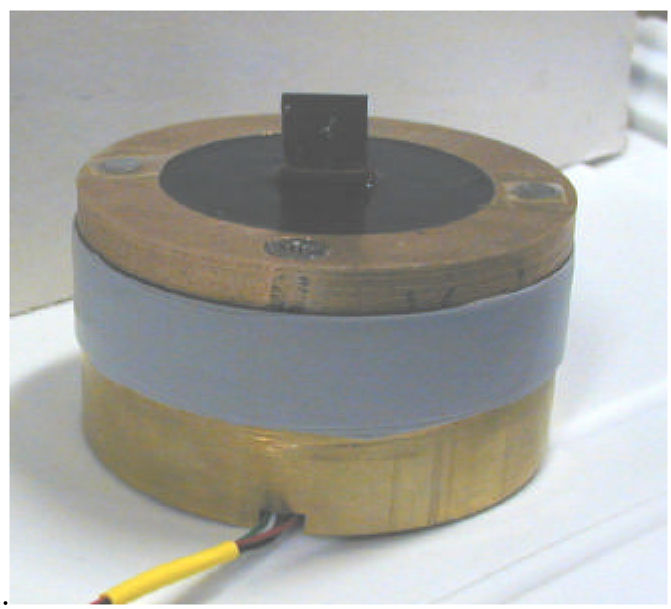
LIST OF ACRONYMS AND ABBREVIATIONS

AE	=	Acoustic Emission
GAIS	=	Geomechanical Acoustic Imaging System
OU	=	The University of Oklahoma
PAC	=	Physical Acoustics Corporation
RMI	=	Rock Mechanics Institute at the University of Oklahoma
SIRT	=	Simultaneous Iterative Reconstruction Technique
SWF	=	Shallow Water Flows
VHF	=	Very High Frequency
V_p	=	Compressional Wave Velocity
V_s	=	Shear wave velocity
V_p/V_s	=	Ratio of compressional wave velocity to the shear wave velocity

Project month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Task 1 **Obtain Rock Samples**	X	X																						
Task 2 **Construct New Acoustic Platens**	X	X																						
Task 3 **Calibrate Equipment**	X	X																						
Task 4 **Prepare Sandstone & Chalk Samples**		X	X	X																				
Task 5 **Construct Lateral Acoustic Sensors**		X	X	X																				
Task 6 **Reconnaissance Test Chalk & Sandstones**				X	X	X																		
Task 7 **AE Hypocentral Location & Full Dynamic Tensor**							X	X	X	X	X													
Task 8 **Correlate Static & Dynamic Parameters**											X	X												
Task 9 **Test Sand Pack Samples**													X	X	X									
Task 10 **Ultrasonic Tomography on Sandstone & Chalks**																X	X	X	X	X				
Task 11 **Make Deformation Velocity Maps**																					X	X		
Task 12 **Final Report**																							X	X

Table 1: Project timeline with first quarter targets highlighted

Axial acoustic platen for soft rocks. The piezoelectric elements are mounted in the center recess. The platen mounts on top of the rock in this orientation. The pore fluid port is hidden from view in this picture.



.
This is a view of the axial acoustic platen for unconsolidated sand samples. This a base platen and the jacketed sand sample would sit on top of the platen. The bender element for shear wave generation extends above the platen.

Fig.1. Axial acoustic velocity platens constructed for the project.

Fig.2. The 3,000,000 lb. TerraTek frame with its 20,000 psi triaxial pressure vessel. The command and control, acoustic emission, and ultrasonic velocity systems are located to the left of the load frame. These components comprise a major part of the new Geomechanical Acoustic Imaging System.

Technologies in the Keck Geomechanical Acoustic Imaging System

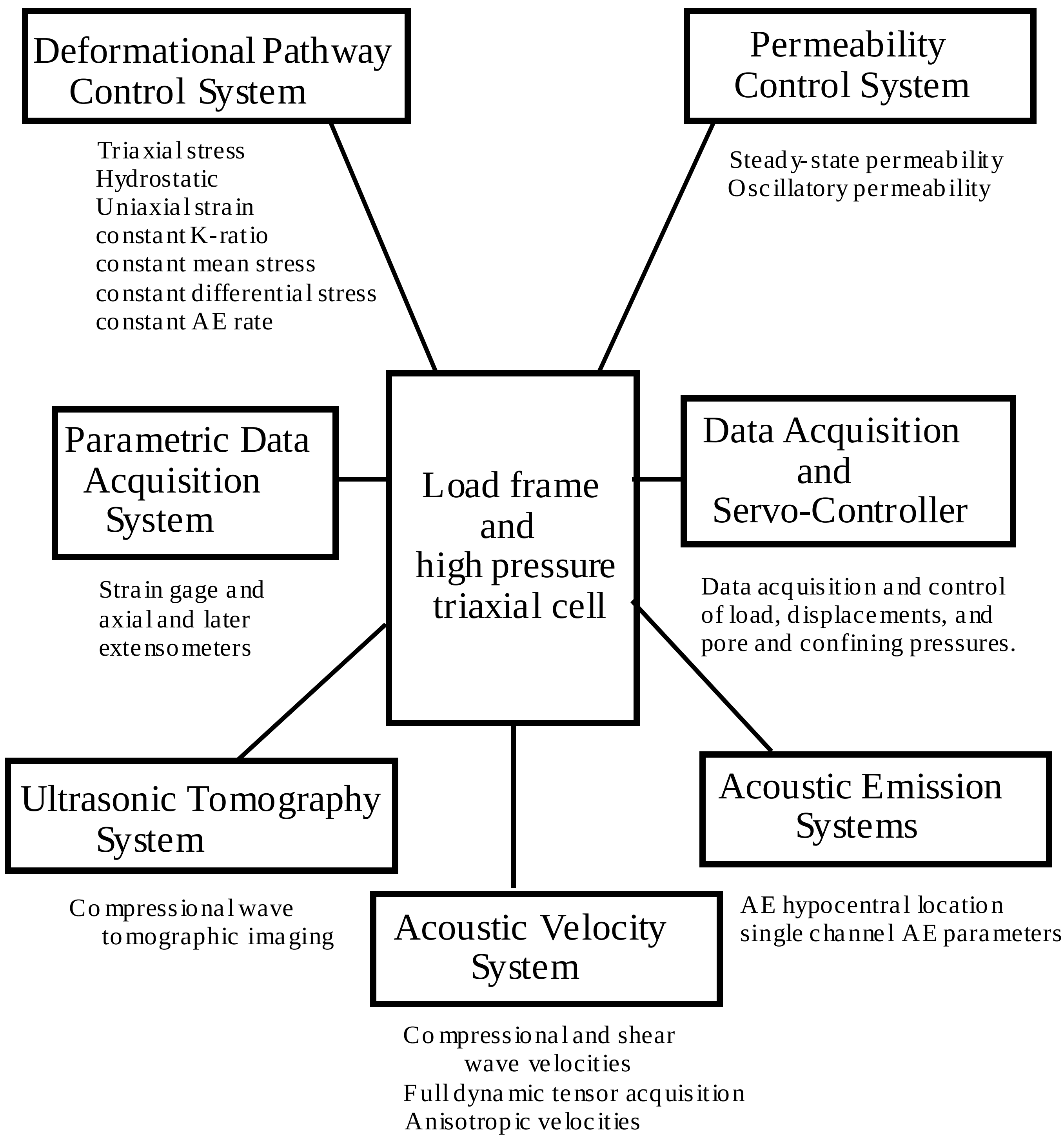


Fig. 3. Schematic of the components in the Geomechanical Acoustic Imaging System

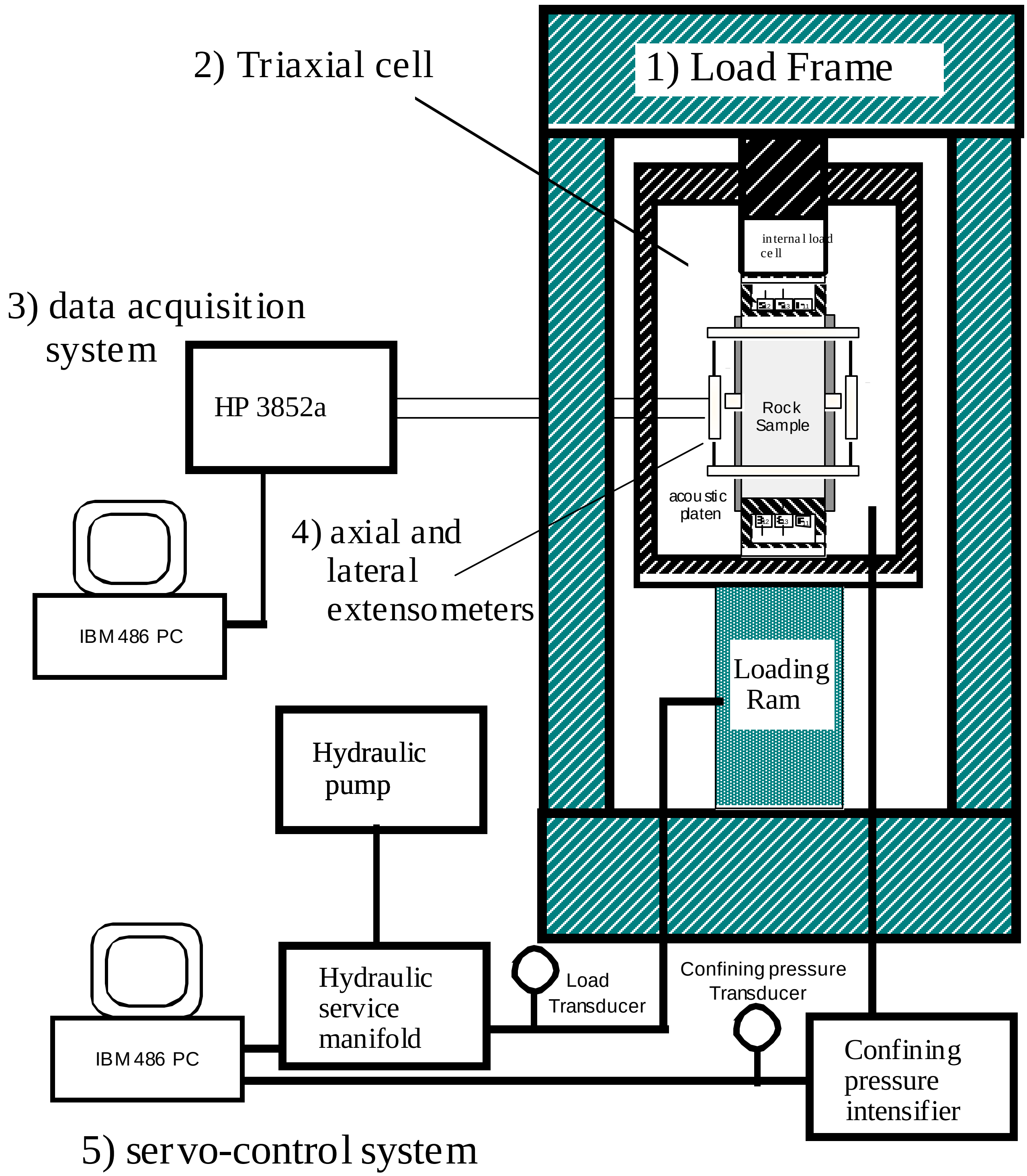


Fig. 4. Schematic of the load frame, triaxial cell, and data acquisition modules of the Geomechanical Acoustic Imaging System.

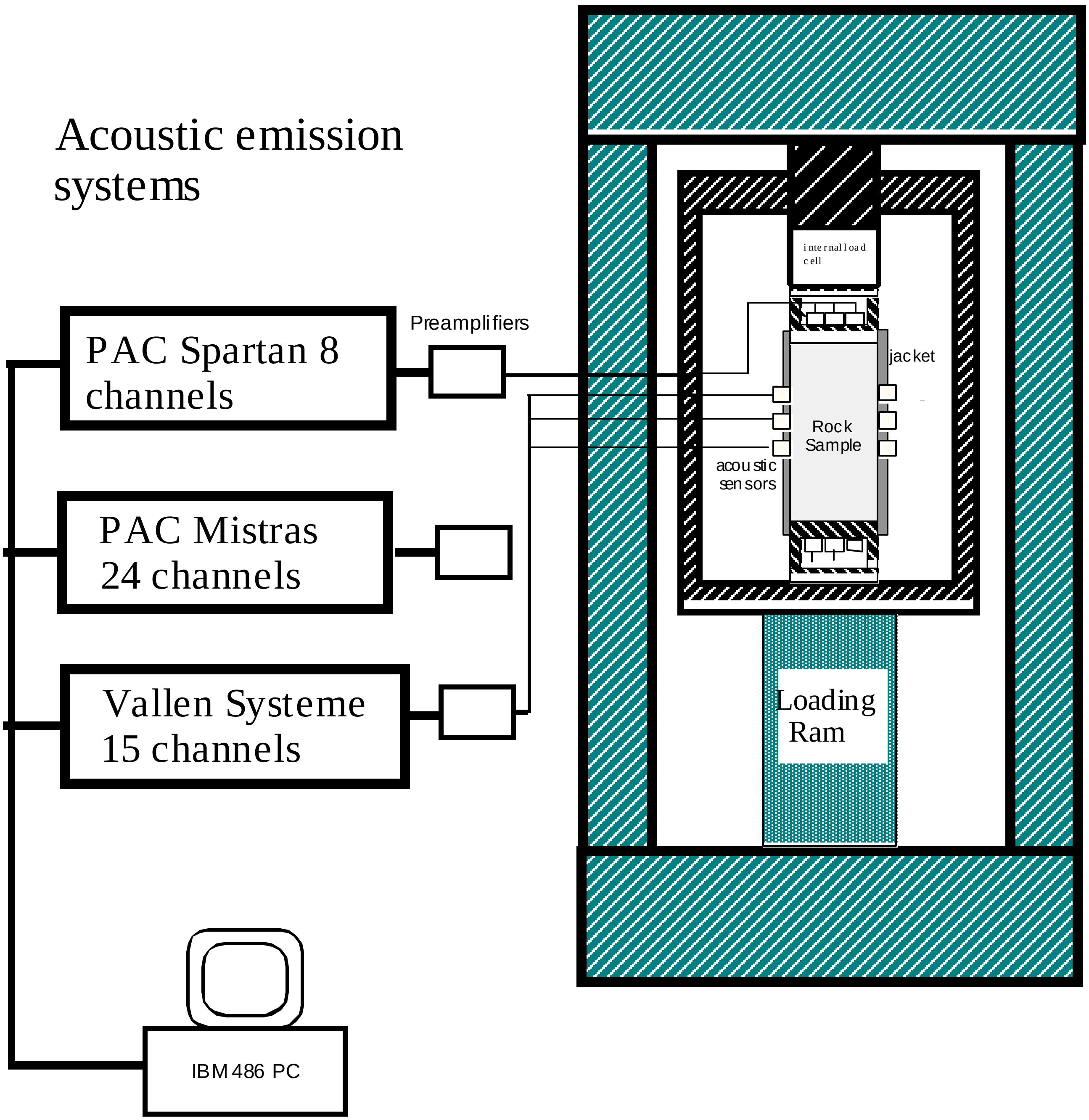


Fig. 5. Schematic of acoustic emission systems in the Geomechanical Acoustic Imaging System.

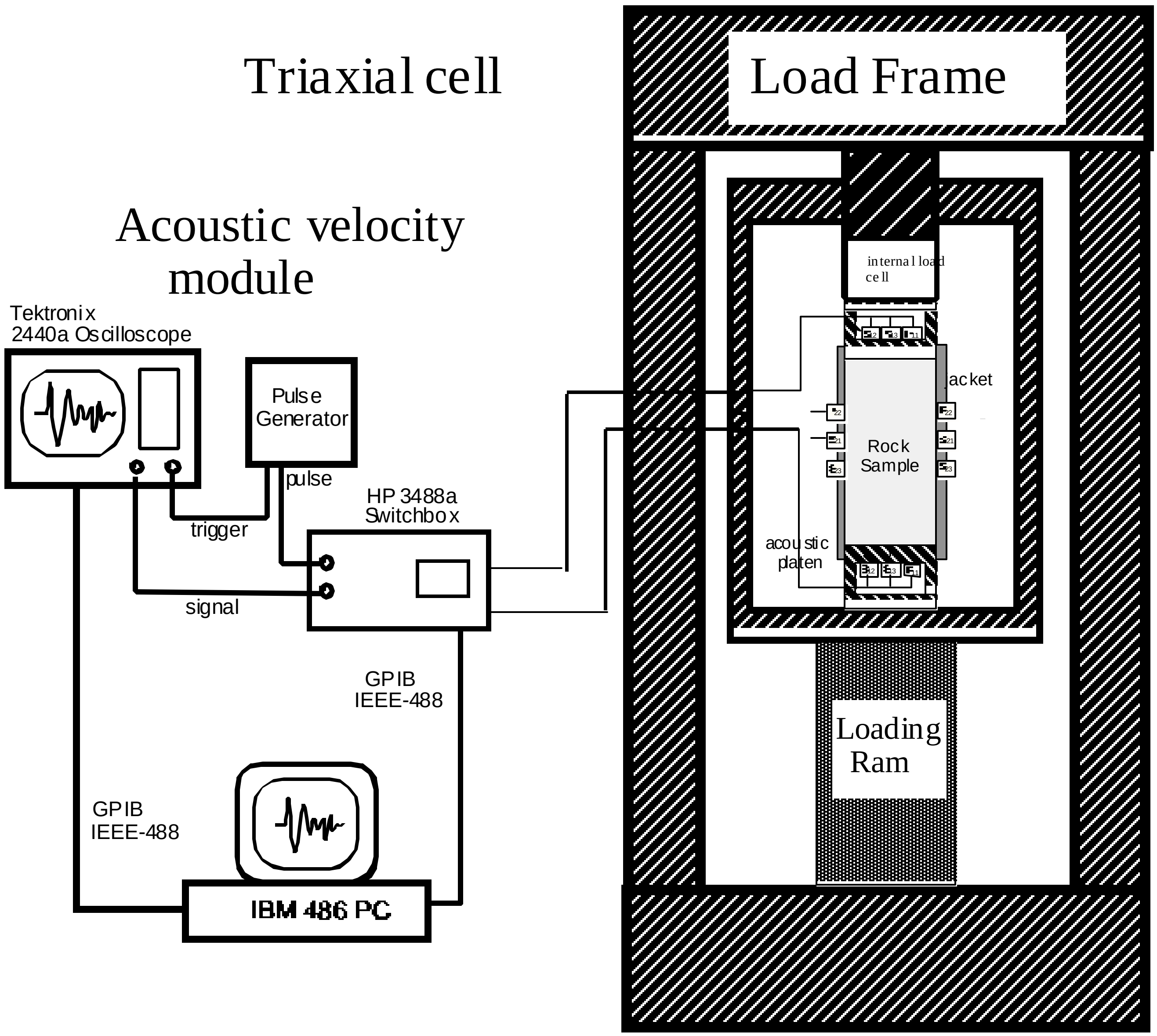


Fig. 6. Schematic of the acoustic velocity system for compressional and shear wave anisotropy measurements and for acquisition of the full dynamic tensor data set.

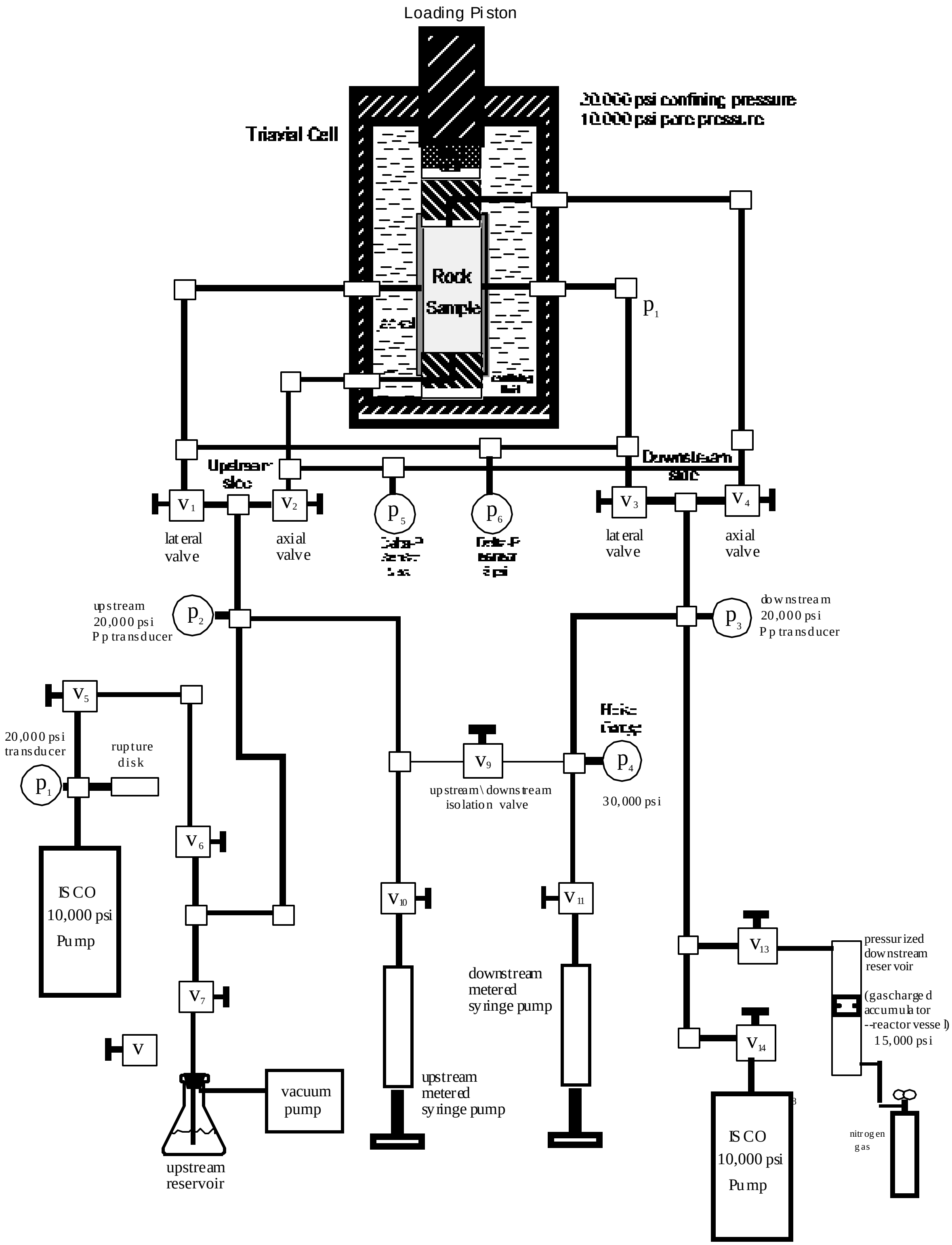


Fig. 7. Detailed schematic of the pore pressure and permeability system to be used in the project.

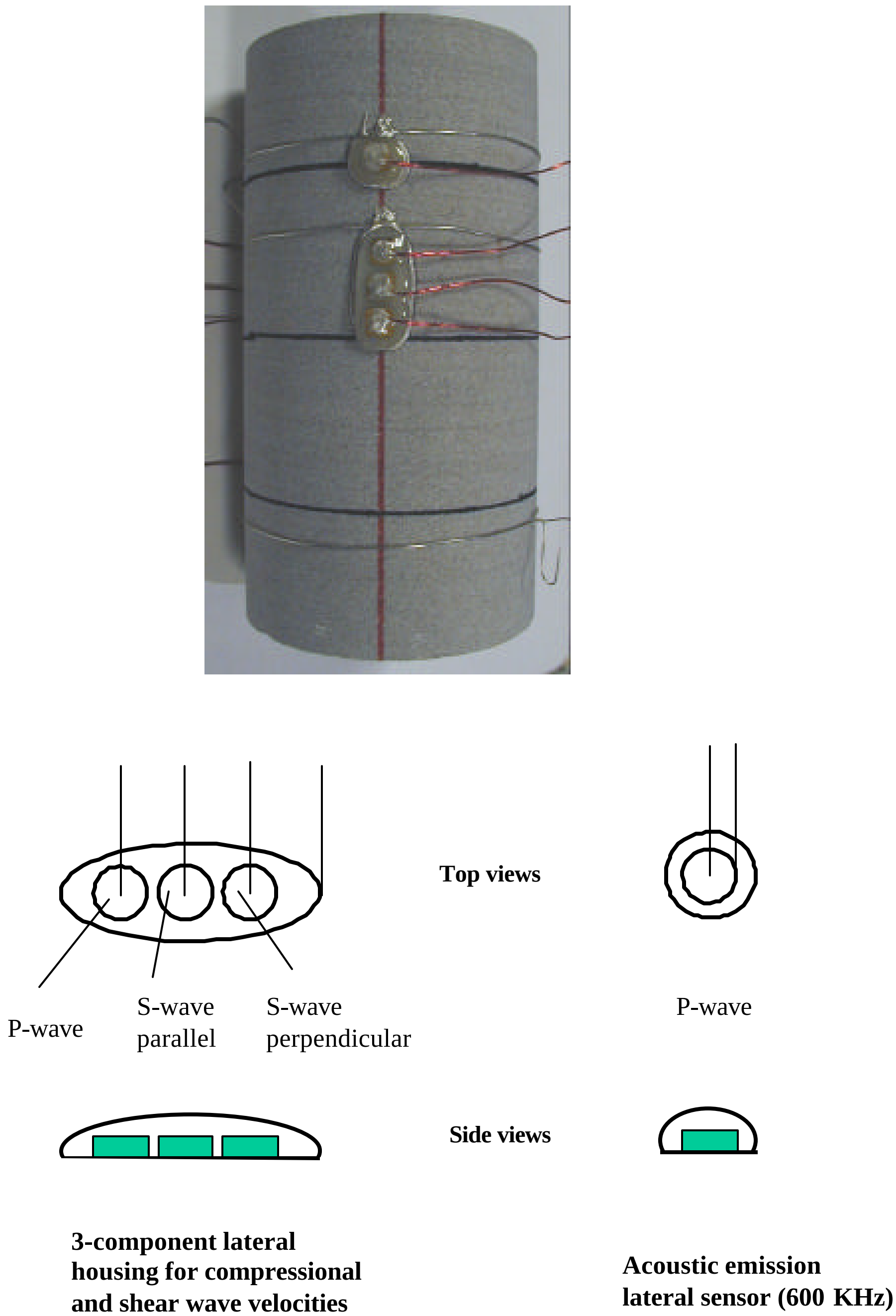


Fig. 8. Diagram illustrating the lateral acoustic velocity sensors constructed for the project. The top photograph shows a rock core sample with both a 3-component sensor and a single component acoustic sensor mounted on the surface.

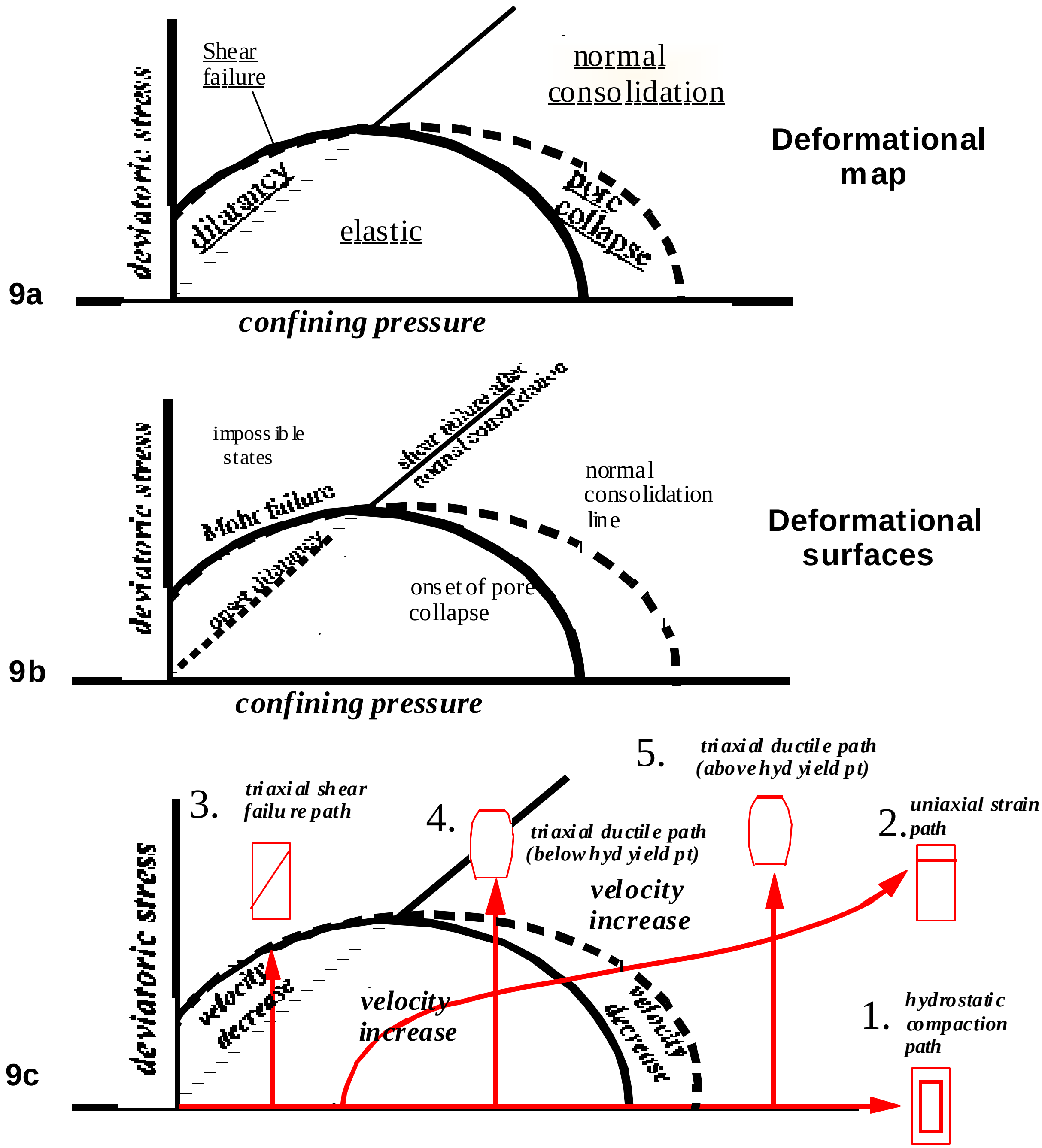


Fig. 9. Schematic of the deformational mechanisms and deformational surfaces that will be examined in the experimental study. Each of the underlined labels represents an area which represents a key word for searches in the preexisting scientific literature.