A Motion Decoupled Hydraulic Delivery System for the IODP

Integrated Ocean Drilling Program–Class B Engineering Development Proposal

The University of Texas at Austin Institute for Geophysics

Texas A&M University

Lamont Doherty Earth Observatory of Columbia University
Borehole Research Group

Mohr Engineering Division of Stress Engineering Services, Inc.

Fiscal Year 2009-Fiscal Year 2010

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Project Summary:

The USIO, Mohr Engineering, and The University of Texas Institute for Geophysics (“UTIG”) propose to build a new motion-decoupled Hydraulic Delivery System (MDHDS) for use on the USIO’s SODV and potentially for application on other IODP vessels. The MDHDS will deploy the two pore pressure penetrometers used in the IODP: the DVTPP and the T2P. Repeated application of these penetrometers has demonstrated a fundamental problem with how these probes are deployed. Currently, the penetrometers are deployed by wireline on the Colletted Delivery System (CDS). The CDS latches into the Bottom Hole Assembly and the tool is then pushed into the formation by lowering the drill string. The drill string is then raised and decoupled through the sliding CDS. **Analysis of previous deployments shows that when the drill string is raised, the penetrometer is pulled out of the formation more than 80% of the time.** As a result, measurements of pore pressure, temperature, and permeability are severely compromised.

The new MDHDS will 1) remove the problem of tool dislodgement because the bottom hole assembly will not be driven into the base of the hole during penetration, 2) improve control over the penetration process by using the drilling fluid to hydraulically insert the penetrometer, 3) more effectively decouple the penetrometer from drill string heave, 4) allow real-time communication with the downhole tool through an armored conductor cable that is available on the SODV, and 5) allow deployment of other downhole tools that may be developed by third parties.

We propose a two-year project to 1) design and build a prototype of the MDHDS, and 2) field test the MDHDS on land. In Year 1, the probe will be built at Mohr Engineering with supervision by UTIG. In Year 2, the probe will be field tested and protocols will be developed for by the USIO with supervision by UTIG.

IODP-MI has defined projects as composed of four phases: Concept, Design, Fabrication, and Implementation. We have already completed the Concept Phase and we are midway through the Design Phase. We ask for support to complete the Design Phase, the Fabrication Phase, and the Implementation Phase.

Development of the new MDHDS occurs coincidentally with several advancements. The USIO is standardizing their data acquisition system so that it will work across their downhole tools. We envision that the MDHDS will become a platform upon which other third parties will develop other downhole tools (e.g., geotechnical corer, etc.) and that the MDHDS will be a standard tool deployed on IODP vessels according to the IODP Third Party Guidelines. We also envision that the MDHDS will be ultimately used on the CHIKYU, because it uses a similar BHA.

Motivation and relevance to the Initial Science Plan and IODP Goals:

The ability to rapidly measure pressure and permeability in mudstones through the depth of Advanced Piston Core drilling is a critical need to achieve the scientific goals of the IODP as expressed in the Initial Science Plan [*Integrated Ocean Drilling Program, 2003*].

Fluid pressure impacts the solubility of gas in water, governs the stability of gas hydrate [*Kvenvolden, 1993; Ruppel, 1997*], and affects permeability. In situ pressure gradients and permeability drive the flow field. A better understanding of pressure and permeability will allow us to (1) better define the volume of gas stored as hydrate and as free gas beneath hydrate [*Kvenvolden, 1993*]; (2) understand the mechanics by which gas migrates and is released [*Holbrook, et al., 2002; Hyndman and Davis, 1992; Liu and Flemings, 2002*]; (3) characterize the role of hydrate dissociation in slope failure [*Dillon, et al., 1998; Dillon, et al., 2000*]; and (4) estimate the role of catastrophic methane release on climate [*Dickens, et al., 1997*] (Fig. 1C).

The ISP poses an initiative to study the seismogenic zone (Fig. 1B). Fluid pressure is cited as a driving force in the geometry and structure of accretionary complexes [*Dahlen, et al., 1984; Davis, et al., 1983; Saffer and Bekins, 2002*]. Porosity and seismic data have been used with models to estimate pressure, flow paths, and fluid fluxes [*Bekins and Dreiss, 1992; Brown, 1995; Screaton, et al., 2001*]. Many of these models await validation because of the lack of direct pressure measurements.

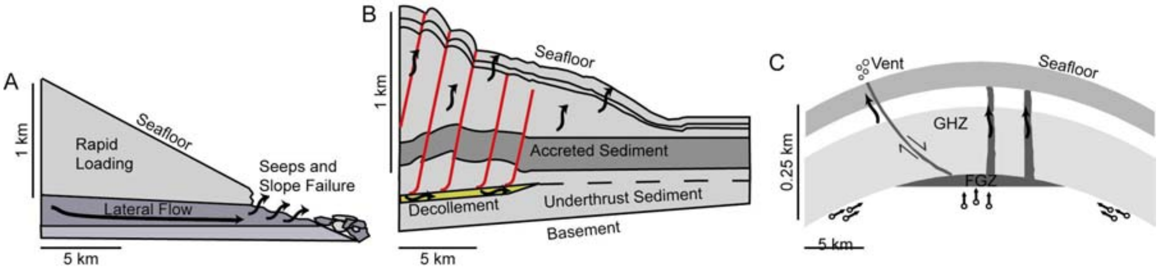

Figure 1: Direct measurements of pressure and permeability will illuminate sub-seafloor processes. (A) On continental margins, high fluid pressures drive failure. (B) In accretionary prisms, we would like to know the in situ pressure and permeability of faults and bounding sediment. (C) Gas hydrate provinces are dynamic hydrologic systems where gas and water pressures affect the formation and dissociation of gas hydrate. GHZ = gas hydrate zone. FGZ = free gas zone.

The role that pore fluids have in sculpting continental slope geomorphology has intrigued scientists since the diverse structure of slopes was identified [*Johnson, 1939; Rona, 1969*] (Fig. 1A). Excess fluid pressure was attributed to causing landslides and failures on low angle slopes that would not fail without excess pressure [*Bombolakis, 1981; Terzaghi, 1950*]. More recently, focused flow along permeable layers was invoked as a major contributor to the timing and distribution of sediment deformation and failure [*Boehm and Moore, 2002; Dugan and Flemings, 2000; Dugan and Flemings, 2002; Flemings, et al., 2002; Haneberg, 1995*]. Models predict the magnitude of pressure required to generate instability and provide insights into the origins of the excess pressure. Few direct measurements exist to test these models.

The Hydrogeology PPG stressed the importance of developing, improving, and maintaining tools (Recommendation 4), the importance of the routine collection of hydrogeologic data (Recommendation 3), and described hydrogeologic science problems where understanding hydrologic properties and in situ pressures are critical (Recommendation 2) [*Ge, et al., 2002*]. The PPG proposed initiatives in the study of hydrates, extreme climates/rapid climate change, and the deep biosphere. The Hydrogeology PPG also proposed focused hydrogeology legs on hydrate systems and the deep biosphere [*Ge, et al., 2002*]. Expedition 308 'Gulf of Mexico Hydrogeology', was driven by the desire to understand the spatial distribution of fluid pressure in the subsurface [*Flemings, et al., 2005*]. The Engineering Development Panel recently prioritized measurements of in situ pressure as one of the critical technologies in need of development [*Engineering Development Panel Members, 2006*]. The Science and Technology Panel (STP) defines measuring in situ pressure as a 'standard measurement' and they defined a standard measurement as *measurements that shall, whenever practicable and appropriate, be carried out across all platforms and/or shore-based labs [Integrated Ocean Drilling Program - Management International, 2006].*

537-CDP, A,B	OTF	Costa Rica Seismogenesis Project
545-Full3	OTF	Juan de Fuca Flank Hydrogeology
553-Full2	OTP	Cascadia Margin Hydrates
557-Full2	SPC	Storegga Slide Gas Hydrates
564-Full2	OTF	New Jersey Shallow Shelf
589-full3	OTF	Gula of Mexico Overpressures
603-CDP3, A, B, C, D	OTF	NantroSeize Phase 1, 2, 3
635-Full2	SSEP	Hydrate Ridge Observatory
637-Full2	OTF/SPC	New England Margin Hydrogeology

Table 1: IODP Proposals that would be strengthened by a functional delivery system and pore pressure penetrometer [interim Science Advisory Structure Office, 2002]

Each proposal in Table 1 would be strengthened by a functional pore pressure penetrometer. In the near future, the most critical need is for the NantroSeize Mission. Key questions that must be answered include: 1) what is the pressure in the first 1 km, 2) can pressure be predicted within the accretionary wedge from a porosity-based prediction?

The DVTPP and the T2P: Pore Pressure Penetrometers in the IODP

The T2P and the DVTPP were deployed extensively on IODP Expedition 308 [*Flemings, et al., 2005; Flemings, et al., 2006*] (Fig. 2). The DVTPP was deployed previously during ODP Legs 190, 201, and 204 [*D'Hondt, et al., 2003; Moore, et al., 2001; Trehu, et al., 2003*]. The primary difference between the two tools is that the T2P has a 6mm diameter tip, whereas the DVTPP has a ~23mm diameter tip that rapidly widens backwards from the tip. The T2P was designed both to dissipate more rapidly and to dissipate with a characteristic pressure profile. Both properties allow the T2P to be deployed for shorter periods than the DVTPP in order to interpret in situ pressures.

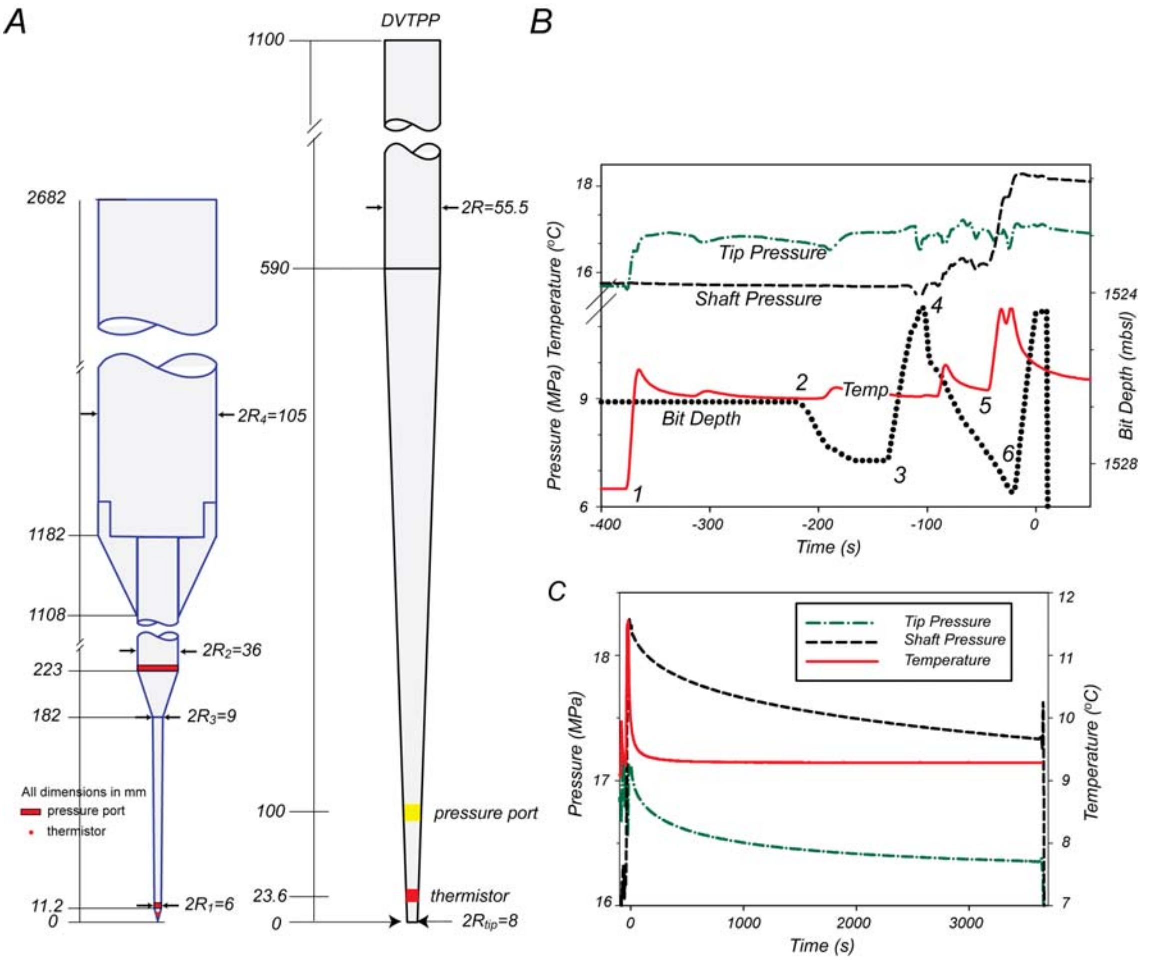

Figure 2: A) Geometry of the "Temperature-Two Pressure" (T2P) probe and the "Davis Villinger Temperature Pressure Probe" (DVTPP). In the T2P, Pore pressure and temperature are measured at the end of the tip extension and the base of the shaft. In the DVTPP, temperature and pressure are measured at the tip. B) Penetration phase of T2P deployment. Zero time is marked at the start of the dissipation phase of the deployment. Time is plotted in seconds. Bit depth is the depth of the bit in meters below sea level (mbsl). C) Dissipation phase plotted in linear time. The temperature dissipates to a constant value within 500 seconds. The tip pressure dissipates more slowly and the shaft dissipates the least by the end of the 60-minute deployment (modified from Flemings et al., 2006).

Figure 2B, C illustrates a successful deployment of the T2P. When the tool is pushed into the formation, pressure is induced at both the tip and the shaft. Subsequently the pressure and temperature decline rapidly. The pressure dissipation that results after penetration is used to infer in situ pressure and rock properties (Fig. 3). Additionally, both tools measure the formation temperature.

In all there were 25 T2P and 20 DVTPP Deployments. At Site 1322 numerous deployments were made (Fig. 3). Site 1322 and Site 1324 are the first locations in ocean drilling history where a detailed vertical profile of pore pressure was obtained.

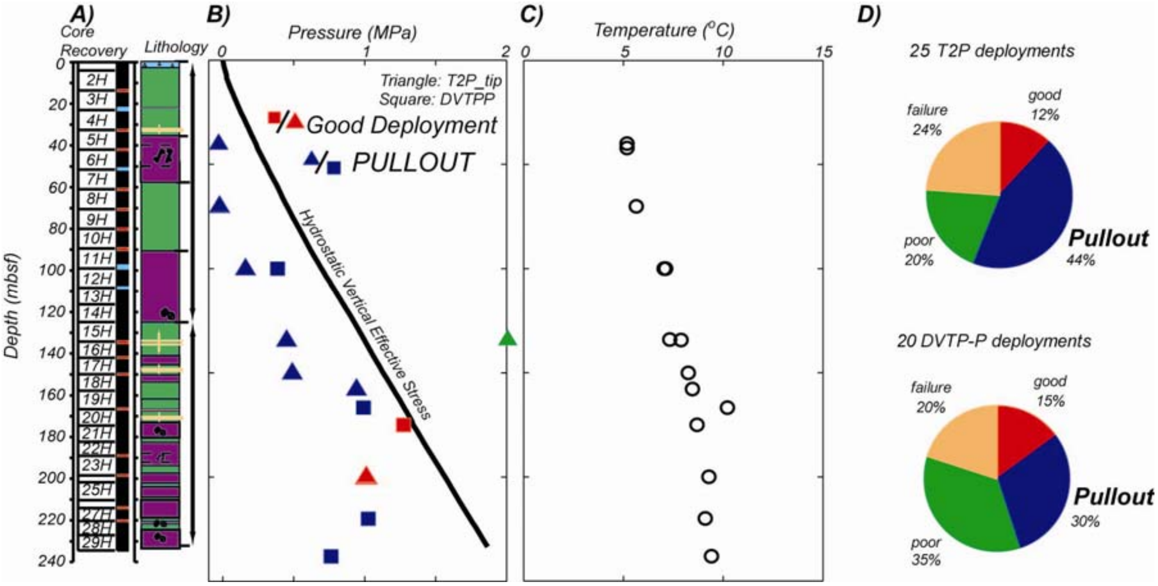

Figure 3) **Pressure interpretations at IODP Site 1322. A) Lithostratigraphic interpretation (green = undisturbed mudrock; purple = mass transport complexes). B) Over-pressure vs. Depth. There were only two successful penetrometer measurements. Pore pressures rise to 80% of the overburden stress at at 100 meters depth. C) Temperature measurements for the T2P. D) An extraordinary number of measurements suffered 'pullout' (see Fig. 4). Good stands for deployments that have clean penetration and typical dissipation curve. Fair represents deployments that have no typical dissipation curve but still can be used to interpret in situ pore pressure.**

The Colletted Delivery System (CDS): A flawed delivery system

Despite the exciting results, pore pressure measurements during Expedition 308 were extremely challenging [*Flemings, et al., 2005*] because a large fraction of the deployments were compromised because of the failure of the Colletted Delivery System (CDS). The problem is that both the T2P and the DVTPP had difficulty remaining coupled to the sediments (Figs 3 & 4). During more than half of the deployments (and in all deployments at less than 100 mbsf), after the drill string was raised and subsequent to penetration, there was an abrupt drop in pore pressure. This is coincident with a frictional heating pulse associated with the drill string being raised. In addition, the accelerometer in the DVTPP recorded movement of the tool when the drill string was raised. These results record the partial dislodgment of the tool due to friction in the colleted delivery system (Fig. 4a). Review of DVTPP records from Legs 201 and 204 suggest that tool dislodgement during elevation of the drill string has been a persistent problem with the DVTPP [*D'Hondt, et al., 2003; Trehu, et al., 2003*]. The problem is well illustrated at Site 1322 (Fig. 3B). Out of the 12 deployments where we recorded data, ten of them suffered pullout (blue symbols) and only two were successful (red symbols). The problem is ubiquitous to both the T2P and the DVTPP (Fig. 4D).

We have already completed the Concept Phase and we are midway through the Design Phase (Table 2). In the preceding section we resolved Items 1a, 1c, and 1e. In the ensuing section, we discuss 1b, 1d, and 1f and the components of the Design Phase that we have completed. We then ask for support to complete the Design Phase, Fabrication Phase, and Implementation Phase.

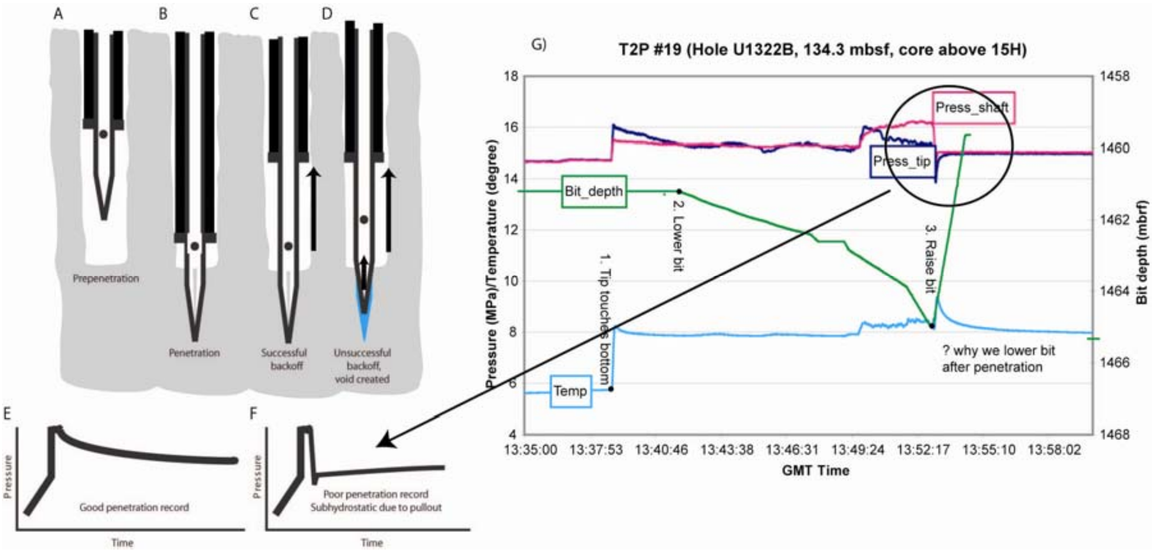

Figure 4) A) Illustration of the procedure for deployment of the penetration probes. A, B) The drill string pushes the probe into the formation. After penetration, the drill string is raised. C) The probe should stay in the ground and the bottom-hole assembly should slide upward as the drill string is raised a few meters. D) In many deployments, when the drill string was raised, there was partial coupling between the drill string and the tool was partially pulled out of its hole. E) During a successful penetration, there is an abrupt increase in pressure during penetration and then there is a slow dissipation of pressure after the tool is left in the ground. F) During unsuccessful deployments, the pore pressure record sharply drops during pullout. The result is a subhydrostatic pressure that gradually builds back to the formation pressure. G) Pressure and temperature response during an unsuccessful deployment. At Stage 3, as the drill string is raised (bit depth decreases), the pore pressures drop abruptly and the temperature rises. The probe is being pulled out of the formation as the drill string is raised.

Engineering Development Plan

IODP and EDP have defined projects as composed of four phases (Table 2).

1. Concept Phase	3. Fabrication
a. Functional requirements/specifications b. Rough cost c. What problem will be addressed/benefits d. Rough schedule e. Fit with the ISP objectives f. Probability of success (Risk Analysis)	a. Product b. Test results (component, performance, field) c. Comparison of results with testing plan d. Draft operations manual, shipboard procedures e. Training materials f. Sea trial or field test results, if needed
2. Design Phase	4. Implementation
a. Drawings and schematics b. Testing of unproven components c. Cost +/-15% d. GAANT chart schedule or equivalent e. Work breakdown structure f. Physical mockup if needed g. Testing plan	a. Evaluation of performance versus requirements

Table 2: Project phases as envisioned by IODP-MI.

The Motion Decoupled Hydraulic Deployment System (MDHDS)

We propose to complete the design, build, and test a new delivery system: the MDHDS. The equipment will be compatible with the Bottom Hole Assembly used on the IODP riserless vessel, and it will solve the current problems that plague the Colleted Delivery System. The delivery system will be capable of deploying either the DVTPP or the T2P. Furthermore, it will have the capability to use a live umbilical, which will allow the user to observe pressure and temperature response during deployment.

The new delivery system will be part of a broad effort to strengthen downhole tool measurements. The USIO is expending significant time and effort to redesign the data acquisition system that will replace existing outdated loggers. Recent technological advances in the data acquisition field have lead to breakthrough levels of accuracy and design flexibility. Features of the new acquisition system include Motorola 32-bit microcontroller with 512 kb RAM, eight analog inputs at 24-bit resolution, programmable gain, ultra low noise amplifier, and SPI and RS-232 serial interfaces to accommodate intelligent transducers. The acquisition system will greatly simplify deployment, calibration, and maintenance procedures, directly impacting the quality of downhole data. This new data acquisition system is envisioned to be a standard data acquisition module that other third party developers could also use. An example of this is the T2P tool. UTIG and MIT are currently working with the USIO to use this data acquisition system in a second generation version of the T2P.

The USIO, UTIG (Flemings), MIT (Germaine), and MOHR Engineering Division of Stress Engineering Services, Inc. (“Mohr”) (Tom Pettigrew) worked together to develop a preliminary design for a new delivery system. Tom is a design engineer with extensive ODP experience. After extensive debate, analysis, and three meetings in Houston with Mohr, we concluded that a piston-type delivery system should be developed. This preliminary design includes dimensional configuration of the components, compatibility with the existing BHA, shipboard operation, and experience with latching mechanisms.

The Motion Decoupled Hydraulic Deployment System (MDHDS) is a wireline deployed system that uses mud pressure to advance a penetrometer into the formation. It has been designed to accommodate both the DVTPP and the T2P. Furthermore, it will accommodate a standard three-inch diameter thin walled fixed piston geotechnical sampler. After hydraulic deployment of the penetrometer, the BHA is raised to completely decouple the tool from the BHA thus eliminating the adverse effects of pipe heave.

The MDHDS will be used to deploy the DVTPP and the T2P on either the IODP logging or coring wireline. The new MDHDS assembly will be compatible with the standard IODP APC/XCB BHA. The MDHDS also uses mud pressure to insert the tool rather than lowering the BHA, which will eliminate the mud plugging problem that has plagued the CDS. The MDHDS is designed for up to a 4m penetration stroke which is adjusted by lifting the BHA a prescribed distance from the bottom of the hole.

The MDHDS will have the capability of being deployed either on the coring wireline or on an armored conductor cable such as the logging line. When deployed on the wireline, complete decoupling will occur due to separation of the wireline from the tool. Alternatively, when employed on the conductor cable, the conductor will remain attached to the MDHDS, and a small tether (or ‘pigtail’) will connect between the MDHDS and the penetrometer. Complete decoupling will virtually eliminate any heave-induced effects imparted by the BHA. The capability of a ‘hot’ line to the tool opens a range of exciting possibilities for future tool developments.

MDHDS Design:

The MDHDS has three subassemblies as shown in Figure 5: 1) the Outer Subassembly, 2) the Inner Subassembly, and 3) the Bridle or Wireline Extender (not shown). The **Outer Subassembly** is about 12 m long and consists of an *upper latch* union connected to a long structural *body* tube. At the end of the body tube is a second *lower latch* union and then the T2P housing *guide*. The subassembly has a maximum outer diameter of 3.75 inches except for the upper latch union which also serves as the landing shoulder into the BHA which is 4 inches in diameter. The guide tube functions to protect the T2P and open the flapper value. The guide tube would not be used when deploying the DVTPP. The DVTPP—which has a larger diameter than the T2P and was designed to open the flapper valve—would be attached directly to the lower latch.

The **Inner Subassembly** consists of a *piston rod RS fishing neck*, connected to a shoulder stop. The shoulder stop prevents the inner subassembly from exiting the outer subassembly. Below the shoulder stop is a 4m *upper piston rod* which provides the stroke when the tool is decoupled from the BHA. This is followed by the *lower piston rod* which provides a hydraulic seal with the lower latch union and serves as the drive piston to insert the tool. The lower piston rod provides 4 meters of stroke to penetrate the tool into the formation. The lower piston rod terminates with the *lower latch dogs* and a *quick release* to connect the tool. Electrical cabling will be integrated into the Inner Subassembly. The quick release connection will also contain a high pressure electrical connection. The wire to the back side of this connector will pass through the lower piston rod where it will convert to a 10 m long spiral cable (similar to the cord on a telephone). In the relaxed position this spiral cable will reside inside the upper piston rod. The high pressure connector on the end of the spiral cable will mate with a connector inside the modified RS overshot. The upper piston rod will be a tube (with most likely a ¾” bore). There will be a hole through the RS fishing neck rather than the cone shown in Figure 5. The upper piston rod will provide a sleeve almost 4 meters long that will contain the closed coil of a pigtail. Stretching the pigtail to provide a 4 meter gap between the RS overshoot and the top of the RS fishing neck would than only require a doubling of the coil length. This would be a relatively low amount of extension and reduce the force interaction with the tube. The coil will then retract into the tube as the RS overshot is lowered to recover the tool.

The third subassembly (not shown) is the **Bridle** (*wireline* extender), which consists of an IOPD female quick release connected to a length of cable and terminated with the *RS overshoot* and upper latch mating union. This extender will provide direct connection of the MDHDS to the standard IODP coring wireline which is terminated with a sinker bar assembly.

MDHDS Deployment:

The design of the MDHDS is primarily driven by the need to decouple the tool from the BHA in order to eliminate tool motion during the pore pressure dissipation period. The proposed design is rather intricate and operational procedures had to be integrated into the design process.

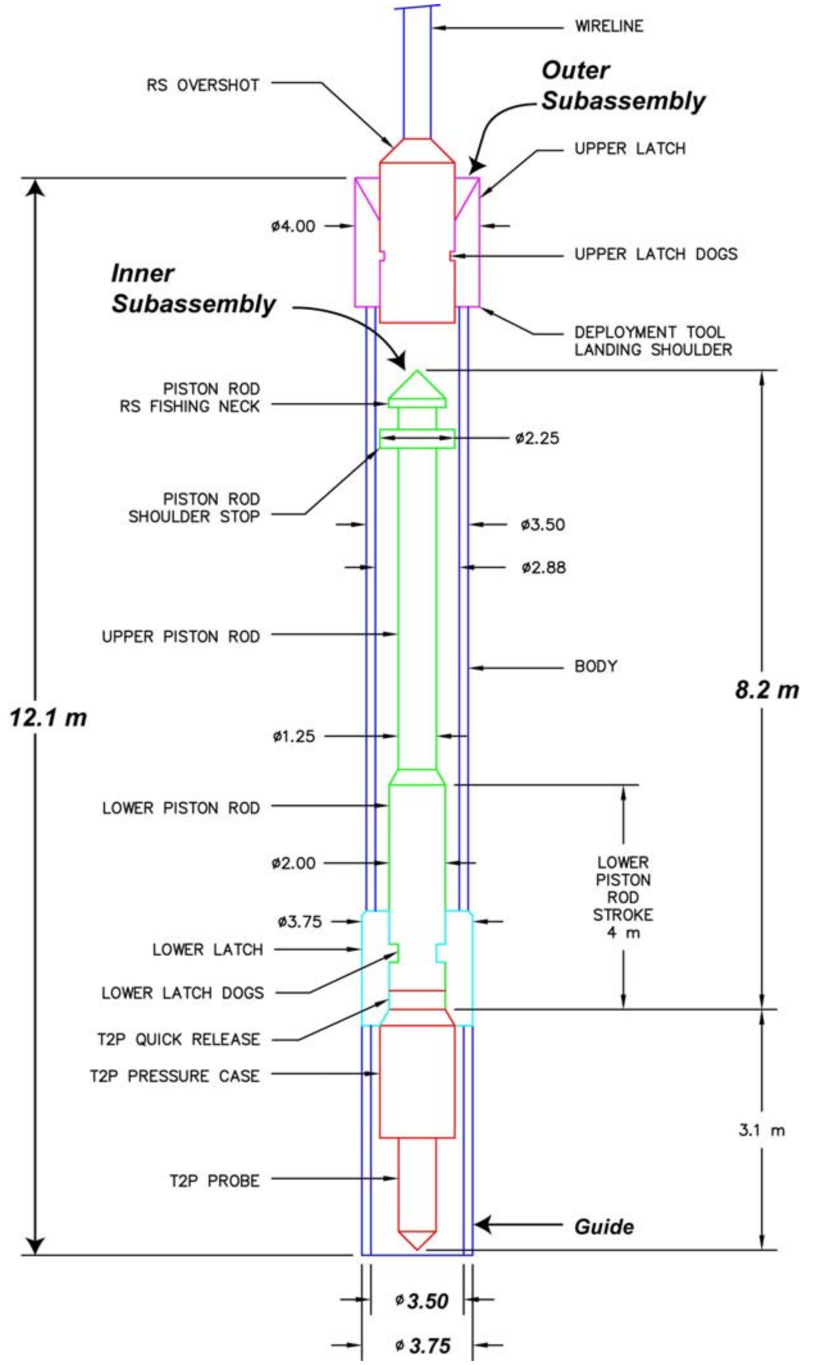

Figure 5: Schematic drawing of the new MDHDS. The figure has a compressed vertical scale to make it legible. All diameters are in inches (as conventional ODP practice for pipe sizes) and lengths are in meters.

The following paragraphs provide an overview of the important steps and some of the rationale underpinning the decisions. Figure 6 provides a true scale schematic of the MDHDS with the T2P located in the BHA during various stages of deployment. This image provides a much better sense of the overall system but hides the important detailing necessary for a functional design. Figure 7 provides a more detailed but distorted scale image of three deployment stages to help show the operation of the tool.

The MDHDS can be stored in one of the standard IODP core barrel storage shucks on board ship. In preparation for deployment, the tool will be moved from the storage shuck to the rig floor. The upper and lower latches are then reset and the guide tube removed. The latch sub on the bottom of the bridle is snapped into the upper latch and the female quick release on top of the bridle is made up to the male quick release on the bottom of the IODP wireline sinker bar assembly.

With the MDHDS set and the guide removed, the male quick release attached to the end of the lower piston rod is exposed. A mating female quick release is attached to the top of the T2P. When the T2P is ready for deployment, it is carried out to the rig floor, the female quick release on top of the T2P is made up to the male quick release attached to the MDHDS lower piston rod. The guide tube is installed while the end of the T2P is supported with a centering block. The complete MDHDS is then picked up with the IODP coring wireline, suspended in the vertical orientation to remove the centering block, inserted into the drill string, and lowered to the BHA. Note that when assembled for deployment, the T2P is trapped inside the MDHDS. The T2P cannot drop through the bottom tool nor be pulled out through the top.

When using the MDHDS to deploy the DVTPP, a 4m long spacer sub is added to the upper barrel and the lower barrel is removed. Adding the spacer sub will space out the MDHDS such that the lower latch mechanism will hold the BHA flapper valve open, thus preventing it from dragging on the DVTPP due to residual heave of the BHA. Removal of the lower barrel makes room for the larger pressure case diameter of the DVTPP.

With the hole cleaned of cuttings using the circulating fluid and the BHA lifted 2m off the bottom of the borehole, the MDHDS is landed in the BHA on the standard IODP core barrel landing shoulder (Fig. 6C). When the tool lands in the BHA a seal is created inside the BHA at the core barrel landing shoulder. At this point, the guide tube will extend through the BHA flapper valve, keeping the flapper valve open and out of the path of the penetrometer as it is inserted into and extracted from the formation at the end of the experiment.

The drill string is then pressurized actuating the upper latch which releases the RS Overshot attached to the bridle. Note that when the upper latch is actuated, the latch dogs are fully retracted allowing the RS Overshot and latch sub to pass through the upper latch union. Although the proposed upper latch design is a new latch design for IODP, it is a design that has been used successfully in the oil field. The decoupled wireline is then pulled uphole several meters to prevent the RS Overshot from engaging the RS Fishing Neck attached to the upper piston rod. When the upper latch is actuated, pressure is allowed to reach the lower latch actuating this locking mechanism. The pressure only unlocks the lower latch but will not release the T2P (Fig. 7A). Thus, the T2P instrument is not “shot” into the formation similar to an APC core barrel deployment.

The drill string pressure is then released allowing a spring inside the lower latch to retract the latch dogs. At this point, the T2P is set for deployment. This pressure actuated latch mechanism is an adaptation of an existing IODP design successfully used in the deployment of flow meters in conjunction with packers. The drill string is once again pressurized in a controlled manner to pump the T2P instrument out of the BHA and into the formation (Fig. 6E, Fig. 7B). The force used to drive the T2P into the formation is created by the pump pressure acting on the lower piston rod cross section area sealed inside the lower latch and is controlled by the pump pressure applied to the drill string. Once the top of the lower piston rod reaches the lower latch internal seal (4m stroke) fluid will begin to by-pass the seal relieving the piston force driving the T2P into the formation. This action limits the distance the T2P can be pumped into the formation.

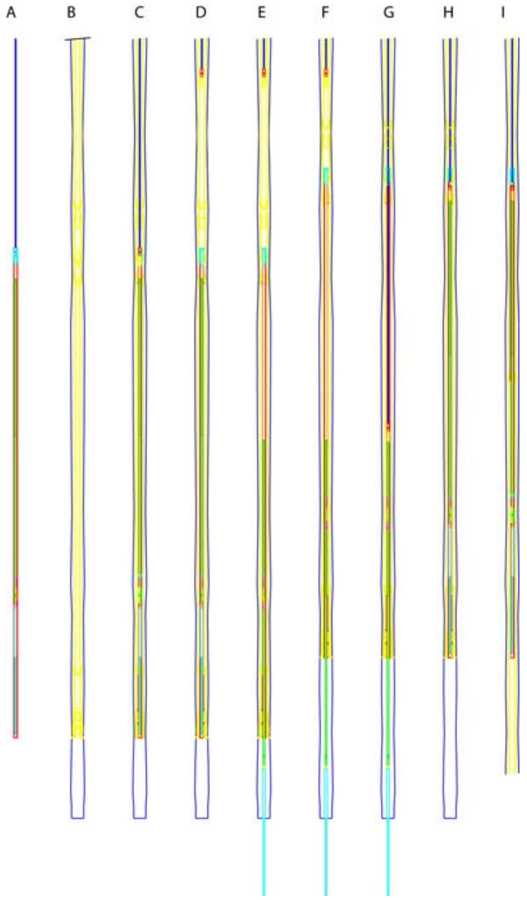

Figure 6: A) T2P/Deployment tool on wireline. B) IODP APC/XCB Bottom Hole Assembly (BHA) lifted 2 meters off bottom of hole. C) T2P landed in BHA using wireline. D) Upper latch actuated, RS overshot pulled up hole. D) Lower latch actuated, T2P pumped into formation. F) BHA raised 2 meters (4m off bottom). G) RS Overshot lowered on wireline and latched onto piston rod RS fishing neck. H) T2P extracted from formation, inner subassembly raised until T2P pressure case contacts lower latch. I) T2P/ MDHDS assembly being recovered.

Note that unlike the CDS, which is driven into the formation by lowering the BHA to the bottom of the borehole, the MDHDS allows the BHA to remain 2m off the bottom of the borehole. This clearance will greatly reduce the possibility of jamming borehole cuttings and/or other detritus inside the BHA which could result in coupling between the tool and the BHA. In the case of DVTPP deployment, the drill bit will have to be positioned approximately 6m off bottom since when the MDHDS lands in the BHA, the DVTPP will extend approximately 4m beyond the bit.

Once the penetrometer has been driven into the formation, the BHA is raised an additional 2m while maintaining circulation (Fig. 6F). Raising the BHA will position the bottom of the MDHDS guide tube 3m above the top of the T2P pressure case and the lower latch union will be moved upward 2m to the middle of the upper piston rod. In this configuration, with large clearances between the upper piston rod OD and the lower latch ID, as well as, the lower piston rod OD and the guide tube ID, the BHA is free to heave up and down 2m (4m total stroke) without loading the T2P. By maintaining circulation while picking up the BHA, the T2P is held in place relative to the formation as the BHA is raised and detritus is prevented from entering the BHA. The weight of the wireline will allow it to automatically strip through the oil saver on top of the drill string thus maintaining its position relative to the tool as the BHA is raised.

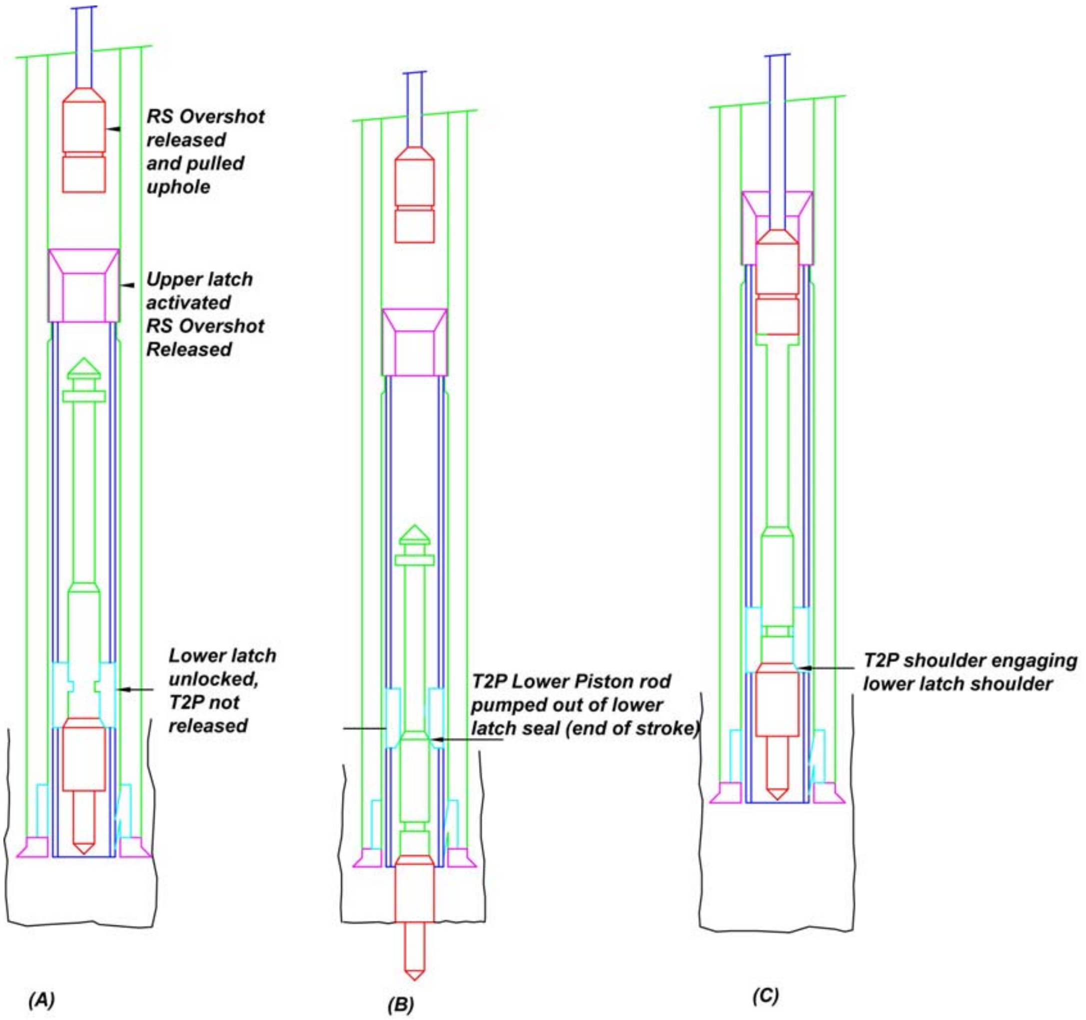

Figure 7: **Three stages of Penetrometer Deployment: A) RS overshoot and lower latch released. B) Drill String Pressurized to pump penetrometer out of BHA and into formation, C) Penetrometer raised with wireline to engage deployment tool.**

The penetrometer is extracted from the formation by lowering the wireline through the upper latch union allowing the RS overshot to latch onto the RS fishing neck attached to the upper piston rod. In the case of a “hot line” deployment, the soft tether will recoil itself inside the upper piston rod allowing the RS overshot to latch onto the RS fishing neck.

The wireline is then raised, extracting the penetrometer from the formation (Fig. 6H, Fig 7C). Note, should the force required to extract the penetrometer from the formation exceed the limits of the wireline, the BHA can be raised until the lower latch union contacts the upper piston rod shoulder. Raising the BHA further will extract the penetrometer from the formation. Once extracted from the formation, the T2P is raised by the wireline until the T2P pressure case contacts the bottom of the lower latch union. When contact is made, the MDHDS will begin to move upward with the T2P. The assembly can then be recovered as a single unit with the coring wireline.

The overall deployment procedure is slightly different when deploying the MDHDS with a “hot line.” The soft electrical tether (coiled cable) will be run through the piston rods and connect to the MFTM. The tether will be in the retracted configuration inside the upper piston rod. As the tool is hydraulically inserted into the formation, the tether will extend allowing increased separation between the RS overshot at the end of the wireline and the Inner Subassembly. Upon release of the hydraulic pressure, the BHA and the wireline will be raised simultaneously to further increase separation and elongate the tether to about 8 m. This will be the fully deployed configuration with the tether stretched to about double length. The tool will be recovered by lowering the RS overshot through the Outer Assembly with the wireline. As the Overshot is lowered, the tension in the coil will retract the tether back into the upper piston rod. The Overshot will connect to the Fishing neck. Finally the wireline will be used to extract the tool from the formation.

Telemetry System

The USIO (Lamont Borehole Research Group) will design the telemetry system needed to transmit selected engineering data from the penetrometer via a standard logging cable in conjunction with the MDHDS. The Telemetry system shall consist of three (3) subsections: 1) Multi-Functional Telemetry Module (MFTM); 2) Schlumberger 7 conductor Wireline cable; Telemetry Surface Control Panel (TSCP).

The MFTM will provide the following functions:

- Capture data stream from probe attached to the Inner Subassembly (e.g. such as DVTPP or T2P)
- Monitor three-axis acceleration
- Monitor internal temperature
- Format output data stream and Broadcasts to Surface Panel
- Latches to top of Outer Subassembly

The TSCP provides the following functions:

- Captures formatted data stream from MFTM
- Supplies power to the MFTM
- Formats output data stream to serial RS232 for interface to computer

LDEO, TAMU, and the Principal Investigator will jointly agree to communication protocols between MFTM and the penetrometers.

Work Plan:

The project will be completed in two years. Our work plan is divided into 1) **MDHDS & Telemetry Development**, and 2) **Field Application/Testing** (Fig. 8). The project will be supervised by UTIG with subcontracts to Mohr Engineering and the USIO (Texas A&M and Lamont-Doherty). Field Application and Testing will led by the USIO-TAMU. However, UTIG, Mohr Engineering, and the USIO-Lamont will also participate. Mohr, U.T., and the USIO will meet every 4 months to review the project progress.

Year 1: MDHDS & Telemetry Development:

UTIG will be responsible for managing 1) the final design and manufacturing of the MDHDS, 2) the completion of the telemetry system, and 3) the interactions between Mohr Engineering and the USIO (both TAMU and Lamont) During the year, there will be monthly conference calls and meetings in Houston with Mohr Engineering. The purpose of these meetings will be to ensure the development is meeting project goals and to address any design changes that occur. Germaine, Flemings, and a TAMU USIO and a Lamont USIO engineer will participate in meetings and conference calls. At the end of Year 1, a fully manufactured prototype delivery system will be delivered to the USIO for testing.

Thirteen tasks will be completed in the first year of the project. Each task is summarized below and is detailed in Appendices 4, 5, & 6. The schedule for completing tasks is illustrated in Figure 9.

Task	**Year 1**						**Year 2**					
	A	J	A	O	D	F	A	J	A	O	D	F
Motion Decoupled Hydraulic Deployment System												
Detailed design												
Task Mohr-1) lower latch mechanism subassembly	■											
Task Mohr-2) upper latch mechanism subassembly	■											
Task Mohr-3) T2P Piston Rod subassembly		■										
Task Mohr-4) Design the hot line connect		■										
Task Mohr-5) Integrate Deployment Tool assembly		■										
Fabrication												
Task Mohr-6) Fabrication Drawings Package		■										
Task Mohr-7) Technical Manual for Deployment			■									
Task Mohr-8) Fabrication of prototype tool			■	■								
Task Mohr-9) Inspection, Assembly, Bench Test					■	■						
Task BRG-2) Develop MFTM (Telemetry)		■	■	■	■							
Task BRG-3) Develop TSCP (Telemetry)		■	■	■	■							
Communication												
Task Mohr-11) Project Management	■	■	■	■	■	■	■	■	■	■	■	■
Task UTIG-1) Des./Prog. Meetings (also BRG-1, TAMU-1)	■		■		■		■		■		■	
Field Trials and Data Evaluation								■	■	■		
Task Mohr-10) Field Test								■	■	■		
Task BRG-4) Field Test								■	■	■		
Task TAMU-2) Field Testing								■	■	■		
Task TAMU-3) Space-out design							■					
Task TAMU-4) Analysis of Field Data									■	■	■	
Reports and Deliverables												
Task TAMU-5) Drafting									■			
Task TAMU-6) Performance Analysis											■	■
Task TAMU-7) Operations manuals											■	■
Task BRG-5) Operations Manual											■	■

Figure 9. WorkPlan: Tasks are defined individually in Appendices 4, 5, and 6 for Mohr, TAMU, and Lamont.

Year 2: Interfacing downhole tools with the MDHDS and Field Testing, Analysis, and Documentation:

In Year 2, the USIO will be responsible for ensuring that the MDHDS interfaces with downhole tools within the IODP, that the electrical tether works and that communications protocols are successful and field testing the MDHDS (Appendix 5). Mohr Engineering, and the USIO (TAMU and Lamont), and UTIG will participate in field testing and periodic design and testing discussions. Tasks are defined in Appendices 4, 5, & 6. In addition to field testing there will be analysis of the field data, drafting, performance analysis, and the writing of operations manuals.

Appendix 1

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Davis, D., J. Suppe, and F. A. Dahlen, Mechanics of fold-and-thrust belts and accretionary wedges, *Journal of Geophysical Research*, *88*, 1153-1172, 1983.

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Dillon, W. P., J. W. Nealon, M. H. Taylor, M. W. Lee, R. M. Drury, and C. H. Anton, Seafloor collapse and methane venting associated with gas hydrate on the Blake Ridge; causes and implications to seafloor stability and methane release, in *Geophysical Monograph*, edited by C. K. Paull and W. P. Dillon, pp. 211-233, 2000.

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Appendix 2

Vitae

PETER B. FLEMINGS

Research Professor

The University of Texas at Austin
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Professional Preparation

Dartmouth College, B.A. Geology, 1984
Cornell University, M.S. Geology, 1987
Cornell University, Ph.D. Geology, 1990

Appointments

2007-present	Research Professor, The University of Texas at Austin
2003-2007	Professor of Geosciences, The Pennsylvania State University
2002-2003	Visiting Scientist, Massachusetts Inst. of Tech., Dept. of Civil and Env. Engineering
1998-present	Co-Director Director of the GeoSystems Initiative, The Pennsylvania State University
1997-2003	Associate Professor of Geosciences, The Pennsylvania State University
1994-2000	Adjunct Associate Research Scientist, Lamont-Doherty Earth Observatory
1993-1997	Assistant Professor of Geosciences, The Pennsylvania State University
1992-1993	Research Scientist and Crosby Lecturer, Massachusetts Institute of Technology
1991-1992	Associate Research Scientist, Lamont-Doherty Geological Observatory
1991	Visiting Scientist, Exxon Production Research Company
1990-1991	Post-Doc. Associate, Lamont-Doherty Geological Observatory

Five Publications Most Relevant To This Proposal

1. Long, H., **Flemings, P.B.**, Germaine, J., Dugan, B., Sawyer, D., and Shipboard Scientific Party, IODP Expedition 308, In Situ Pore Pressure at IODP Site U1324, Ursa Basin, Gulf of Mexico, Paper # 18772, Paper prepared for presentation at the 2007 Offshore Technology Conference held in Houston, Texas, U.S.A., 30 April – 3 May 2007.
2. **Flemings, P.B.**, Germaine, J., Long, H., Dugan, B., Sawyer, D., Behrmann, J.H., John, C., and Shipboard Scientific Party, IODP Expedition 308, 2006, Measuring Temperature and Pressure with the Temperature Two Pressure (T2P) Probe in the Ursa Basin, Gulf of Mexico: Development of a New Pressure and Temperature Probe for the IODP, Paper # 17957, Paper prepared for presentation at the 2006 Offshore Technology Conference held in Houston, Texas, U.S.A., 1–4 May 2006.
3. **Flemings, P.B.**, Stump, B.B., Finkbeiner, T., Zoback, M., 2002, Overpressure and Flow-Focusing in the Eugene Island 330 Field (Offshore Louisiana, U.S.A.): Theory, Examples, an Implications, *American Journal of Science*, V. 302, p. 827-855.
4. Liu, X., **Flemings, P.B**., 2006, Passing gas through the hydrate stability zone at southern Hydrate Ridge, offshore Oregon, Earth and Planetary Science Letters, v. 241, p. 211-226.
5. Sawyer, D., **Flemings, P.B.,** Shipp, C., Winker, C., 2007, Seismic Geomorphology, Lithology, and Evolution of Late Pleistocene Mars-Ursa Turbidite Region, Mississippi Canyon Area, Northern Gulf of Mexico, *AAPG Bulletin*, V. 91, n. 2, p. 215-234.

Five Other Significant Publications

1. **Flemings, P.B.**, and Jordan, T.E., 1989, A Synthetic Stratigraphic Model of Foreland Basin Development, *Journal of Geophysical Research*, vol. 94, p. 3851-3866.
2. **Flemings P.B.**, Stump, B.B., Finkbeiner, T., Zoback, M., 2002, Overpressure and Flow-Focusing in the Eugene Island 330 field (Offshore Louisiana, U.S.A.): Theory, Examples, and Implications, *American Journal of Science*, V. 302, p. 827-855.
3. Dugan, B., **Flemings, P.B.**, 2000, Overpressure and Fluid Flow in the New Jersey Continental Slope: Implications for Slope Failure and Cold Seeps, *Science*, V. 289, p. 288-291.

4. Long, H., **Flemings, P.B.**, Germaine, J.T., (in review), Interpreting In situ Pressure and Hydraulic Properties with Borehole Penetrometers in Ocean Drilling: DVTPP and Piezoprobe Deployments at Southern Hydrate Ridge, Offshore Oregon, Journal of Geophysical Research.
5. Expedition 308 Scientists, 2005. Overpressure and fluid flow processes in the deepwater Gulf of Mexico: slope stability, seeps, and shallow-water flow. IODP Prel. Rept., 308. doi:10:2204/iodp.pr.308.2005

Synergistic Activities

1. Developed educational free-ware STRATA (*GSA Today*, vol. 6, no. 12, p. 1-7.) and StormSed (Cookman & Flemings, 2001, *Computers and Geosciences* 27 (6): 647.).
2. Director GeoFluidsIII: Industry-academic consortium pursuing research on fluid flow in basins.
3. Ocean Drilling Science Advisory Structure: Chair Eng. Dev. Panel; served on SciMP, PPSP, and ESSEP.
4. Led two workshops: 1) the Geofluids of Passsive Margins: *JOI/USSAC Newsletter* **13** (2): 10-11. and 2) Downhole Tools Workshop (with A. Fisher and R. Murray).
5. Co-direct the Petroleum GeoSystems Initiative (http://hydro.geosc.psu.edu/geosystems.html), a cooperative effort between Penn State and industry to train the next generation of engineers and geoscientists for leadership in industry.
6. Co-Chief Scientist IODP Expedition 308, Gulf of Mexico Hydrogeology

Recent Collaborators

B. Dugan (Woods Hole); J. Germaine (MIT); G. Mountain (Columbia Univ.); D. Olgaard (ExxonMobil Upstream Research); D. Saffer (PSU); A. Trehu (Oregon State Univ.)

Graduate Advisor: Teresa Jordan - Cornell

Recent Graduate Students *(Supervised 9 Doctoral and 26 Master candidates since 1993)*

Research Cruises

1997: ODP Leg 174A---New Jersey Margin (logging scientist)
2001: ODP Leg 196---Nankai Accretionary Prism
2002: ODP Leg 204---Hydrate Ridge (shore-based scientist)
2002: JAMSTEC KRO2-10 Cork Data Recovery Cruise
2003: JAMSTEC KRO3 Cork Data Recovery Cruise
2005: IODP Expedition 308—Gulf of Mexico Hydrogeology (co-Chief Scientist)

Honors

2007	JOI-USSAC Distinguished Lecturer
2007	Keynote Speaker and Co-Convener, 'Subsurface sediment mobilisation and fluid flow', Geological Society, London.
2006	Kavli Fellow and Speaker, Humboldt Foundation Frontiers of Science Symposium
2006	AAPG Distinguished Lecturer
2003	Penn State EMS College Mitchell Award for Innovation in Teaching
2001	Best Paper Award, Computers and Geosciences. Cookman and Flemings, STORMSED.
1994-1997	Shell Faculty Fellow
1996	Penn State EMS College Wilson Teaching Award
1995	Best Paper, J.C. Cam Sproule Memorial Award, Alexander, L.L., Flemings, P.B., 1995, Geologic Evolution of a Plio-Pleistocene Salt Withdrawal Mini-basin: Block 330, Eugene Island, South Addition, offshore Louisiana, *AAPG Bulletin* 79 (12): 1737-1756.
1992	Crosby Distinguished Lecturer at M.I.T.
1991	Best Paper Award, Mountain Geologist--Flemings, P. B., Nelson, S. N., 1991, Paleogeography of the Paleocene Wind River Basin

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Professional Preparation

University	Degree	Date
Worcester Polytechnic Institute	Bachelor of Science	1976
Massachusetts Institute of Technology	Master of Science	1980
Massachusetts Institute of Technology	Doctor of Science	1982

Appointments

Employer	Position	Beginning	Ending
MIT Civil & Environmental Eng.	Senior Research Associate	2006	Present
MIT Civil & Environmental Eng.	Principal Research Associate	1989	2006
MIT Civil Engineering	Research Associate	1988	1989
MIT Civil & Environmental Eng	Lecturer	1982	Present
MIT Civil Engineering	Graduate Instructor	1981	1982
MIT Civil Engineering	Geotechnical Laboratory Director	1980	1982
MIT Civil Engineering	Teaching/Research Assistant	1976	1980

Publications: Most Related

1. Whittle, A.J., Germaine, J.T., Sutabutr, T, and Varney, A., (2001) “Prediction and Interpretation of Pore Pressure Dissipation for a Tapered Piezoprobe,” *Geotechnique* 51, No. 7, 601-617.
2. Zreik, D.A, Ladd, C.C., and Germaine, J.T (1995) “A New Fall Cone Device for Measuring the Undrained Strength of Very Weak Cohesive Soils.” *Geotechnical Testing Journal*, ASTM, 18(4), 472-482.
3. DeGroot, D.J., Germaine, J.T. & Ladd, C.C. (1993) “The Multidirectional Direct Simple Shear Apparatus,” *Geotechnical Testing Journal*, ASTM, 16(3), 283-295.
4. Sheahan, T.C. & Germaine, J.T. (1992) “Computer automation of conventional triaxial equipment,” *Geotechnical Testing Journal*, ASTM, 15(4), 311-322.
5. Jamiolkowski, M., Ladd, C.C., Germaine, J.T. & Lancellotta, R. (1985) “New developments in field and laboratory testing of soils: Theme lecture No. 2.”

Publications: Other Significant

1. DaRe, G., Santagata, M.C., and Germaine, J.T., (2000) “LVDT-based System for the Measurement of the Prefailure Behavior of Geomaterials,” Geotechnical Testing Journal, ASTM,. 24, No. 3, 288-298.
2. Sinfield, J.V., Germaine, J.T., and Hemond, H.F., (1999) “Effects of Soils on Laser Induced Florescence of BTX Contaminated Pore Waters,” Journal of Geotechnical and Geoenvironmental Engineering, ASCE, 125(12), 1072-1077.
3. Bloch, J., Johnson, B., Newbury, N., Germaine, J., Hemond, H. and Sinfield, J., (1998) “Field test of a Nobel Microlaser-Based Probe for In Situ Fluorescence Sensing of Soil Contamination,” Applied Spectroscopy, 52(10), 1257-1368.
4. Zeeb, P.J., Hemond, H.F., and Germaine, J.T., (1997) “Design and Performance of a Portable Piezocone Driver for High Resolution Profiling of Wetland Sediments,” Geotechnical Testing Journal, ASTM, 20(2), 191-198.
5. Andersen, G.R., Swan, C.W., Ladd, C.C., and Germaine, J.T. (1995) “Small-strain behavior of frozen sand in triaxial compression.” Canadian Geotechnical Journal, 32(3), 428-451.

Synergistic Activities

1. ASTM International: Active in the administrative and technical activities of ASTM committee D18 on soil and rock. This includes authoring several technical standard methods and integrating a new subcommittee on Bulk Solids.
2. Developed, implemented in research, and teaching at the graduate level a building block approach to experimental investigation called Flexible Automation Technology for Computer Aided Testing.
3. US Patent for “Method and Apparatus for the Direct Measurement of Moisture Characteristics of Porous Samples of Soil, Wood, Concrete and the Like” Sjoblom, K and Germaine, J. T. (2000). This is a new method to rapidly a continuous suction curve on soils.
4. Institute for Standards Research: instrumental in the development of a new program to formulate precision statements for ASTM Soils standards and prepare four Standard Soils for use in the testing community.

Collaborators

Thesis Advisor: Charles C. Ladd (retired, MIT)

Others:
G. Andersen (Burns Cooley Dennis)
P. J. Culligan (Columbia, Geotechnical)
H. Hemond (MIT, Ground Water)
P. Flemings (Penn State, Geology)
T. Sheahan (Northeastern)
C. Swan (Tufts, Geoenvironmental)
F. Ulm (MIT, Materials)
R. Whitman (MIT, retired)
A. J. Whittle (MIT, Geotechnical)

Recent Students:

Alexander, Desma SM 2001
Pahuja, Sanjay PhD 2001
Vladimir, Ivanov SM 2001
Zhang, Guoping PhD 2002
Fidalgo Valverde, Beatriz SM 2002
Toker, Nabi Kartal SM 2002
Levy, Laurent PhD 2002
Lee,Yew Choong
Paonessa,Michael SM 2003
Pei, Jianyong SM 2003
Brooks, James SM 2004
Aw, Eng Sew SM 2004
Tan, Brain SM 2004
Yoon, Joon Sik PhD 2005
Ho, Chu PhD 2005
Chartier, Matthew SM 2005
Patrick Meng 2003

Supervised 22 Doctorate and 45 Master theses since 1985

THOMAS L. PETTIGREW, P.E.

Specialized Professional Competence

Mechanical design of instrumented (thermistor strings, borehole fluid sampling, seismometers, strain meters, tilt meters, borehole pressure meters, etc.) deep sea borehole equipment (CORK, ACORK, Borehole Instrument Hanger) including seafloor wellheads, hangers, associated subsurface equipment, deployment and recovery tools, as well as, development of deployment and recovery procedures for said equipment.

Design of specialized drilling, workover, production, and coring down hole tools for the oil and gas industry, as well as, deep ocean research.

Research

Mr. Pettigrew has been involved in research to develop hostile environment down hole tool seals for the oil and gas industry.

Employment History

Staff Consultant, Mohr Engineering, Div. of Stress Engineering Services, Inc., April 2004 – Present
Staff Engineer, Chief Engineer, Supervisor of Engineering, Assistant Supervisor of Engineering, Sr. Development Engineer, Ocean Drilling Program, Texas A&M University, December 1986 – February 2004
Technical Services Engineer, Design Engineer/Metallurgist, Guiberson Div. of Dresser Industries, Inc., August 1980 – November 1986
Design Engineer, Rector Wellhead Equipment Company, November 1977 – July 1980

Academic Background

B.S., Mechanical Engineering, University of Texas at Arlington, 1976
30 hours graduate work in Materials Science, University of Texas at Arlington

Registrations

Registered Professional Engineer, Texas No. 50882

Professional Societies

American Society of Mechanical Engineers
American Society for Metals

Publications

1. T. Pettigrew, G. Holloway, “Hammer Drill: An Overview and Post Leg 179 Update”, *JOIDES Journal*, Vol. 24, p. 19, 1998
2. T. Pettigrew, G. Holloway, R. Deane, “Drilling Casing into Fractured Hard Rock Formations in Deep Water Using a Water Powered Hammer Drill”, *American Society of*
3. T. Pettigrew, “Design and Operation of a Drill In Casing System (DIC)”, *Ocean Drilling Program Technical Note #21*, 1993
4. T. Pettigrew, “Design and Operation of a Wireline Pressure Core Sampler”, *Ocean Drilling Program Technical Note #17*, 19992
5. K. Becker, H. Mikada, E. Davis, M. Kinoshita, T. Pettigrew, and Leg 196 Scientific Party: “Leg 196 Advanced CORKs for Long-Term Hydrological and Seismological Studies at the Nankai Trough”, *Eos*, v. 81, no. 48, p. 1099

6. Davis, E. E., K. Becker, T. Pettigrew, B. Carson, and R. MacDonald (1992): "CORK: A Hydrological Seal and Down hole Observatory for Deep ocean Boreholes", *Ocean Drilling Program Initial Reports*, v. 139, pp 43-45
7. G. Meyers, D. Goldberg, K. Grigar, T. Pettigrew, S. Mrozewski, C. Arceneaux, T. Collins, Shipboard Scientific Party ODP Leg 204, "Logging-While-Coring: First Results from ODP Leg 204, Hydrate Ridge", *Geophysical Research Abstracts,* Vol. 5, 01578, 2003
8. D. Goldberg, G. Meyers, K. Grigar, T. Pettigrew, S. Mrozewski, C. Arceneaux, T. Collins, Shipboard Scientific Party ODP Leg 204, "Logging-While-Coring: New Technology Advances Scientific Drilling", *Geophysical Research Abstracts,* Vol. 5, 01578, 2003

Patents

U. S. Patent 4,750,564–Tubing Resetable Well Packer.

Engineering Design and Analyses

Mr. Pettigrew has extensive experience in the design of instrumented subsea wellheads (CORK, ACORK, and Borehole Instrument Hanger) for deep ocean scientific research and has personally supervised six each CORK installations—three off western Canada in 2400 m water depth, one off Oregon in 800 m water depth, and two in the Barbados Trench in 5000 m water depth; two each ACORK installations off Japan in 4800 m water depth; and two each borehole instrument hanger installations off Japan in 4800 m water depth from the *D/V JOIDES Resolution*. Assisted in numerous recoveries of long-term fluid samplers, thermistor strings, and data loggers from existing instrumented borehole installations via the submersible *Alvin* and ROV *Jason* on board the *R/V Atlantis*, the ROV *Kaiko* on board the *R/V Kairei*, and the *D/V JOIDES Resolution*. While at the Ocean Drilling Program Mr. Pettigrew worked on developing many different specialized drilling and coring tools such as core catchers, a rotary drill-in casing system, a 10,000 psi wireline pressure core sampler, a water powered hammer drill-in casing system, a 4½" custom liner hanger and liner, a 10,000 psi test chamber, an inflatable straddle packer system, a 4" air jet oil saver, a 4" ID drilling jar, a formation fluid sampler, and stuck wireline logging tool recovery tools.

Mr. Pettigrew has provided down hole tool technical expertise, designed and deployed special application down hole tools, designed mechanical, hydraulic and wireline set packers both retrievable and permanent types, as well as, other types of down hole service and production tools, researched and developed hostile environment seals and packing elements for down hole tools, designed down hole tools for tubing conveyed perforating, and designed a wireline deployable, tubing resetable, packer, for the oil and gas industry.