DEPARTMENT OF THE INTERIOR
U. S. GEOLOGICAL SURVEY

SEAPCONE: a seafloor piezometric cone penetrometer system

by

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Open-File Report 92-719

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for conformity with U.S. Geological Survey editorial
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Woods Hole, Massachusetts 02543

December 1992

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ABSTRACT

A unique subaqueous, in-situ cone penetrometer test system, which is capable of measuring subbottom penetration resistance and other related properties (friction resistance, pore water pressure, and temperature), was constructed and operated by the U.S. Geological Survey. This apparatus produces profiles that represent actual in-situ sediment behavior which can then be related to stratigraphic changes, grain size, and engineering properties. It can provide valuable assistance to projects working in shallow marine, lacustrine and fluvial environments where sediment properties are required for geologic-related studies such as determining the thickness of the mobile layer, the depth to erosional surfaces, and "ground-truthing" interpretations of seismic reflection profiles. The SEAPCONE can also be used by projects for determining location and thickness of offshore sand deposits to be used for beach nourishment, installing shore-protection structures, and dredging. The SEAPCONE may be used as a short-term piezometer for studies requiring knowledge of in-situ pore pressures for the assessment of slope stability.

INTRODUCTION

Members of the U.S. Geological Survey Branch of Atlantic Marine Geology, in 1991, designed, fabricated and successfully deployed a new SEAfloor-sitting Piezometric CONE penetrometer system (SEAPCONE). The device pushes an instrumented cone into the seafloor and records the penetration data on board ship. Resultant data profiles can then be used for interpreting many geologic and engineering related properties including lithologic changes in all types of sediment, relative density in coarse-grained sediment, and strength and stress history in fine-grained sediment (Fig. 1; Robertson and Campanella, 1989; Schmertmann, 1978). Numerous other properties, such as earthquake-induced liquefaction potential, can also be correlated with cone penetration test (CPT) results. Once the properties in question are evaluated, the possibly complex sedimentary history (sedimentary sequences, depositional environment) of an area can be inferred. In addition, the response of the seafloor sediment to future geologic or engineering loading events can be estimated.

The purpose of this report is fourfold: (1) to present a brief discussion of the historical evolution and limitations of cone penetrometers; (2) to describe the physical components of the SEAPCONE system and its operation in general terms within the body of the report and in detail in two appendices; (3) to show sample data produced by the system; and (4) to discuss how the SEAPCONE can be modified to produce more representative data profiles.

DEVELOPMENT OF CONE PENETROMETERS

The cone penetration test (CPT) was introduced in Holland in the 1930's (Clayton and others, p. 235). Since that time, the test procedure of measuring the load required to advance a pointed cone attached to push rods into the ground has changed relatively little compared with the technological advances in the production of more sophisticated cones. Initially, a simple mechanical cone (no electronics were located in the cone itself) with a 60° apex angle was pushed deeper by increased weight on an internal rod. The internal rod was surrounded by an outer hollow rod that prevented the measured load from being influenced by friction along the entire length of the internal rod (Clayton and others, 1982, p. 236). That device was improved by the Delft Laboratory for Soil Mechanics by incorporating a design that reduced clogging between the inner and outer rods during penetration (Vermeiden, 1948). Another improvement, by Begemann (1965), was the introduction of a 150 cm^2 surface area friction sleeve (a cylindrical length of tubing used to measure the force exerted by the soil friction during penetration) behind the cone tip.

Many of the inherent problems encountered by the above mentioned mechanical cones were removed after the Fugro electric cone was introduced (Fig. 2). Because the cone and friction sleeve are permanently connected, a nearly continuous uninterrupted record can be obtained. As testing has progressed the number of different designs and sizes of cones has decreased to the extent that a cone with a 60° apex angle, a friction sleeve of 150 cm^2, and a projected cross sectional area of 10 cm^2 has been adopted by European and American standards (ASTM, 1991; Robertson, 1986). The installation of a piezometer, to measure pore water pressure, and an inclinometer, to measure probe tilt, are two recent advances in the evolution of the cone penetrometer probe. Other new developments include: a seismic cone to measure in situ shear wave velocity (Robertson and others, 1986), a vibratory cone to assess liquefaction potential in cohesionless sediment and a cone that can measure in-situ lateral stress (Jamiolkowski and Robertson, 1989). Research is presently underway that utilizes acoustic sensors in cone tips to aid in data interpretation.

The CPT is widely used around the world for subsurface exploration and possesses many benefits which include in-situ measurement of subsurface properties, without the typical disturbance created by sampling, and the ability to quickly produce deep, continuous subbottom profiles. Large areas can thereby be surveyed at low cost.

DESCRIPTION OF THE SEAPCONE

The SEAPCONE was designed to be used in shallow (scuba depth) water to help evaluate the geology and engineering properties of seafloor sediments. It was built to enable cone penetration tests (CPT) to be performed in underwater environments where few such instruments have been operated. Four requirements were adhered to during the design and construction of the penetrometer system: (1) relatively low initial cost (approximately $20k in 1991); (2) ability to be easily transported to and operated from a small vessel; (3) simple and easy operating procedures; and (4) a necessity to keep the reaction weight (weight of complete tripod) low and yet allow versatility so that the instrument could be used with and set upon different seafloor sediment types.

A shipboard computer was interfaced with the SEAPCONE to enable real time data profile viewing and logging. This configuration has the benefit of decreasing the complexity of the system and eliminating the potential for damage caused by water leakage into an underwater housing containing an instrument-mounted data recorder. Also, to reduce the need for electric operating power or hydraulic lines to be supplied from the ship to the instrument, a pneumatic/hydraulic cylinder that operated from an ordinary diver's tank was used to push the cone into the sediment. SCUBA divers operate the instrument and can add more push rods if deeper subbottom penetration is required at any site. The factors which limit the subbottom penetration depth are reaction weight of the tripod and pushing force developed by the pneumatic/hydraulic cylinder. If required, the tripod can be disassembled into individual pieces to facilitate transportation.

The SEAPCONE was initially deployed off a 22-m long boat without any problems (Fig. 3). The vessel possessed a 2,700 kg capacity crane with a 9.4 m boom length. In its present configuration, the SEAPCONE can be operated to any safe diver depth (approximately 30 m) and has the capability of pushing a cone at least 5 m into the seafloor, depending of course on local penetration resistance. During its initial deployment in southern Lake Michigan, probe penetration in excess of 3 m was obtained in very fine sand at a water depth of 10 m.

Mechanical components

The principal components of the cone penetrometer system are: a tripod with weighted legs, pneumatic cylinder and ram (piston rod), push rod(s), piezometric cone, subbottom penetration depth sensor, frame tilt inclinometers and shipboard data acquisition unit. These elements and other minor parts are listed and described in Table 1 and are shown in Figures 4-7. Table 1 presents a detailed listing of the components including the supplier for the benefit of readers who would like to construct a device using similar parts.

Cones with a projected cross section of either 5 cm^2 or 10 cm^2 can be used with the SEAPCONE. Although the 10 cm^2 cone is standard, it requires a greater reaction load to be pushed into the seafloor. The 5 cm^2 cone allows the same amount of penetration to occur but with a substantially smaller reaction weight. That may be important when deploying the instrument off a small boat or a ship with limited crane capacity. Schematic drawings of the two cones show the various internal and external components (Figs. 8 and 9).

Electronics and data acquisition system

All of the data-acquisition electronics were located onboard ship. In addition to making any modifications in the field easier, this setup also provided a means of monitoring all phases of the analog signals during data acquisition. During the initial field trials in water depths of 4 to 10 m, connection to the sensors was made through two cables, greater than 60 m long. One cable was connected to the cone and the other to the tripod tilt and penetration sensors.

A personal computer (80286 based) was used to control data-acquisition and storage onto a 20 Megabyte hard disk. The AD converter connected to the computer was set to record data from all eight sensors (cone tip resistance, friction sleeve force, pore pressure, cone inclination, temperature, cone tip penetration depth, tripod inclination x-axis and y-axis) at a user-defined rate of 100 times per second. Those data were displayed in real time during penetration in both analog and digital form (Fig. 10).

The data was transferred in ASCII format to other post-process computers for interpretation and reduction. Available commercial software was then used to plot results from different sensors in various configurations (Fig. 11). Refer to Appendix A for a more detailed description of the data acquisition system and its operation.

OPERATION OF THE SEAPCONE

After the tripod is lowered to the seafloor, the divers enter the water and visually check that all the tripod's feet are firmly resting on the bottom. A diver manually adjusts the circular tripod bubble level (Fig. 12). The bubble level serves as a diver-observable reference against tripod lift off, which could severely damage or break push rod or cone connections.

The shipboard data acquisition system is started and begins displaying and logging base-line data. A diver causes the cone to advance until it is just above the sediment surface (Fig. 6) by intermittently opening and closing the rate control needle valve (Fig. 13). Upon direction from shipboard personnel, through a wireless or hard-wired communication system, a diver opens the rate control needle valve which causes compressed air from the diver's tank to enter the top of the pneumatic/hydraulic cylinder. That increased pressure causes the internal piston, attached piston rod (loading ram), and external push rods to move downward (Fig. 14). The air in the bottom of the pneumatic/hydraulic cylinder is simultaneously forced out the vent and appears as bubble-phase gas (Fig. 12). The rate control needle valve is adjusted to maintain an approximate 2 cm/sec penetration rate.

After penetration is finished, a hose clamp is fastened to the push rod at the sediment surface (Fig. 15) so that correlation with the electronic depth sensor is possible, in case minor adjustment is required. Additional cone penetration can be obtained by loosening the ram-push rod connector bolts, retracting the ram, installing another push rod (Figs. 16 and 17), and repeating the entire procedure. A more detailed description of tripod operation is presented in Appendix B.

CONCLUSIONS AND RECOMMENDATIONS

The SEAPCONE can produce useful Cone Penetrometer Test data at underwater sites. Additional push rods (each rod is 1-m long) can be added to increase the cone penetration depth as constrained by the reaction weight of the tripod or maximum force exerted by the pneumatic/hydraulic ram. In southern Lake Michigan subbottom cone penetration in excess of 3 m was obtained.

CPT results can be used to investigate a number of geologic and engineering-related topics such as: (1) stratigraphic profiling; (2) estimation of the thickness of loose or weak sediment related to bioturbation or mixing; (3) estimation of relative density, stress history, or the occurrence of erosion; (4) "ground truthing" high-resolution seismic-reflection records; and (5) evaluation of other engineering behavior, e.g., liquefaction potential, especially where undisturbed samples are difficult to obtain. A small-scale sampling program should be conducted to facilitate correlation with the CPT data.

The SEAPCONE performed remarkably well during its first cruise which included 13 deployments. However, some modifications would make the system more versatile. The elimination of divers required to operate the equipment would increase the amount of time that the SEAPCONE can be used on a daily basis and would increase the water depth in which the equipment can be used. In the present configuration the attachment of additional push rods would be the most difficult task to accomplish without divers. One long rod could be used with a different type of drive mechanism, or a complicated "gatling gun" system could be used to add shorter lengths of rod. A computer-controlled feed-back mechanism would be able to control penetration rate more accurately than is possible at present and would produce more consistent results. In the present configuration, hydraulic pressure should be used instead of pneumatic pressure within the pneumatic/hydraulic cylinder.

ACKNOWLEDGMENTS

The authors wish to thank the following people for their help and assistance during the assembling and construction of the SEAPCONE: Dave Mason, Bob Hamblin and Jay Auxt. Page Valentine, Larry Poppe and Ron Circe provided helpful reviews of the manuscript. Dann Blackwood, Ron Circe and Ken Parolski provided constructive advice and were the divers who operated the SEAPCONE during its initial field testing. Dann Blackwood provided the underwater photos used in this report (which were taken under poor visibility conditions). Brad Butman and Bill Strahle provided the tripod frame and weights that were used. Dick Race and Ken Gerkin, owner and captain respectively, of the *R/V Neptune* are thanked for their assistance during the initial deployments of the SEAPCONE.

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APPENDIX A. DETAILED DESCRIPTION OF AND OPERATION OF DATA ACQUISITION SYSTEM

Because the sensor signals are not amplified at the cone, noise reduction techniques are required to maximize the signal resolution. Differential inputs are used in each amplifier to reduce the common mode noise generated by the long cable lengths. The gain of each amplifier is set to provide the resolution desired for each sensor. A 30 Hertz, 6-pole, Butterworth low-pass filter is used to further reduce any noise generated by the system. The signals from each sensor are then connected to a 12-bit analog-to-digital (AD) converter for conversion into digital format.

The information is sent to the computer using direct memory access (DMA) into two memory buffers. Each buffer holds one second of data. The AD converter automatically switches to the other buffer when the current buffer becomes full. The computer detects when one buffer is full, writes the data from the buffer to hard disk for storage, and clears the data in it before the AD converter uses it again. This provides a means of continuously recording data from all sensors 100 times per second.

Software written to control and record the data creates an empty data file and a log file. The data file is given a station name and uses the extension name of ".DAT" to indicate that the file contains data. The log file uses the same station name but has the extension ".LOG" to indicate that this file contains the timing information for the matching data file. The program automatically saves the program start time into the log file. Data acquisition for all sensors begins immediately, displaying the value of each sensor (values are expressed as the digital number resulting from the AD conversion) as a time series, which is updated every second. The display also shows status information including the amount of storage space left, whether or not the data is being saved, and a text display of the converted values for each sensor (Fig. 10).

When calibrating the sensors, hitting the "F3" key changes the text display to show sensor AD counts instead of the converted values. The program does not start saving any of the acquired data to the hard disk until instructed to do so by the user. The "F1" key is used to start and stop data storage. Initiating data storage results in the data storage start time being saved in the log file, a message appearing on the display indicating data is being saved, and an event mark drawn on the graphic display to indicate where the start of saved data begins. Hitting the "F1" key again stops data recording, clears the message indicating that data is being saved, logs the data storage stop time in the log file, and draws an event mark on the graphical display indicating where data storage stopped. This process can be repeated any number of times, but all data are saved in the same data file. To conclude the data acquisition, the "ESCAPE" key is used. This shuts down the AD converter, saves the program stop time in the log file, closes the data and log files, and exits the program. The raw data is recorded in binary format with no header information. This method provides the most space efficient means of saving the data. The log file is used to determine the start and stop times in the data file. Data storage start and stop are done on 1 second boundaries, so determining time positions within the data set is accomplished by multiplying the number of seconds x 8 (the number of sensors) x 2 (the number of bytes recorded for each sensor value).

Software has also been written to provide a means of graphically viewing the data after the acquisition process, and converting the data to ASCII text files, which are compatible with a number of post-processing commercial software packages. The graphical display function will plot one sensor's data, using AD counts or converted engineering values, against either time or depth of penetration. This plot can then be panned or zoomed to analyze any details within the data set. The conversion function generates a separate ASCII text file for each sensor. The text file consists of the sensor value converted to the approximate engineering units and either time in seconds or depth of penetration in centimeters.

APPENDIX B. DETAILED OPERATION OF SEAPCONE TRIPOD AND MECHANICAL COMPONENTS

After all mechanical components are visually checked, the SEAPCONE is readied for deployment. For ease of reading, the following operational procedures are listed as a series of steps that are performed during operation of the SEAPCONE.

1. The rate control needle valve is fully closed and the ram direction control valve is set so that the ram will move up (Fig. 5). The ram must be in the fully retracted position and the instrumented cone should be attached to the push rod.
2. The seafloor-marking hose clamp is moved to the top of the attached push rod.
3. The diver tank valve is opened while the tripod is on deck. The air pressure remaining in the tank is then displayed on the tank pressure gauge (Fig. 5). A full compressed air tank is installed if the present tank pressure is too low to perform a test.
4. The tank regulator is set for the desired pressure to flow into the pneumatic/hydraulic cylinder. For water depths to 10 m a pressure setting of 930 kPa (135 psi) was found to be satisfactory.
5. SEAPCONE is lowered into the water. Simultaneously the umbilical cords are payed out.
6. The divers enter the water, visually check the tripod's stability on the seafloor, and manually set the adjustable circular frame bubble level (Fig. 12).
7. The ram safety strap and sheath covering the cone tip (to keep the piezometric element saturated when on deck) are removed.
8. The pneumatic ram direction control valve (Fig. 5) is rotated to the ram-down position.
9. Tripod status is communicated to shipboard personnel by a wireless or hard-wired communication system.
10. The collection of baseline data is started by hitting the "F1" key of the shipboard data logging computer.
11. The rate control needle valve is intermittently opened and closed (Fig. 13) until the cone almost contacts the seafloor (Fig. 6).
12. Collection of baseline data is continued.
13. Upon direction from shipboard personnel, a diver opens the rate control valve thereby advancing the cone into the seafloor (Fig. 14). The rate control valve

can be opened 1/4 turn as an initial setting.

14. Shipboard personnel view the real-time penetration graph and direct the diver to increase or decrease penetration rate by turning the rate control valve appropriately. The penetration rate should be maintained at a constant value of 2 cm/sec.
15. During penetration, the tip resistance, penetration, and tilt indicators are watched closely. The test should be stopped immediately if a tilt indicator shows any movement of the frame or the tip resistance approaches the maximum allowable tip load. The tip value is an inaccurate and unconservative indicator of liftoff potential because it doesn't account for rod friction. As a backup, a diver can watch the circular bubble level mounted on the tripod top plate and can stop penetration if movement of the bubble is observed.
16. A push interval is finished after full travel of the piston rod has occurred or the tip resistance has increased to a sufficiently high value. The "F1" key can be pushed to pause data collection if necessary or the "ESCAPE" key can be pushed to end data collection.
17. A hose clamp is fastened to the top-most push rod at the sediment-water interface by a diver to show the amount of penetration (Fig. 15). That measurement will be checked against the computer recorded data and will enable adjustments to be made if necessary.
18. If additional penetration is desired, then push rods can be added and the data collection and tripod operation procedures can be repeated. An additional rod can be installed by loosening the ram-push rod connector bolts, retracting the ram, threading a pre-strung push rod onto the existing penetrated rod, and remaking the ram-push rod connection (Figs. 16 and 17).

TABLE 1
Description of SEAPCONE components

COMPONENT	DESCRIPTION/SPECIFICATIONS/COMMENTS
1. Tripod	Horizontal and inclined pipe: schedule 40 stainless steel outside diameter: 6.0 cm Vertical leg construction: schedule 80 steel pipe outside diameter: 6.0 cm Distance between leg centers: 2.3 m Max. distance between outside of lead weights on adjacent legs: 2.54 m Flange bolt/nut size: 2.38 cm (15/16 inches) Top plate (at base of pneumatic cylinder): diameter: 46.0 cm thickness: 2.1 cm Lead weights (each): diameter: 35.6 cm height: 7.6 cm mass: 87 kg Lower assembly, without pneumatic cylinder: height with 3 weights per leg: 2.3 m mass, in air, not including lead weights: 135 kg Fully assembled, with pneumatic cylinder: height to lifting plate with 3 weights per leg: 4.1 m mass (approx): 1010 kg
2. Pneumatic/hydraulic cylinder:	size: 10.16 cm (4 in.) bore, 152 cm (60 in.) stroke height: 165 cm top plate width: 11.4 cm bottom plate width: 15.9 cm internal finish: hard coating max. pneumatic working pressure (approx.): 3450 kPa (250 psi) max. pneumatic force: 14 kN (3140 lbs) max. hydraulic working pressure (approx.): 6900 kPa (500 psi) max. hydraulic force: 28 kN (6280 lbs)

Ram (piston):
  material: 416 stainless steel
  diameter: 2.54 cm
  end thread size: 14 pitch (English) machine thread
supplier: Advance Automation Co.

3. Tripod frame tilt inclinometer:

Sensor:
  type: dual axis clinometer
  range: ± 20° x and y axis
    (Data acquisition range: ±20° x and y axis, resolution: 0.013°)
  model: AccuStar® II - 02753-01
  mating connector model: 09-01-1061A
  supplier: Lucas Sensing Systems. Inc.

Umbilical cable:
  type: 18 gauge - 8 conductor S.O. (Synthetic rubber, Oil resistant) waterproof
  length: 76.2 m (250 ft.)
  supplier: Anixter
  cable connector:
    type: female plug, S.O. type, 8 conductor, 18 gauge
    model: IL8FX
    supplier: Burton Electrical Engineering
  bulkhead connector:
    type: male bulkhead with face "O" ring
    thread size: 0.625 cm (5/8 in.) x 18 UNS
    model: BH8MX
    supplier: Burton Electrical Engineering

4. Subbottom penetration depth sensor:

Sensor type: 100 K - 10 turn precision potentiometer
  1 turn ≈ 19.949 cm (7.854 in.) travel of main gear
  maximum recordable penetration ≈ 2 m
    (Data acquisition range: 0-194 cm, resolution: 0.0482 cm)
  linearity: 0.01 %
  wiring: slider - red
    CCW - black
    CW - green

Main potentiometer drive shaft: 2-012 "O" ring size
Drive chain:
type: plastic coated wire
width: 7 mm
length: 275 cm
supplier: Winfred M. Berg, Inc.
model: 24GCF
Umbilical cable:
(see Tripod frame tilt inclinometer specifications)
Machining performed by: Oceanic Industries, Inc.

5. Push rods

5 cm^2 cone
material and type: 4130 steel tubing
length, assembled: 100 cm
length, unassembled: 102.5 cm (40.375 in)
outside diameter: 2.54 cm (1.0 in.)
wall thickness: 0.635 cm (0.25 in.)
thread: Metric 20 x 2.54 cm (1 in.)
supplied by: Kilsby-Roberts

10 cm^2 cone
material and type: 4130 steel tubing
length, assembled: 100 cm
length, unassembled: 104 cm (40.9 in)
outside diameter: 3.625 cm (1.4 in.)
wall thickness: 1.03 cm (0.41 in.)
thread: proprietary drill thread
supplied by: Hogentogler & Co., Inc.

6. Piezometric cones (note: measurements are approximate)

5 cm^2 cone
maximum sensor capability:
tip: 22.2 kN (5,000 lbs)
(Data acquisition range: 0 - 13.42 kN, resolution: 3.28 N)
friction sleeve: 3.3 kN (750 lbs)
(Data acquisition range: 0 - 3.3 kN, resolution: 3.28 N)

pore pressure transducer: 3450 kPa (500 psi)
(Data acquisition range: 0 - 3450 kPa, resolution: 1.23 kPa)
inclinometer: 9 degrees
(Data acquisition range: 0 - 9 degrees, resolution: 0.001 degrees)
temperature range (data acquisition): -10 to 70° C, resolution: 0.0195° C)

length, assembled: 30.2 cm
length, unassembled: 34.5 cm
diameter: 2.53 cm
tip height: 2.5 cm
piezometric element height: 0.5 cm
friction sleeve:
length: 9.5 cm
surface area: 75 cm^2
friction reducer:
length: 15.3 cm
max. diameter: 3.015 cm
umbilical cable - length: 64 m (210 ft)
outside diameter: 0.818 cm
supplied by: Hogentogler & Co., Inc.

<u>10 cm^2 cone</u>

maximum sensor capability:
tip: 44.5 kN (10,000 lbs)
friction sleeve: 6.7 kN(1500 lbs)
pore pressure transducer: 3450 kPa (500 psi)
inclinometer: 9 degrees

length, assembled: 36.0 cm
length, unassembled: 39.2 cm
diameter: 3.58 cm
tip height: 3.0 cm
piezometric element height: 0.5 cm
friction sleeve:
length: 13.0 cm
surface area: 150 cm^2
friction reducer:
length: 25.3 cm
max. diameter: 4.072 cm

umbilical cable - length: 62 m (204 ft)
outside diameter: 0.870 cm
supplied by: Hogentogler & Co., Inc.

7. Shipboard data acquisition system
computer: Compaq (80286-based)
mass storage: Compaq 20 Megabyte hard disk
monitor: EGA (Extended Graphics Array)
AD board model: DT 2801
manufacturer: Data Translation

8. Miscellaneous components
Compressed air tank:
type: standard diver's
maximum pressure: 20 MPa (3000 psi)
volume: 1300 cm^3 (80 in^3)
Compressed air tank regulator:
type: Conshelf SE2 with gauge
supplier: Mar-Vel Underwater Equipment
Regulated air pressure gauge:
type and size: 6.35 cm (2.5 in) 1/4 in. NPT 0-3450 kPa (0-500 psi) silicon filled
Housing for depth potentiometer and frame inclinometer:
material: aluminum
pressure rating: 3000m
main seal: 2-241 "O" ring size
Pneumatic ram direction control valve:
material and type: brass 4-way
thread size: 1/2 in. Female NPT
supplier: Cambridge Valve and Fitting Co.
model: B-45YF8
Vent check valve:
material and type: stainless steel spring activated
cracking pressure: 6.9 kPa (1 psi)
thread size: 1/2 in. Female NPT
supplier: Cambridge Valve and Fitting Co.
model: SS-CHF8-1

Pressure relief valve:
- material and type: stainless steel adjustable
- thread size: 1/2 in. Male NPT
- activation pressure: variable 1035 kPa - 2415 kPa (150 - 350 psi)
- supplier: Cambridge Valve and Fitting Co.
  - model: SS-8CPA2-150

Rate control valve:
- material and type: stainless steel needle

Bleed valves:
- material and type: stainless steel "BV" series
- size: 1/2 in. Male NPT
- supplier: Cambridge Valve and Fitting Co.
  - model: SS-BVM8-SH

Pneumatic ram direction control valve:
- type: 4-way

Top lifting plate:
- size: 30.5 cm x 30.5 cm x 1.6 cm thick (12 in x 12 in x 0.625 in)

Lifting rods:
- quantity: 4
- material: threaded steel
- diameter: 1.9 cm (3/4 inch)
- length: 183 cm (6 ft)

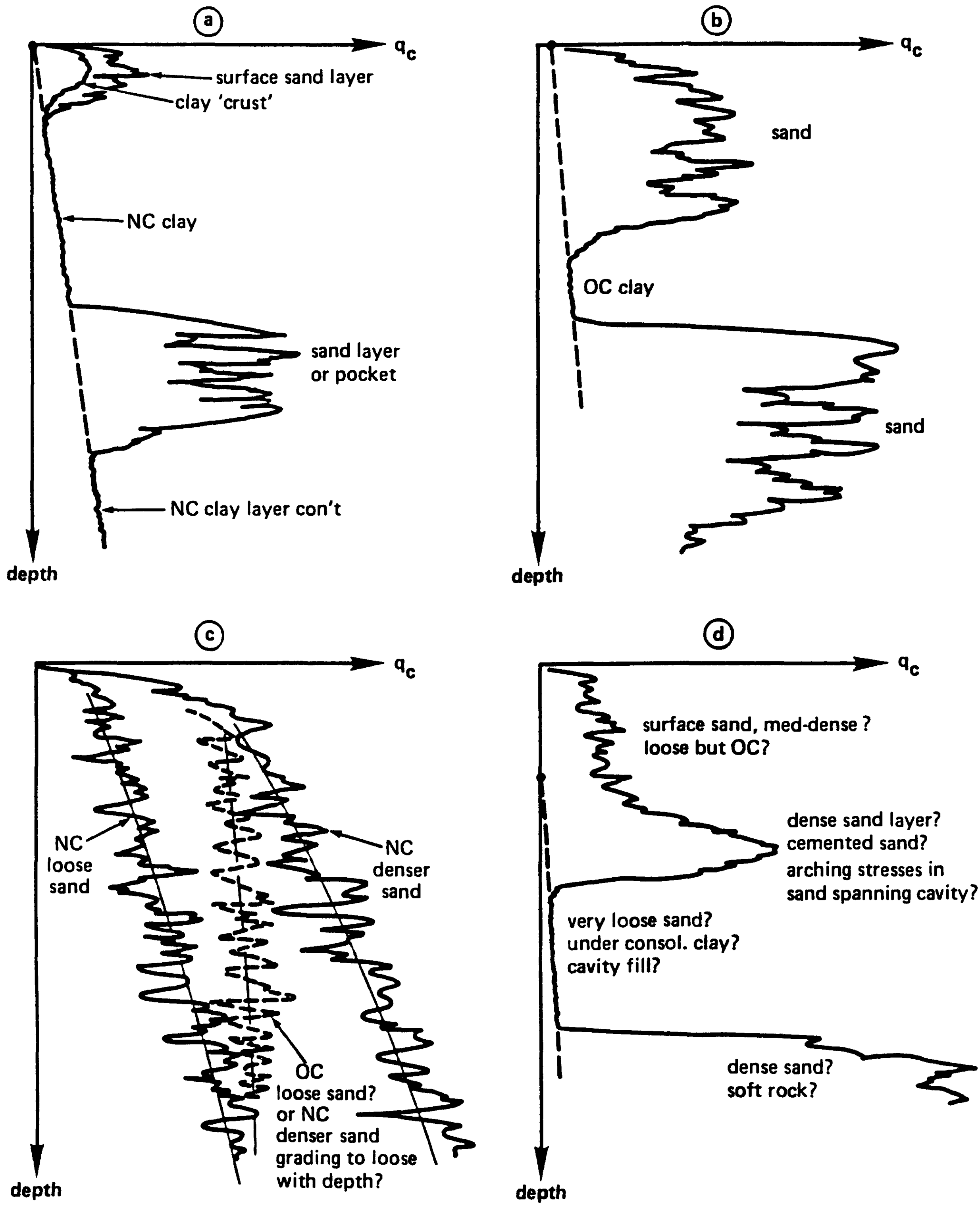


Fig. 1. Four simplified Cone Penetration Test (CPT) profiles (a-d) with possible interpretation of grain size, density, and stress history (from Schmertmann, 1978, p.5). Note: q_c = cone resistance; NC = normally consolidated; OC = overconsolidated.

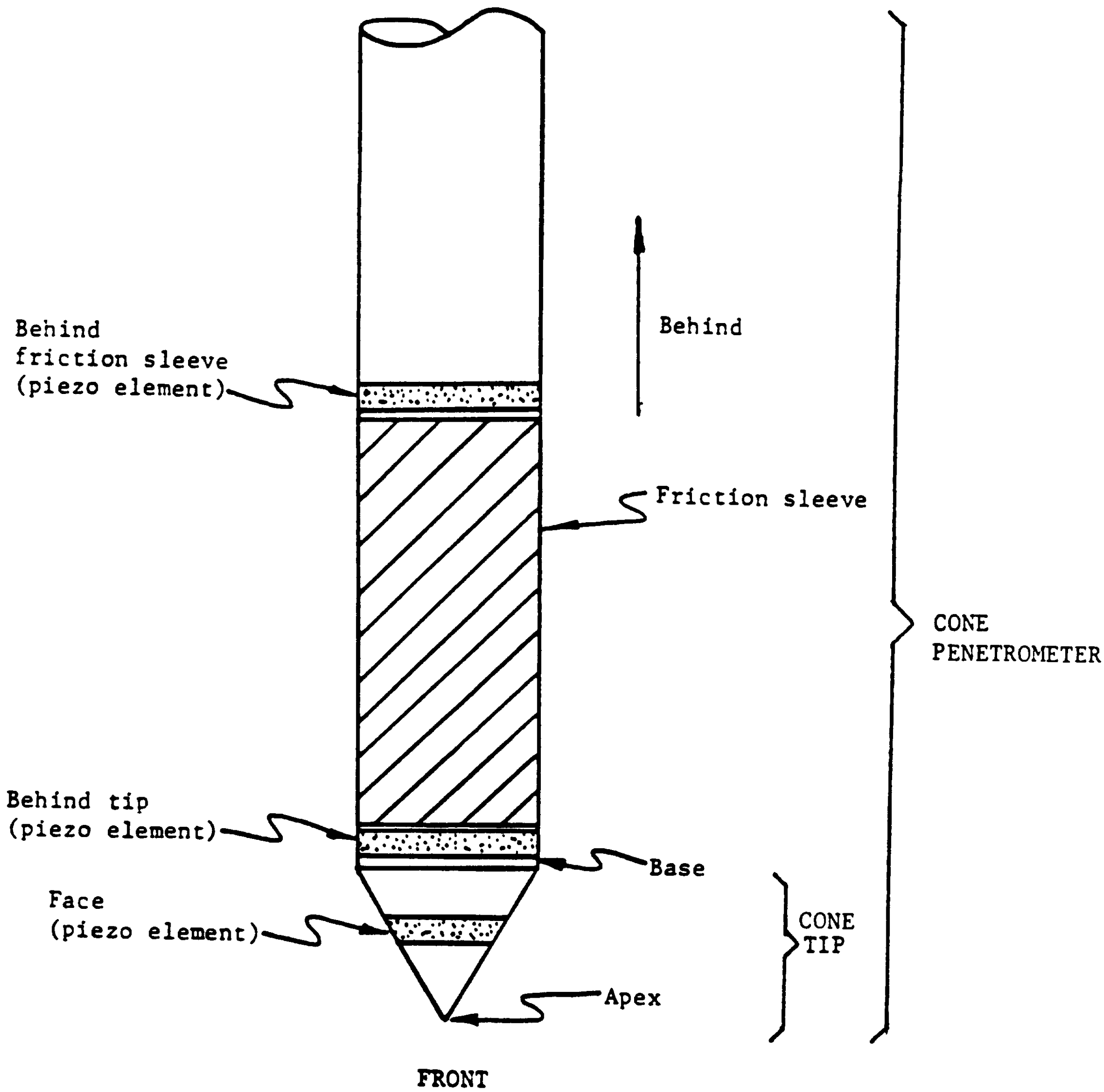


Fig. 2. Side view of an electric cone illustrating three possible locations for the placement of a piezometric element (modified from Robertson and Campanella, 1989, p. 13).

Fig. 3. Deployment of SEAPCONE from *R/V Neptune* off Illinois Beach State Park.

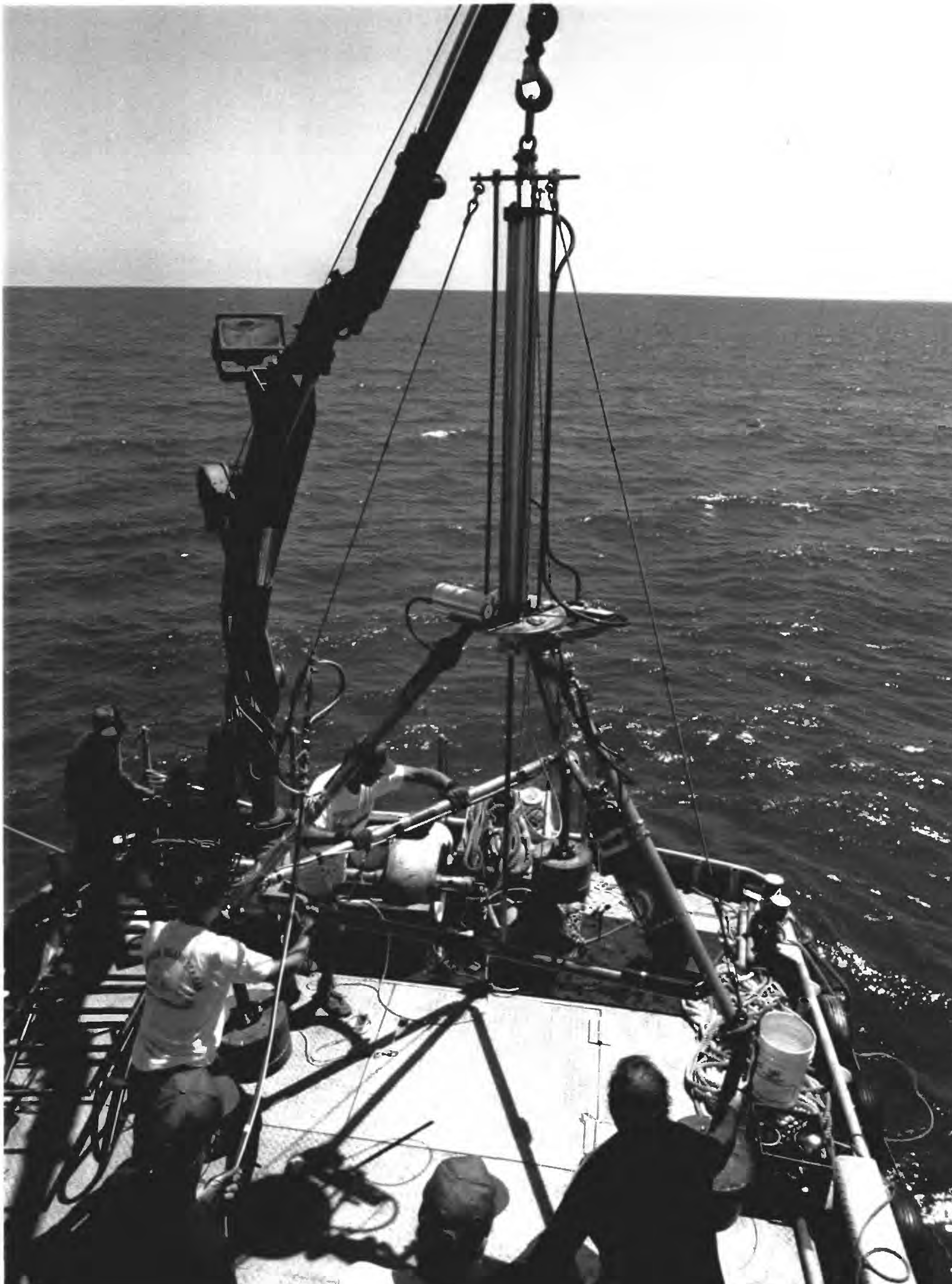


Fig. 4. Side view of the SEAPCONE tripod; major components are labeled.

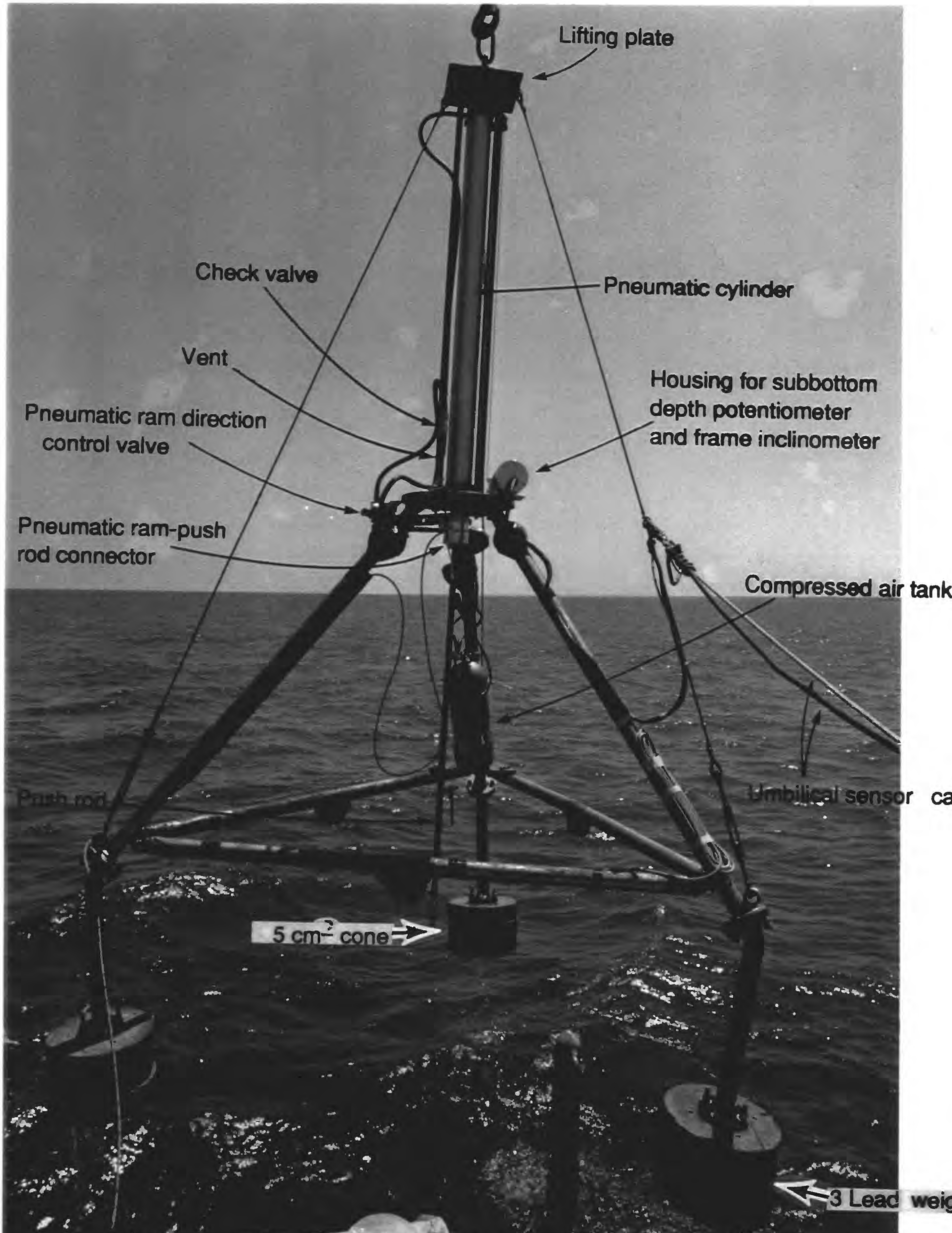
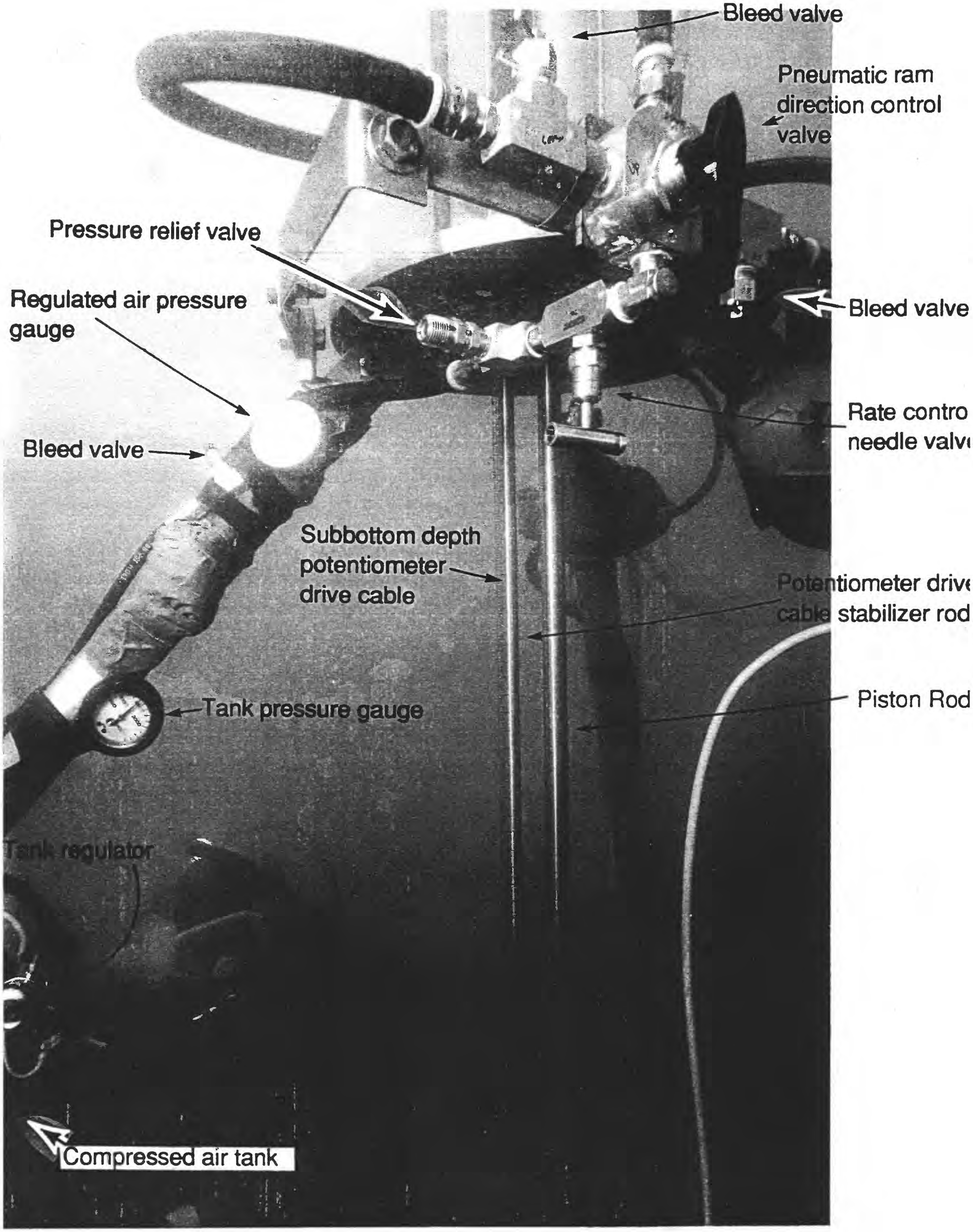

Lifting plate
Check valve
Pneumatic cylinder
Vent
Housing for subbottom depth potentiometer and frame inclinometer
Pneumatic ram direction control valve
Pneumatic ram-push rod connector
Compressed air tank
Push rod
Umbilical sensor
5 cm^2 cone
3 Lead

Fig. 5. Underwater photograph of valves and gauges taken after the cone penetrated the seafloor.



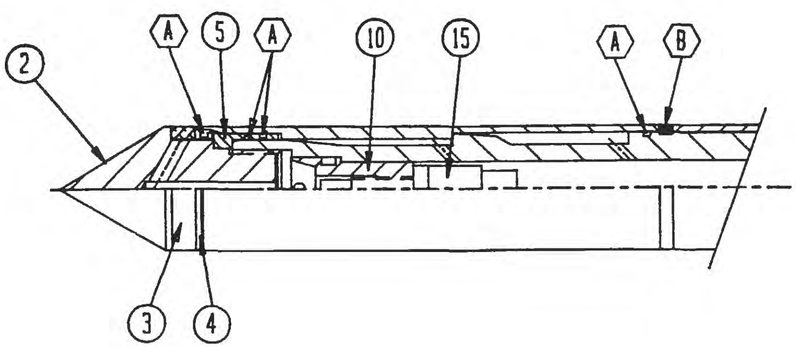
Bleed valve
Pneumatic ram direction control valve
Pressure relief valve
Regulated air pressure gauge
Bleed valve
Rate contro needle valv
Bleed valve
Subbottom depth potentiometer drive cable
Potentiometer driv cable stabilizer rod
Tank pressure gauge
Piston Rod
Tank regulator
Compressed air tank

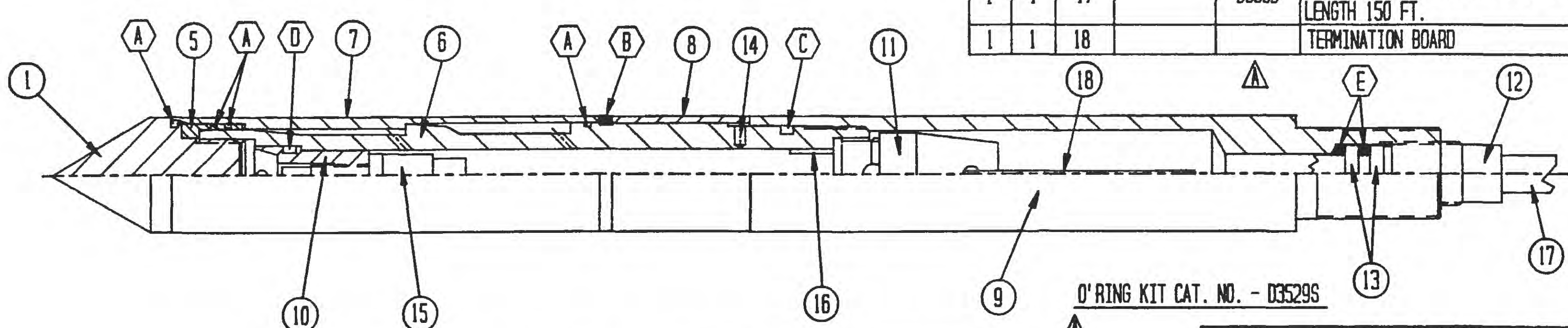
Fig. 6. Piezometric cone tip with external components identified.


Friction Sleeve
Pore Pressure Element
Tip

Fig. 7. Shipboard data acquisition system.

-2	-1	ITEM	PART NUMBER	CAT NO	DESCRIPTION
	1	1	1190A176	D3525A	STANDARD TIP
1		2	1190A177	D3525B	PORE PRESSURE TIP
1		3	1190A178	D3951B	PORE PRESSURE ELEMENT
1		4	1190A179	D3525E	PORE PRESSURE RING
1	1	5	1190A181	D3525F	EQUAL END AREA ADAPTOR
1	1	6	1190B182	D3525P	STRAIN ELEMENT
1	1	7	1190A183	D3525G	FRICTION SLEEVE
1	1	8	1190A184	D3525H	COLLAR
1	1	9	1190A185	D3525I	ELECTRONICS HOUSING
1	1	10	0188A014	D3525L	PORE PRESSURE CHAMBER
1	1	11	1290A192	D3545N	INCLINOMETER ASS'Y (MODIFIED)
1	1	12	0987A145		CONE CABLE CONNECTOR NUT
2	2	13	0987A146		CONE CABLE CONNECTOR WASHER
1	1	14			PIN - 3/32" DIA. x 3/16" LG. S.S.
1	1	15		D3545M	PRESSURE TRANSDUCER - DRUCK #PDCR 200, 500 PSI. 10-32 x .75 LG. TH'D OR KULITE #XT-190-500, 500 PSI. 10-32 x .75 LG. TH'D
1	1	16		D3997	THERMISTER - NAT'L. #LM-335
1	1	17		D5559	CABLE - VERTREX COMPUTER 12 COND., 22 AWG. LENGTH 150 FT.
1	1	18			TERMINATION BOARD





O'RING KIT CAT. NO. - D3529S

O'RING GUIDE

- A 20mm x 1.0
- B Q4116
- C 17mm x 2
- D 9.5mm x 2
- E 8mm x 2.5

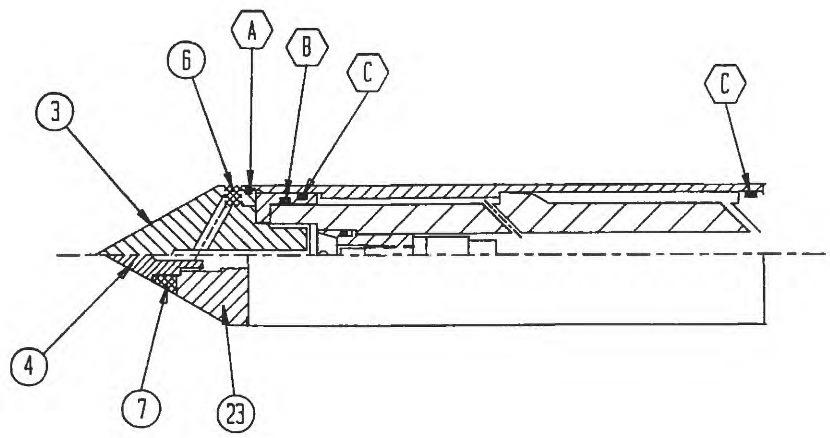
1090B175-1 NON PORE PRESSURE CONE
1090B175-2 PORE PRESSURE CONE

CH. BY	DR. BY	REV	DESCRIPTION
	RR-V	B	Q4116 WAS Q019
	RR-V	A	ADDED CATALOG NOS.

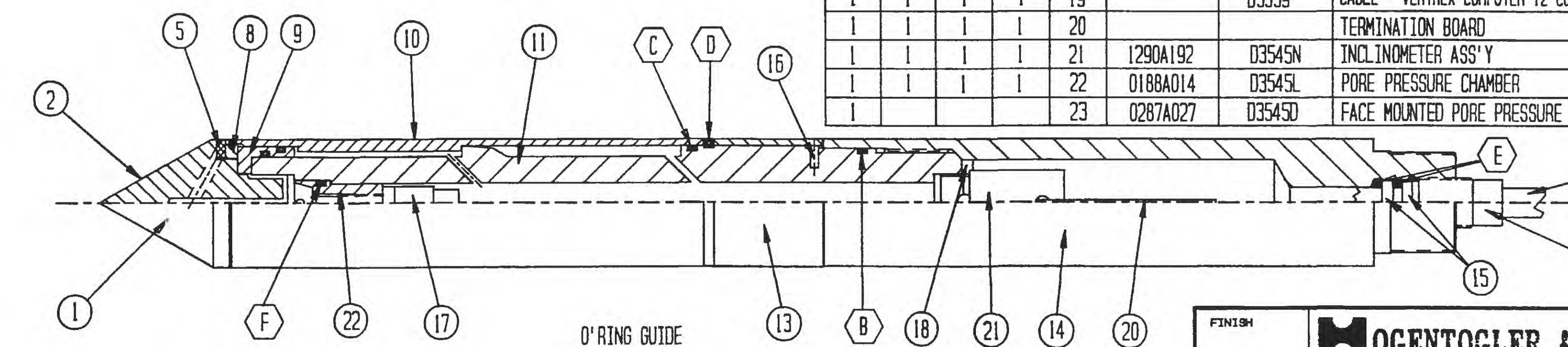
HOGENTOGLER & CO., INC.

FINISH		NEXT ASSEMBLY	QTY.
DECIMAL/.XXX +/-	MATERIAL	SCALE FULL	DRAWN BY RR-V
			CHECK BY JAR
FRACTIONAL/.XX +/-	TITLE 5cm² ELECTRIC CONE		APPR BY JAR
			CAT NO D3525
ANGULAR +/-	DATE 10-10-90	DRAWING NUMBER 1190B175 REV B	TAPE NUMBER

Fig. 8. Schematic drawing of 5 cm^2 cone tip (used by permission of Hogentogler & Co., Inc.).



-4	-3	-2	-1	ITEM	PART NUMBER	CATALOG NUMBER	DESCRIPTION
			1	1	0287A024	D3545A	STANDARD TIP
		1		2	0287A025	E5843	2.5mm PORE PRESSURE TIP
	1			3	0287A026	D3545B	5MM PORE PRESSURE TIP
1				4	0287A030	D3545C	FACE MOUNTED PORE PRESSURE TIP,POINT
		1		5	0287A032	E5885	2.5MM PORE PRESSURE ELEMENT
	1			6	0287A031	D3955B	5MM PORE PRESSURE ELEMENT
1				7	1090A170	D3955C	FACE MOUNTED PORE PRESSURE ELEMENT
	1	1		8	0287A033	D3545E	PORE PRESSURE RING
1	1	1	1	9	0287A036	D3545F	EQUAL END AREA ADAPTOR
1	1	1	1	10	0287A042	D3545G	FRICTION SLEEVE
1	1	1	1	11	0288B016	D3545P	STRAIN ELEMENT
1	1	1	1	12	0987A145		CONE CABLE CONNECTOR NUT
1	1	1	1	13	0287A039	D3545H	COLLAR
1	1	1	1	14	1190A187		ELECTRONICS HOUSING
2	2	2	2	15	0987A145		CONE CABLE CONNECTOR WASHER
1	1	1	1	16			PIN - 3/32" DIA. x 3/16" LG. S.S.
1	1	1	1	17		D3545M	PRESSURE TRANSDUCER - DRUCK #PDCR 200, 500 PSI. 10-32 x .75 LG. TH'D OR KULITE #XT-190-500, 500 PSI.
1	1	1	1	18		D3997	THERMISTER - NAT'L. #LM-335
1	1	1	1	19		D5559	CABLE - VERTREX COMPUTER 12 COND.,22 AWG. 150 FT. LG.
1	1	1	1	20			TERMINATION BOARD
1	1	1	1	21	1290A192	D3545N	INCLINOMETER ASS'Y
1	1	1	1	22	0188A014	D3545L	PORE PRESSURE CHAMBER
1				23	0287A027	D3545D	FACE MOUNTED PORE PRESSURE BODY



0391B032-1 NON PORE PRESSURE CONE
0391B032-2 2.5mm PORE PRESSURE CONE
0391B032-3 5mm PORE PRESSURE CONE
0391B032-4 FACE MTD. PORE PRESSURE CONE

O'RING GUIDE

A	29mm x 1.5mm
B	26mm x 2mm
C	28mm x 2mm
D	04122
E	8mm x 2.5mm
F	9.5mm x 2.5mm

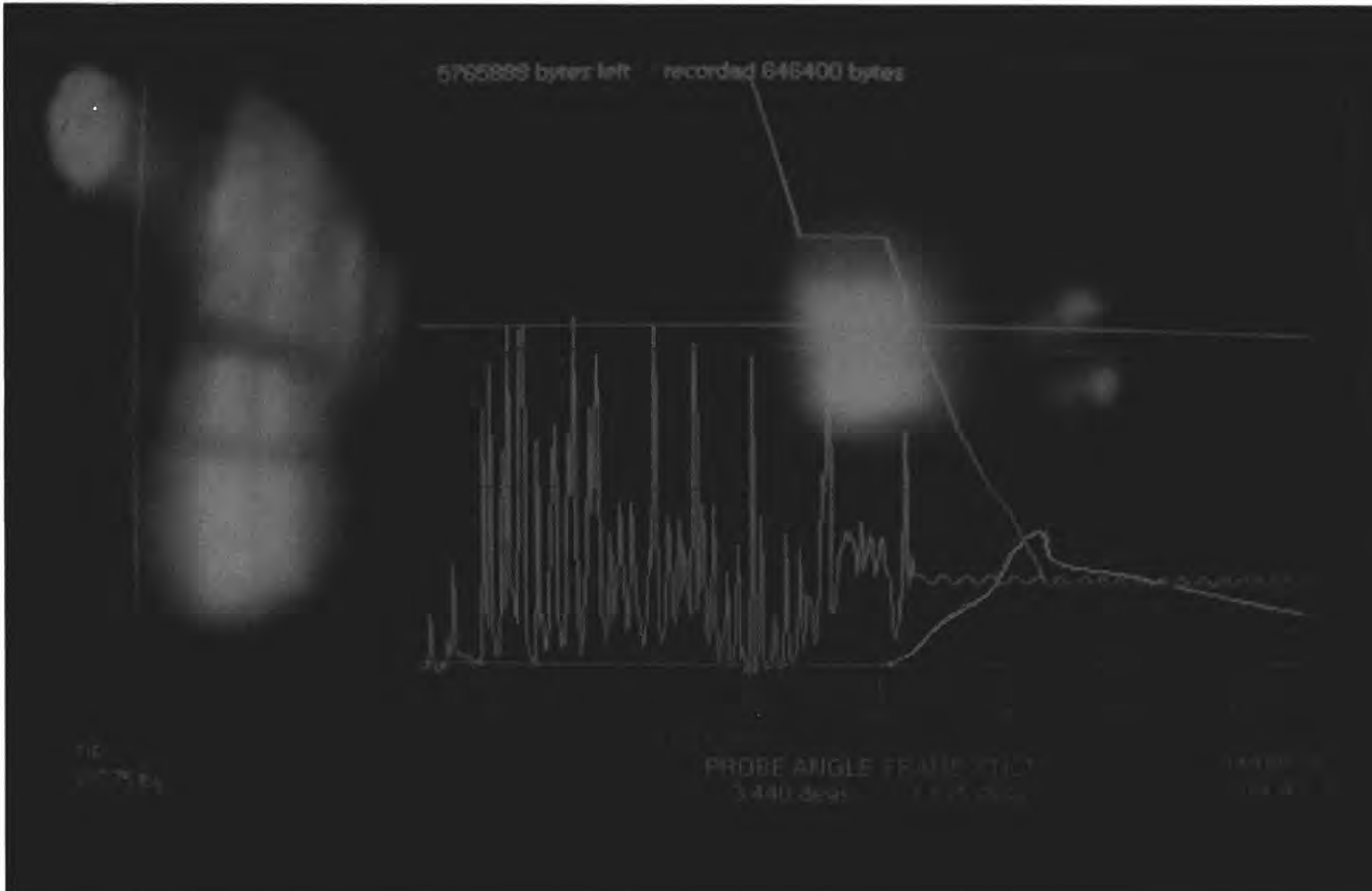
CH. BY	DR. BY	REV	DESCRIPTION

HOGENTOGLER & CO., INC.

FINISH			
DECIMAL/.XXX +/-	MATERIAL	SCALE .8	DRAWN BY RR-V; CHECK BY JAA
FRACTIONAL/.XX +/-	TITLE 10cm^2 ELECTRIC CONE		APPR BY JAA
ANGULAR +/-	DATE 02-28-91	DRAWING NUMBER 0391B032	TAPE NUMBER

Fig. 9. Schematic drawing of 10 cm^2 cone tip (used by permission of Hogentogler & Co., Inc.).

Fig. 10. Photograph of real-time display showing analog and digital forms of data acquired from the SEAPCONE sensors. Note that the cone began penetrating the seafloor approximately 348 seconds after data was initially logged. Full penetration using the first push rod was reached at an elapsed time of about 420 seconds. Data obtained prior to cone penetration provided a baseline.


5765868 bytes left
recorded 646400 bytes
PROBE ANGLE

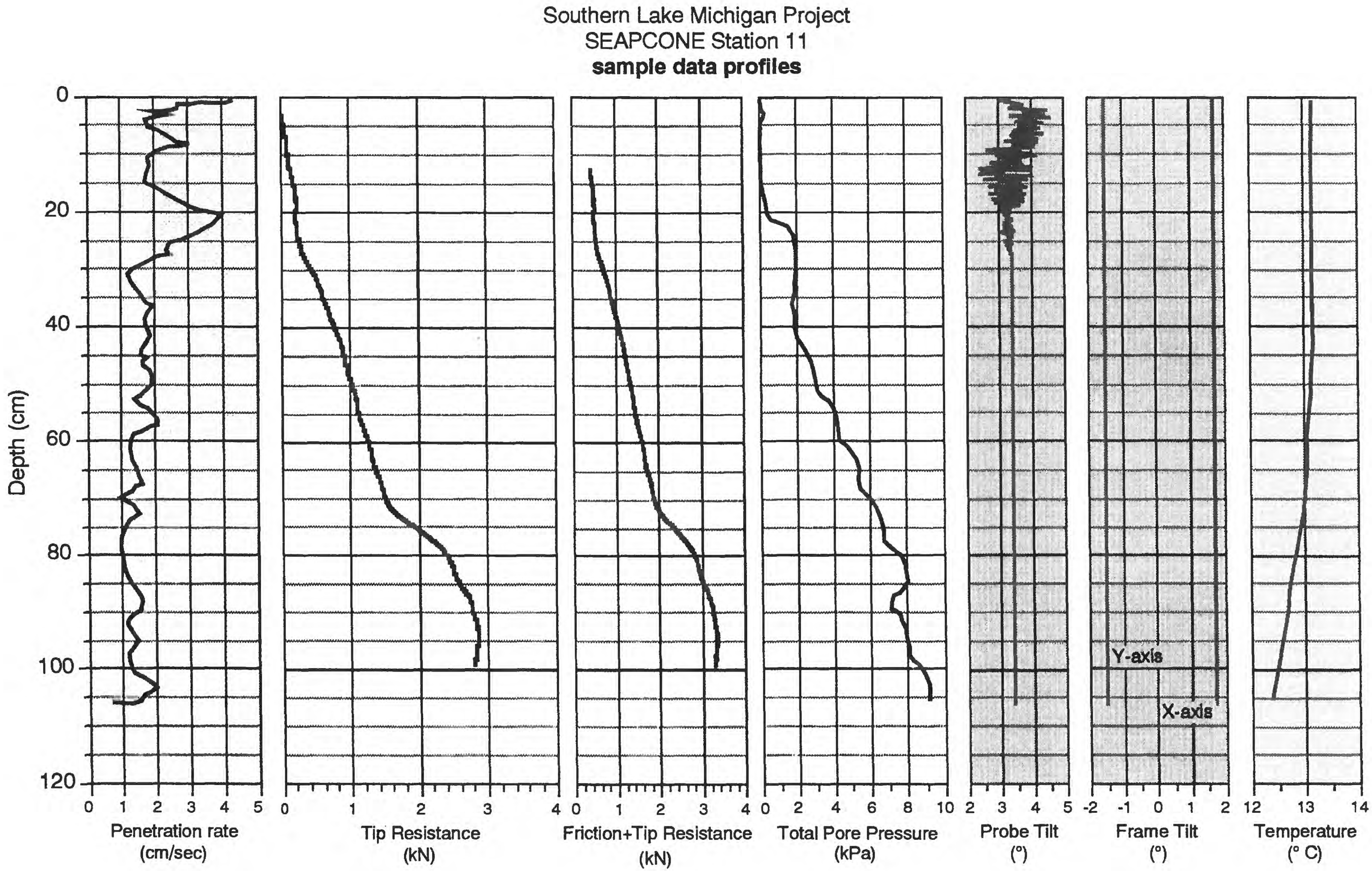


Fig. 11. Preliminary data profiles for a typical penetration test. Note that the cone inclinometer (probe tilt) is very sensitive to horizontal movement. Such movement can occur, as noted by the data, before the cone totally penetrates the seafloor.

Fig. 12. SEAPCONE during operation. Notice the air bubbles escaping from the vent hose in the right center of the photo. The adjustable circular frame bubble level is located on the left side of the tripod top plate just above and right of the photo center.

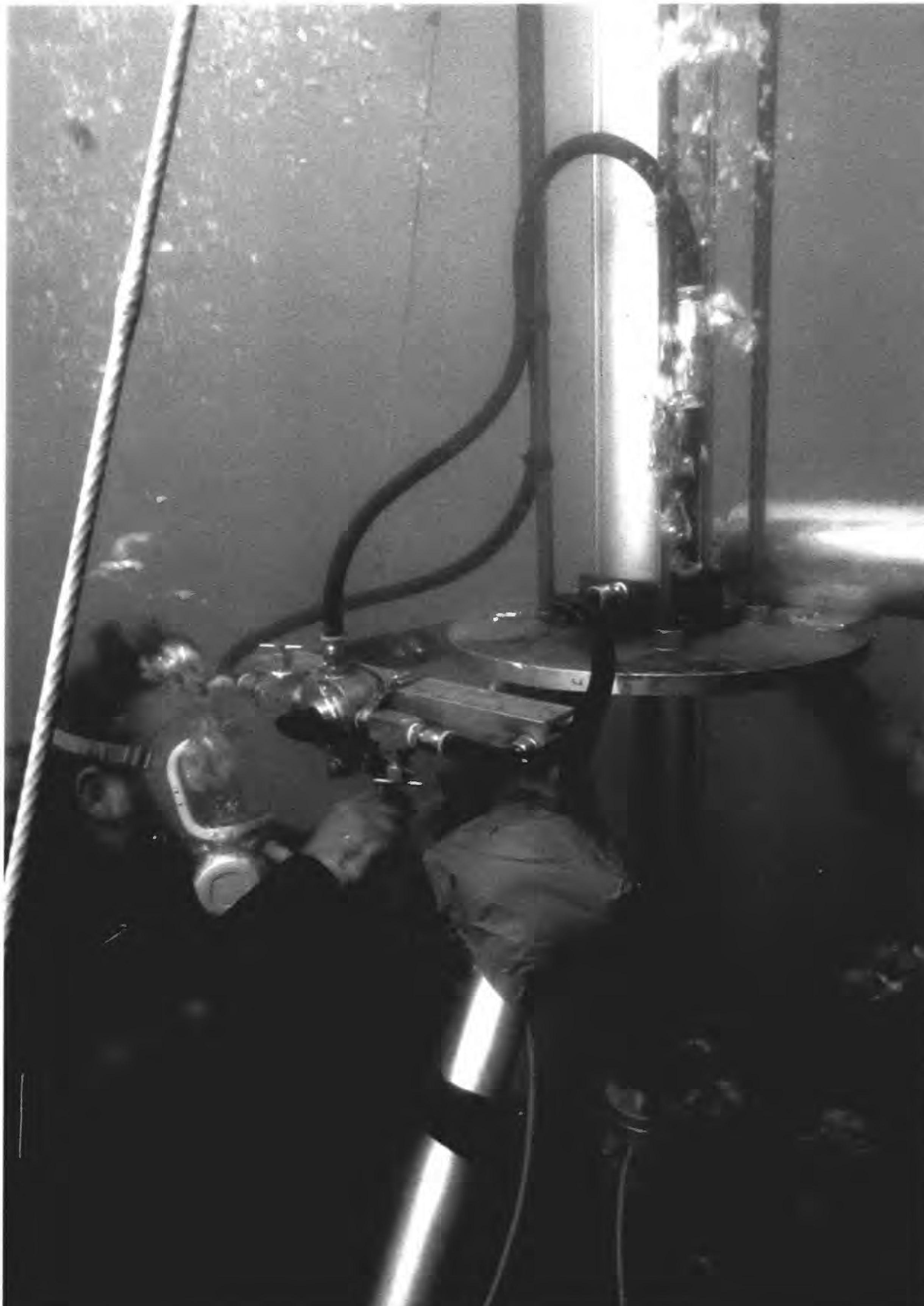


Fig. 13. SEAPCONE during operation. The rate control needle valve was opened which allowed compressed air to flow from the tripod diver tank (bottom left) to the top of the pneumatic cylinder thereby pushing the ram (piston rod) downward.

Fig. 14. Operation of the SEAPCONE. Opening the rate control needle valve has caused compressed gas from the dive tank to enter the top of the pneumatic/hydraulic cylinder which in turn has pushed the piston rod downward.

Fig. 15. Diver tightening a hose clamp at the sediment-water interface thereby marking the furthest level of penetration of the push rod(s).

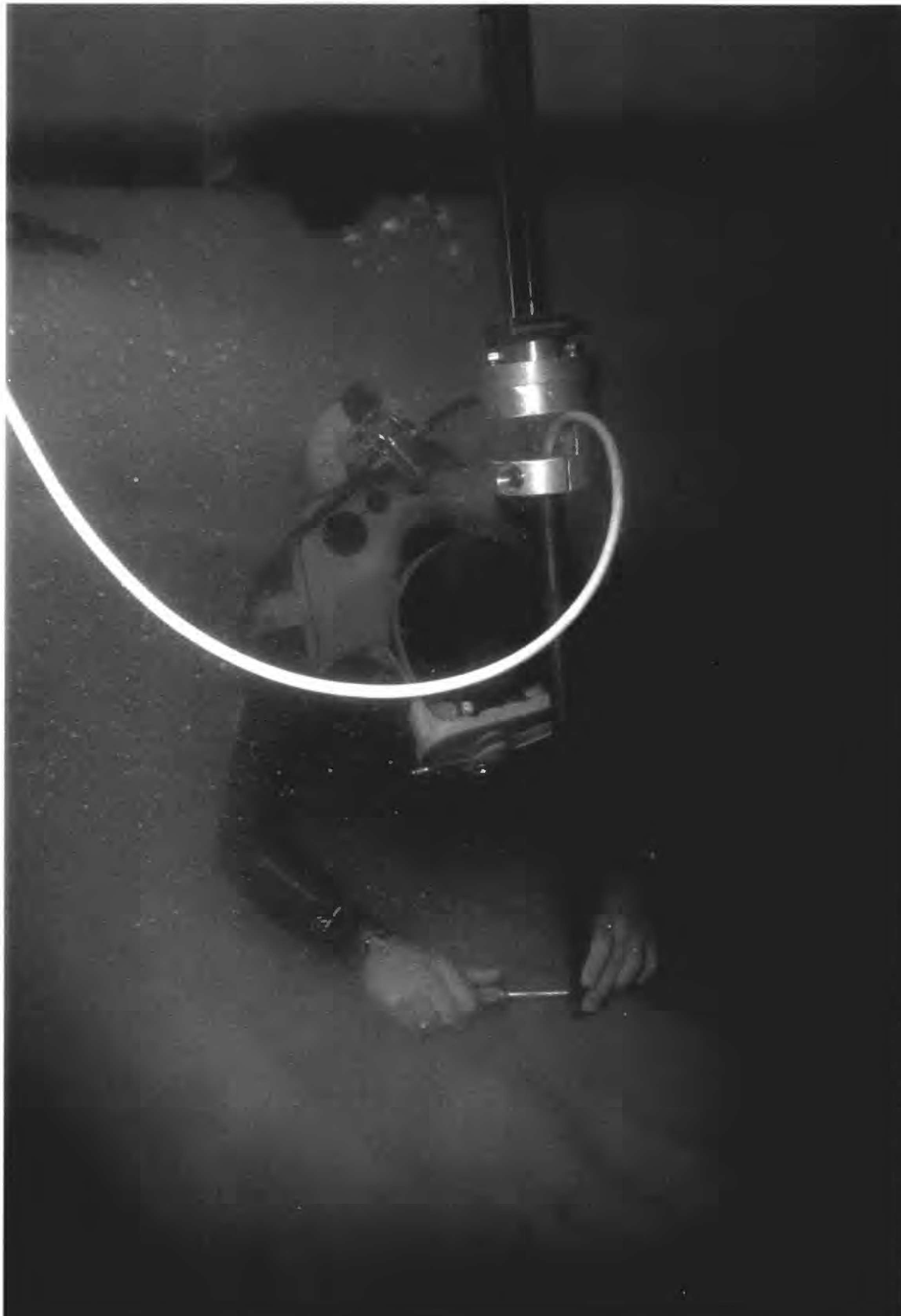


Fig. 16. Initial procedure for installing an additional push rod. The divers have loosened the ram-push rod connector bolts, have disengaged the push rod from the connector, and are in the process of retracting the ram.

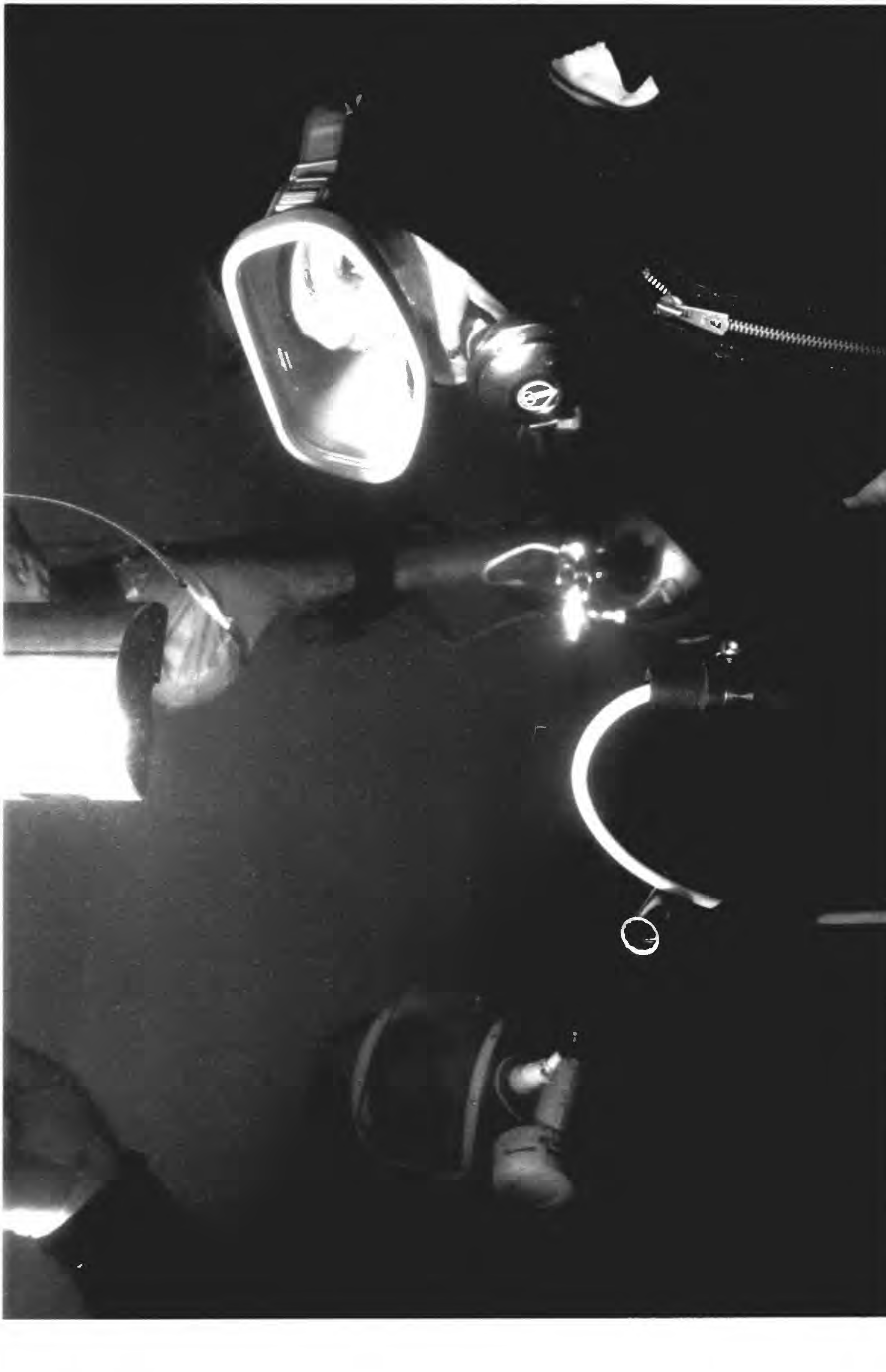


Fig. 17. The ram-push rod connector is being attached to a push rod that will be used to extend the depth of cone penetration.