# AUTOPROBE: AN AUTONOMOUS OBSERVATIONAL PLATFORM FOR MICROSTRUCTURE STUDIES

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## Abstract

Autoprobe is a general purpose autonomous observational platform with the capability of making Lagrangian measurements of any depth dependent property. Autoprobe can change its displacement in response to internal commands as desired, pneumatically forcing fluid into or out of a bladder. An electronic control system generates the commands from the temperature and pressure measurements, utilizing proportional control with rate feedback. The control system has been programmed to operate in the following modes: (1) to stabilize at a constant pressure, (2) to follow a constant temperature, (3) to make vertical excursions, and (4) to respond to remote control. Acoustic Telemetry is utilized in the instrument yielding navigational information as well as temperature and pressure data. Hydrophones are used with a shipboard recorder for tracking the Autoprobe, enabling the operator to monitor Autoprobe's performance. Autoprobe has a multi-level safety system allowing it to blow ballast on a time signal or jettison weight if it goes too deep, if a desired time is reached, or if an acoustic command is received from the surface. Autoprobe has been used as an observational platform for a total of 44 dives.

## Introduction

Autoprobe was developed in response to the scientific need for a free-floating observational platform capable of performing various programmed missions. An active Swallow float[1] device with an internal control system was necessary which would enable it to automatically adjust it's buoyancy in response to changes of any depth dependent property. An analog computer simulation of the dynamics of this type of buoy was performed, and a prototype instrument was constructed in 1966. A second generation Autoprobe[2] was built and operated in 1967 and 1968 for a total of 22 dives. These initial experiments were performed in the constant pressure mode.[3] The third generation Autoprobe was used in the constant temperature mode, rate mode, vertical excursion mode and remote-control mode of operation from 1969 to 1973. The purpose of this paper is to describe the general principles, operation and results of the Autoprobe as applied to the study of microstructure during 1972 and 1973. A photograph of Autoprobe carrying the Optical Salt Finger Detector (OSFD) and Conductivity-Temperature-Depth (CTD) is shown in Figure 1.

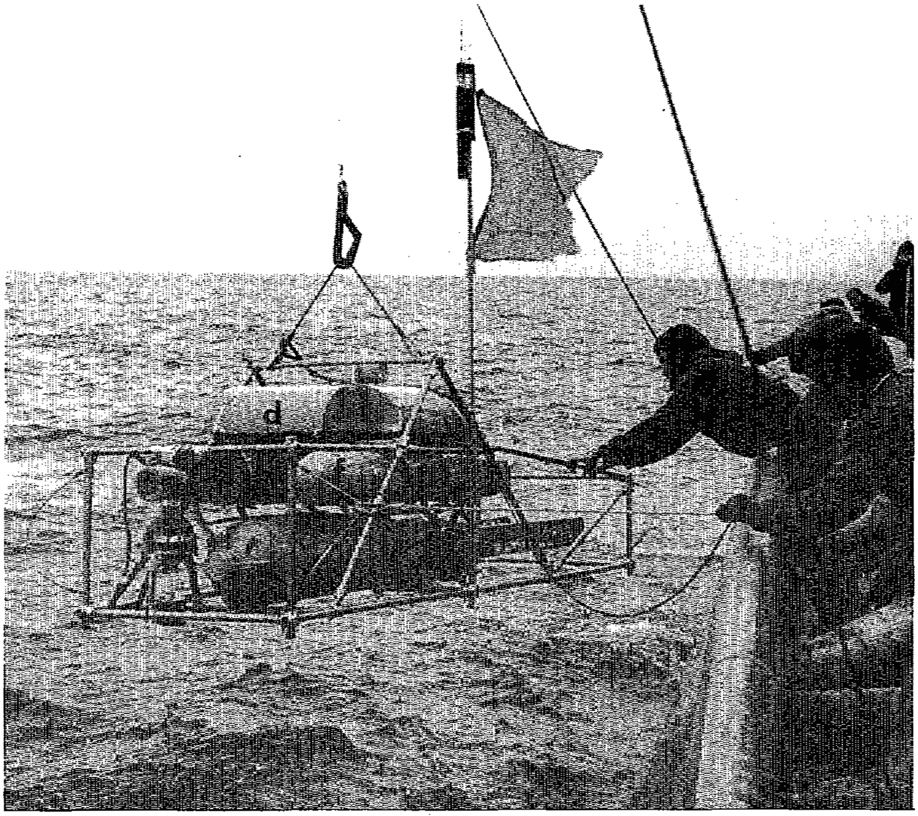

Figure 1. Recovery of the Autoprobe/OSFD/CTD from the R/V CHAIN 109. a) Electronics, b) VDS, c) OSFD, d) Syntactic foam, e) weight release, f) scuba tanks. The CTD is mounted behind the OSFD out of view.

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## Variable Displacement System

The variable displacement system enables the Autoprobe to adjust its buoyancy in response to commands from the electronic control system. The buoyancy of the Autoprobe can be varied so that its density equals that at any desired depth in the ocean. The buoyancy of a free instrument could be varied by changing the mass or the volume.

A variable displacement system is used in the Autoprobe to change buoyancy. Displacement can be changed in a free instrument by transferring fluid into or out of a bladder exposed to the ambient sea pressure. A variable displacement system has the advantage that being a closed, self-contained system, the fluid can be reused. Emphasis was placed on the simple and efficient operation of the design of a variable buoyancy unit (VBU). Since the vehicle is sometimes required to act as a Swallow float (neutrally buoyant float), the VBU must be less compressible than sea water to avoid instability. The system must have sufficient displacement for the several anticipated modes of operation.

The present VBU was designed and built during 1969 and 1970. The system can be described using Figure 2, a simplified diagram of the variable displacement system. Distilled water is admitted into or out of the bladder through solenoid valves. Nitrogen gas stored in two 3,000 psi aluminum Scuba Tanks (170 ft$^3$ @ 1 atm) is regulated with Scuba regulators to provide the energy required by the system. The pressure regulators drop the pressure to 21 psi above ambient which is again reduced to 10 psi where it becomes the energy source used to pump high pressure fluid into the bladder. The gas and fluid chambers are contained in a pressure-protected housing. Flexible rolling diaphragms separate the chambers to equalize their pressure. When an electrical signal operates the Up solenoid valve ($H_p$), high pressure fluid (10 psi above ambient flows through the solenoid valve into the bladder, which is exposed to the ambient sea pressure.

The displacement can be decreased by operating the Down solenoid valve ($L_p$) causing fluid to flow from the bladder, at ambient pressure, to a low pressure chamber at a pressure less than ambient. The low pressure of the chamber is created by the difference in pressures and areas on each end of the floating, differential piston shown in simplified form in Figure 3. The floating differential piston is free to move creating a chamber to accumulate the low pressure fluid.

FLOATING DIFFERENTIAL PISTON

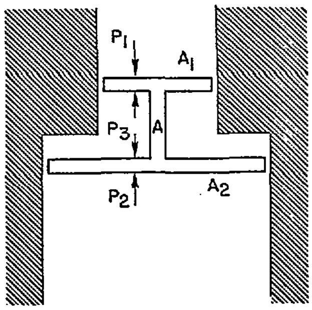
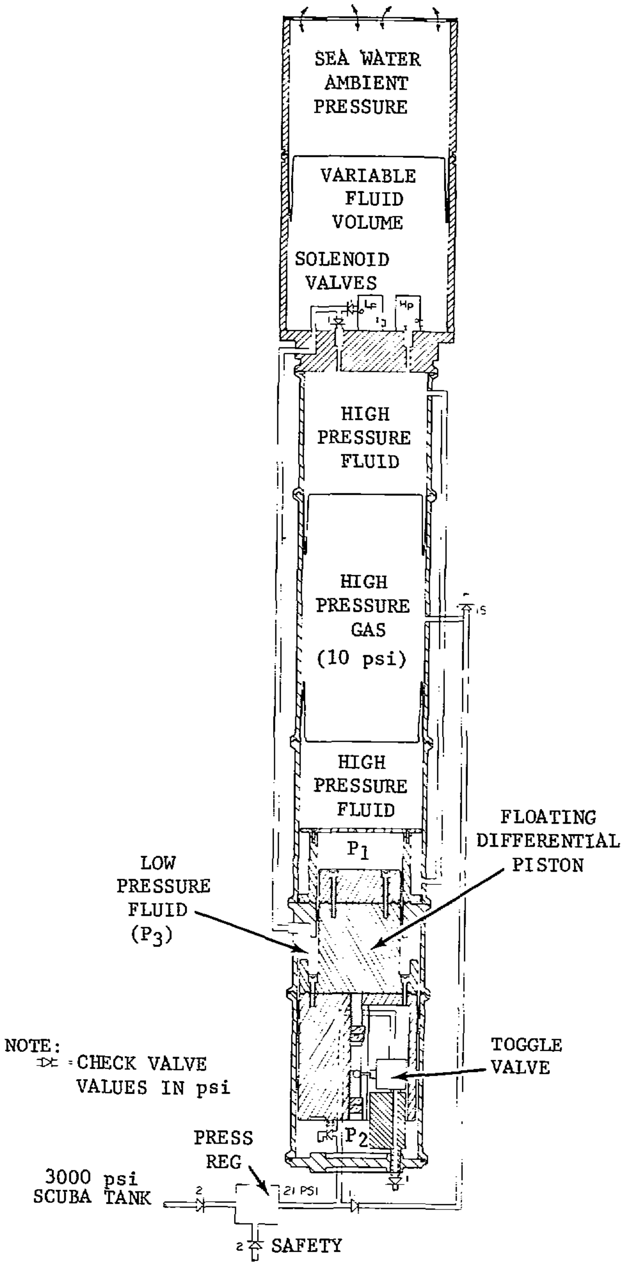


Figure 3. The Floating Differential Piston assembly is used in the VDS to create a low pressure reservoir and to recycle the fluid for future use.



AUTOPROBE VARIABLE DISPLACEMENT SYSTEM

Figure 2. A diagram of the Autoprobe Variable Displacement System (VDS) showing the principle components.

$$F = P_1A_1 - P_3(A_1 - A)$$

$$F = P_2A_2 - P_3(A_2 - A)$$

$$(P_1 - P_3)A_1 = (P_2 - P_3)A_2 \text{ when in equilibrium}$$

If

$$A_1 = \frac{A_2}{2}$$

$$\frac{P_1 - P_3}{P_2 - P_3} = 2$$

$$P_1 - P_3 = 2P_2 - 2P_3$$

$$P_3 = 2P_2 - P_1$$

For normal operation to decrease the displacement, $P_2$ is set at 1 psi, and $P_1$ is 10 psi.

Then $P_3 = 2(1) - 10 = -8$ psi

For recycling fluid from the low pressure chamber to the high pressure chamber, $P_2$ is increased to 21 psi while $P_1$ remains 10 psi.

Then $P_3 = 2(21) - 10 = 32$ psi

A recycle of fluid from the low pressure chamber back to the high pressure chamber is accomplished with a position sensing mechanical toggle valve that acts on the floating, differential piston, as shown in Figure 2. Assuming there is no fluid in the low pressure fluid chamber, the floating differential piston is fully extended in the upward position, toggling the valve upward. This results in a connection between the common port of the toggle valve and a 1 psi check valve to ambient, which makes $P_2 = 1$ psi. Hence, the low pressure fluid chamber is ready for normal operation.

When the low pressure fluid chamber is full, the floating differential piston is at the other end of the stroke, fully downward, tripping the toggle valve down. The result is a connection between the common of the toggle valve and the output of the (scuba) regulator.

The effect is to change $P_2$ from 1 psi to 21 psi causing the floating, differential piston to move upward, forcing the fluid from the low pressure chamber up through a check valve into the high pressure fluid chamber. In this way, fluid can be reused in the system, resulting in a reduced total volume of fluid necessary for operation.

The variable fluid volume chamber has a dynamic range equivalent to ±12 pounds of displacement. The flow rates are adjusted by the solenoid valves for equal flow into or out of the bladder. The check valves in the system were chosen for efficient operation with minimum energy requirements. The system was designed with the capability for mission lengths up to ten days. Obviously, the type of mission required will determine the energy necessary. The scuba tank pressure (3,000 psi) limits the depth that the instrument can operate. The wall thickness of the pressure housing (1/4") is a compromise between weight and pressure resistance. The housing will collapse at a relatively low pressure (1500 psi) in the absence of internal gas pressure. Therefore, the variable displacement system is protected to prevent loss of the equipment if the system runs out of gas. The system will flood with sea water through a 2 psi safety check valve if the output pressure of the scuba regulator is 2 psi less than the ambient pressure. Flooding the system prevents collapse of the housing. Another 2 psi check valve (with 10,000 psi back pressure) in series with the scuba tanks prevents the tanks from flooding. At the predetermined end of mission time the variable fluid volume chamber is pumped full, which will bring the instrument back to the surface.

Several improvements and new developments are possible in the design of a variable displacement system. The greatest improvement to the present system would be utilizing a lighter gas. If hydrogen gas is used in place of the nitrogen gas, the weight of the gas will be decreased by a factor of 14. This savings would consequently reduce the amount of dynamic range required in the variable displacement system necessary to compensate for gas losses. Further, the amount of syntactic foam (flotation material) necessary to provide neutral buoyancy of the instrument would be also reduced. This system still uses the scuba tanks for the storage of energy and, therefore, the maximum operating depth of the instrument is fixed (scuba tanks - 3,000 psi).

A further development would be to generate gas at any pressure as it was needed in the system. Hydrogen gas is generated when lithium hydride reacts with water at any ocean pressure. Hydrogen gas, if safely handled and contained, would be excellent for these applications. The resulting variable buoyancy system would have the obvious advantages of simplicity, unlimited depth operation, and long life.

## Electronics System

The electronics used in the Autoprobe is sub-divided into four functional groups, the temperature and pressure monitoring system, the telemetry system, the acoustic command system, and the control system. Individual circuit descriptions will not be included, but rather the basic ideas and techniques used are discussed. COS/MOS integrated circuits are used for all low level digital circuits. A complete block diagram of the Autoprobe electronics with a breakdown of the various sub-systems is presented in Figure 4. The 2 KHz acoustic projector was not used in these microstructure experiments.

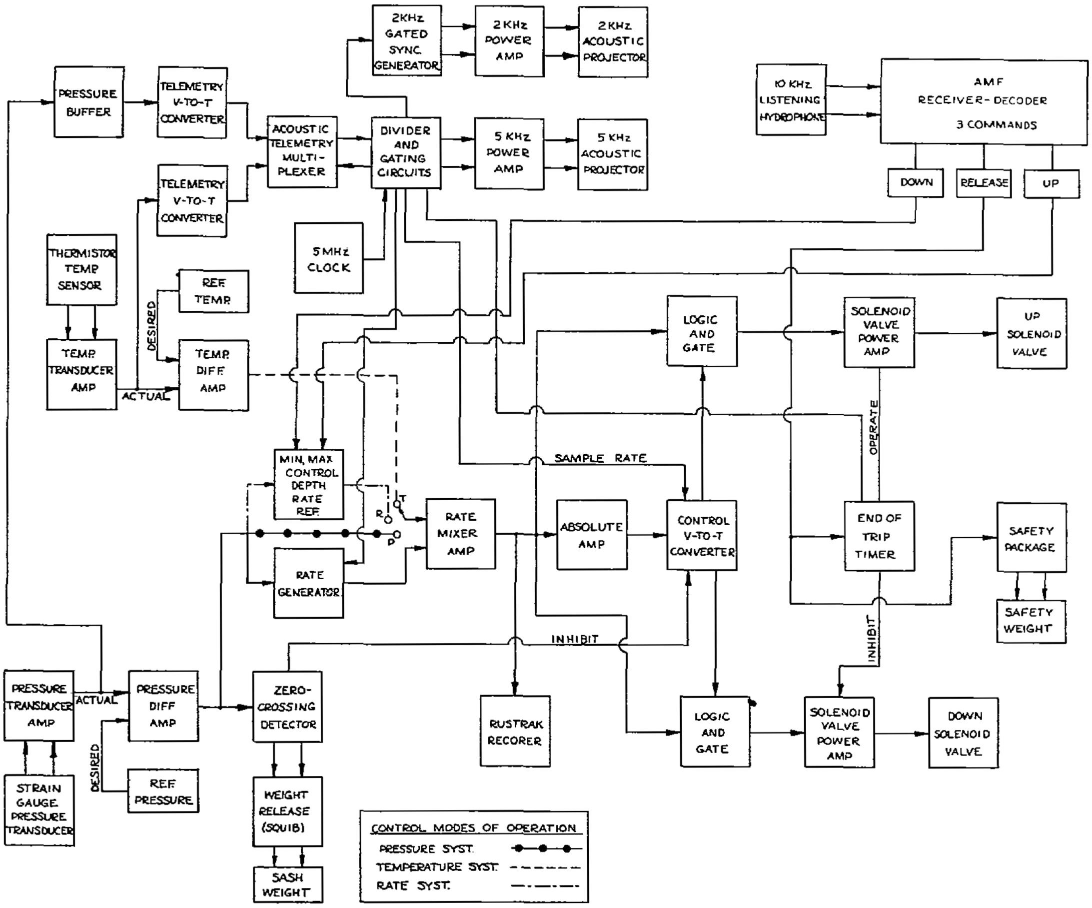
### Temperature and Pressure System

Temperature and Pressure are measured in the Autoprobe and can be used as input signals for the control system and as operational information that is telemetered to the surface. Temperature is measured with a pressure-protected thermistor used in a conventional bridge circuit followed by an operational amplifier resulting in a 0 to 5 volt analog signal. A strain gage pressure transducer is coupled to an operational amplifier resulting in a 0 to 5 volt analog signal.

### Telemetry System

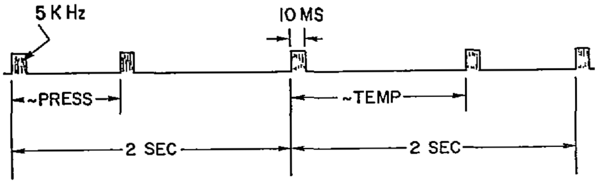
The telemetry system used in the Autoprobe consists of a quartz crystal oscillator, necessary divider and gating circuits, 2 voltage-to-time converters, a multiplexer, a power amplifier and suitable acoustic transducer. A 5 KHz acoustic projector is driven by a time coded telemetry signal at an input level of 40 watts resulting in an acoustic pulse of 5 KHz carrier frequency, 10 ms duration every 2 seconds as shown in Figure 5. This acoustic signal is received by a rectangular array of towed hydrophones from the ship. A shipboard Telemetry Receiver Acoustic Command System (TRACS)[4] is used to receive, process, and record the telemetered data. The electrical signals are filtered, amplified and recorded on a wet paper recorder, which was previously adjusted to be in synchronization with the free instrument's clock. The range error associated with the drift of the oscillators is less than 5 meters in a day.[5] An oscilloscope triggered by the recorder in synchronization with the free instrument is used to display the four hydrophone signals. Using this information, the ship can be directed to the location of the free instrument.

Telemetry is accomplished by a signal delayed from the main reference pulse by a time proportional to the desired variable, in this case, temperature and pressure. A telemetry multiplexer is



AUTOPROBE ELECTRONICS

Figure 4. A block diagram of the Autoprobe Electronics System showing the interconnections.



AUTOPROBE TELEMETRY

Figure 5. A pulse delay telemetry technique is utilized in Autoprobe with pressure and temperature proportional to time delay.

programmed to select alternately pressure for 2 seconds then temperature for 2 seconds. A window of 4 seconds every 20 seconds is provided by the multiplexer providing a quiet period for the reception of an acoustic command signal.

## Acoustic Command System

The acoustic command system consists of an AMF receiver and a 10 KHz listening hydrophone. There are 3 commands available, as follows (1) release - a squib operated release weight is jettisoned for instrument recovery; (2) up - the polarity of the control system is changed causing the instrument to go in an upward direction (towards the surface); and (3) down - the polarity of the control system is changed causing the instrument to go in a downward direction.

## Control System

The electronic control system operates with a proportional control signal with rate feedback. The control system has been used in three control modes of operation, temperature, pressure and rate.

The control system is operated in the constant rate mode for microstructure measurements. The rate signal is derived from the pressure gradient

$$\left(\frac{dP}{dt} \sim \frac{P_2 - P_1}{t_2 - t_1}\right)$$

using a sample and hold circuit to store the pressure $P_1$ at time $t_1$. Pressure $P_2$ is measured at time $t_2$, and the difference of these measurements results in the rate signal. The time interval $t_2 - t_1$ is preset at the sample rate. Thus, the rate velocity signal is available for control functions at the output of the rate generator as in Figure 4. The rate mixer is used as a comparator with an adjustable desired rate input and the actual derived rate at the other input. The output is equal to the Actual Rate minus the Desired Rate = $(R_A - R_D)$. This control information contains both the polarity and the magnitude of the rate signal. The polarity of this signal is identified in Logic And Gate, which is gated with a time duration signal which was derived from the magnitude signal after processing by the absolute amplifier and voltage-to-time converter.

The Logic And Gate output signal turns on the appropriate power amplifier circuit which opens the corresponding solenoid valve for a time proportional to the input signal. The control system can only make a correction at fixed intervals, set by the sampling rate. A dead zone is artifically created to save energy, meaning that the rate is assumed to be correct within certain limits.

The internal control system, therefore, samples the actual rate that the Autoprobe is falling, compares it to the desired rate and makes a proportional change at preset sampling intervals. The rates used for microstructure studies were from 3 cm/sec to 15 cm/sec depending on the experiment.

## Safety and Recovery Systems

Autoprobe's security is enhanced by its multi-level safety system. The safety devices can be summarized as follows:

1. AMF acoustic command system - weight released
2. Independent timer - ballast blown in VBU
3. Overpressure - weight released
4. Self-contained timer - weight released.

Weight considerations are extremely important in the design criteria of autonomous instruments, and therefore, only one weight is carried (18 lbs) which is actuated by any of the above methods.

Safety precautions are also taken for the Variable Displacement System which have been described in the end of that section. The collapse depth of the Autoprobe cylinders is 5,500 meters.

Autoprobe is acoustically tracked by the ship, which insures that the ship will be close by when recovery is desired. An Ocean Applied Research (OAR) flashing light is standard equipment on Autoprobe for night recoveries, and a brilliant flag aids daylight observations. The ship is maneuvered near Autoprobe and a line is attached with a hook. The proper operation of the pole requires the ship to get within 5-10 meters of the instrument, the instrument is hooked with the pole, and then the pole is pulled back out of the hook, leaving only a rope connection to the instrument. Williams has developed a hook that has proven very satisfactory for this procedure.[6]

## Operational Results

Autoprobe, as an observational platform for Microstructure Studies, was outfitted with a Conductivity, Temperature and Depth (CTD) system and an Optical Salt Finger Detector (OSFD) system. The CTD system was designed by Brown[7] of WHOI for microstructure measurements with the following ranges and resolution:

| | Range | Resolution |
|---|---|---|
| Conductivity | 0 → 65.535 mmhos | ±.001 mmhos |
| Temperature | 0 → 32.767°C | ±.0005°C |
| Depth | 0 → 3276.7 M | ±.05 M |

The CTD data is recorded on a Sea Data digital cassette tape recorder[8] located in the CTD pressure cylinder. The data is reproduced on the ship using a cassette reader and computer, where it is processed, printed and plotted. The OSFD was designed by Williams[9] (WHOI) to record photographs of Salt Fingers (optical inhomogeneities) on 16 mm film. A laser light beam is passed through a window in an end cap, one meter of sea water, 2 mirrors and back through the end cap where it is photographed on film. Time signals from the CTD are also recorded simultaneously with the photographs, resulting in proper synchronization for the analysis of the data.

Microstructure observations using the Autoprobe, CTD and OSFD were made by Williams[10] during 1972 and 1973. Autoprobe was used to study microstructure using the CTD and OSFD during 1972 south of Puerto Rico from the R/V CRAWFORD and in the Continental Slope Front Region from the R/V CHAIN 109. Autoprobe performed eleven successful dives in the constant rate mode sinking at uniform rates as desired, providing an excellent platform for the measurements of microstructure.

Autoprobe as a microstructure vehicle was employed from the R/V MARIA PAOLINA G., a Saclant ship in the Tyrrhenian Sea off the coast of Italy in April, May 1973.[11] Autoprobe was again programmed to fall at a constant rate, using its internal control system to make necessary corrections. Shipboard acoustic commands were sent to Autoprobe to reverse its direction when desired, resulting in a Yo-Yo mode of operation. The Yo-Yo mode of operation was employed to obtain repetitive measurements at a particular interface or region of interest. A typical Autoprobe dive in the remote control Yo-Yo mode is shown in Figure 6.

A joint study of microstructure in the Mediterranean Outflow region from the R/V ATLANTIS II was accomplished in July 1973. The Autoprobe was operated successfully in the constant rate mode. The Autoprobe/OSFD/CTD package has been renamed SCIMP for Self-Contained Imaging Micro-Profiler.

## Future Developments

A new instrument, Microstructure Vehicle (MV), incorporating many of the Autoprobe functions and a CTD has been designed and built. This instrument will be operated with a newly designed OSFD, and will be used for continuing microstructure measurements during 1974. This instrument package will also be referred to as SCIMP.

## Conclusions

Autoprobe has proven itself as an autonomous observational platform for microstructure studies in field operations during 1972 and 1973. It was

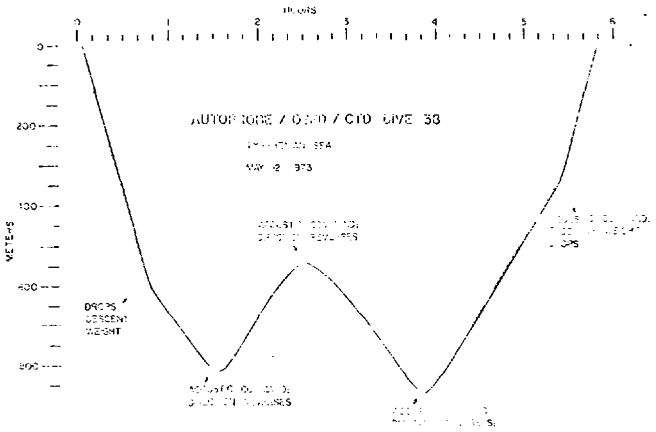


Figure 6. Results of Autoprobe Dive 38, showing the remote control operation in the constant rate mode. Acoustic commands were sent to Autoprobe causing the direction to reverse, resulting in the Yo-Yo operation.

successfully operated in the constant rate mode, and the remote control Yo-Yo mode. Several improvements resulted in increased ease of operation, maintenance, and reliability. Many of the techniques used in the Autoprobe system have been incorporated in other instrument designs.

## Acknowledgements

The author wishes to express his appreciation to L.V. Worthington, D.C. Webb, A.L. Winn and A.J. Williams 3rd for their scientific and technical participation. This work was supported by the Office of Naval Research under contract N00014-66-C0241; NR083-004. Contribution No. 3320 of the Woods Hole Oceanographic Institution.

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