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By

Arnold G. Sharp and Lawrence A. Sh

January 1977

TECHNICAL REPORT

Prepared for the National Science Fo
the Offices of Naval Research and the
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ALVIN, a deep-submergence oceanographic research submarine, is owned by the Office of Naval Research of the U.S. Navy and operated by the Woods Hole Oceanographic Institution (W.H.O.I.). Completed in 1964, it began routine diving for scientific research in 1966. Since that time the submersible has made over 650 dives in many areas of the Atlantic Ocean including the Azores, Spain, the Bahamas, the Straits of Florida and the Gulf of Maine. Many of the dives have been for vehicle test and training purposes, and a

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significant number have been required by the U.S. Navy for various engineering and salvage operations. These activities are summarized briefly and a short list of related Navy reports is given. Extensive engineering research and development in support of the ALVIN project has been provided by personnel from W.H.O.I., U.S. Navy laboratories and private industry. Over 100 technical reports and papers have been produced as part of this effort and they are listed here. Nearly 300 dives have been completed for purely scientific purposes. These latter dives are described briefly in chronological order, and a list of 92 of the resulting scientific publications is presented.

WHOI-76-114

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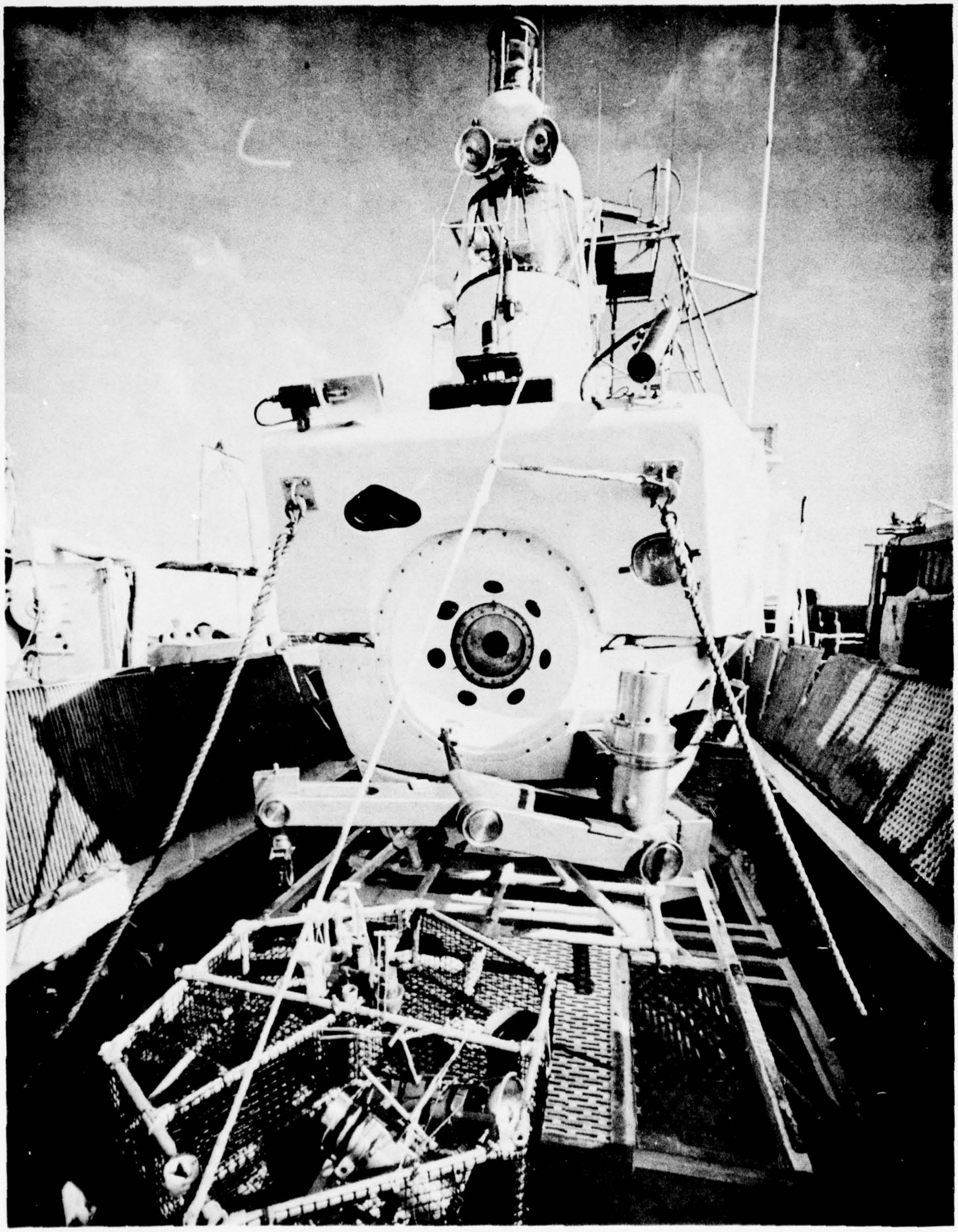
Approved for Distribution Robert G. Walden
Earl E. Hays, Chairman
Department of Ocean Engineering
Acting Chmn.



DSRV ALVIN

Woods Hole Oceanographic Institution

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ABSTRACT

ALVIN, a deep-submergence oceanographic research submarine, is owned by the Office of Naval Research of the U.S. Navy and operated by the Woods Hole Oceanographic Institution (W.H.O.I.). Completed in 1964, it began routine diving for scientific research in 1966. Since that time the submersible has made over 650 dives in many areas of the Atlantic Ocean including the Azores, Spain, the Bahamas, the Straits of Florida and the Gulf of Maine. Many of the dives have been for vehicle test and training purposes, and a significant number have been required by the U.S. Navy for various engineering and salvage operations. These activities are summarized briefly and a short list of related Navy reports is given. Extensive engineering research and development in support of the ALVIN project has been provided by personnel from W.H.O.I., U.S. Navy laboratories and private industry. Over 100 technical reports and papers have been produced as part of this effort and they are listed here. Nearly 300 dives have been completed for purely scientific purposes. These latter dives are described briefly in chronological order, and a list of 92 of the resulting scientific publications is presented.

Table of Contents

List of Figures

I. Background

The ALVIN program was initiated in 1961 under a contract with the Office of Naval Research (ONR) of the U.S. Navy. Using ONR funds the Woods Hole Oceanographic Institution (W.H.O.I.) asked industry for bids to design and build a deep-diving submarine capable of participating in programs in underwater acoustics, ocean bottom geology, and deep-sea biology. In 1962 a contract was signed between W.H.O.I. and General Mills, Inc. for this undertaking. A short time later the Applied Science Division of General Mills was purchased by Litton Industries, who finished the project. ALVIN was completed and commissioned in June 1964, and was considered to be operational by the end of 1965. During that year a series of deep dives were made which concluded with two manned dives to the design depth of 6000 feet.

In the spring of 1966 the Navy called upon ALVIN to assist in the search for the lost hydrogen bomb off the coast of Spain. ALVIN, working with the submersible ALUMINAUT, made a series of 35 dives during which the weapon was found and recovered. Later that year ALVIN made its first deep-water dives solely for scientific research, thus establishing a deep-ocean capability that has continued to the present.

In October 1968 ALVIN was lost in an unfortunate accident. When one of the hoisting cables parted, ALVIN slid off its elevator platform into the water. The three occupants escaped uninjured, but the submersible sank to the bottom, a depth of about 5,000 feet. Preparations for ALVIN's recovery began at once, and continued into 1969. Aided by the submersible ALUMINAUT and the U.S. Navy ship MIZAR, W.H.O.I. personnel made a successful hook-up and recovery in August of that year. Most of ALVIN's major components were found to be in good condition. The main aluminum frame was corroded, and was replaced by a new frame. The conning tower had been badly damaged during the recovery and it also required replacement. The pressure hull and buoyancy spheres needed cleaning but they were otherwise in excellent condition. Reassembly of the vehicle was completed in May 1971, and scientific diving was resumed in June of that year. ALVIN, rebuilt and using many of its original component parts, was returned to service with its former 6000 ft. depth capability for two more diving seasons.

Under the U.S. Navy's Project TITANES a new titanium alloy pressure hull was designed and built for use in ALVIN. The new sphere has a wall thickness greater than that of the original HY-100 steel sphere, but the titanium alloy is about

40 percent lighter than steel. This has resulted in a new hull capable of diving to 12,000 feet (double the working depth of the steel hull) and a significant increase in payload. ALVIN was disassembled in November 1972 and the new pressure sphere was installed along with a newly built variable-ballast system required for the greater depth. In June of 1973 the rebuilding was completed and diving tests commenced in July. Scientific work was begun in January of 1974 with dives conducted at depths of 8000 to 10,000 feet on a routine basis. On 19 May 1975 ALVIN dove to 12,000 feet in the Bahamas area on a geology dive. Since that time the submersible has reached its design operating depth on numerous occasions. This new depth capability of ALVIN has resulted in its use in studies of sea floor spreading.

Two recent scientific programs are especially worthy of note: the submersible participated in the French-American Mid-Ocean Undersea Study (FAMOUS) in the summer of 1974. ALVIN made 17 dives, working closely with the French submersibles CYANA and ARCHIMEDE. In 1976 the Cayman Trough study was undertaken in which ALVIN made 15 dives. Significant scientific publications have resulted from the FAMOUS study and similar results are to be expected from the Cayman Trough operations.

Despite the success of these and other missions it has become very clear over the years that a job-shop approach to funding the ALVIN program does not provide the continuity necessary to retain working level expertise, plan viable scientific programs, and maintain a flexible deep-ocean capability for the U.S. Navy. In order to better support this program, the Office of Naval Research (ONR), the National Science Foundation (NSF), and the National Oceanic and Atmospheric Administration (NOAA) recently agreed to provide a base of funding each year for three years. These funds have allowed the maintenance of a basic capability and have provided for some scientific work. It was agreed that the selection of scientific projects under this funding would be reviewed by an evaluation committee administered by the University-National Oceanographic Laboratory System (UNOLS).

ALVIN's contribution to the success of a scientific mission is obvious to only a few persons at the time the work is performed. Wider recognition comes later (often after a lapse of several years) when the results are published. In an effort to bridge this gap we have chosen to describe in some detail the scientific diving activities of ALVIN, and to identify these activities with the published works directly related to them.

II. Narrative of Scientific Dives

1966 - While 1966 was devoted primarily to U.S. Navy missions, several geological dives were made in the Bahamas for Dr. John Schlee. Schlee (1), and Gibson and Schlee (2) reported on these dives to the U.S. Geological Survey. A 15 dive series was made for the Naval Oceanographic Office (NAVOCEANO) which included photography, coring, bottom profiling and the acquisition of biological fouling data at depths ranging from 2750 to 5500 feet (see Section IV). Back in New England waters Dr. Claes Rooth (3) made measurements, at 615 feet, of the temperature microstructure at the thermocline. Van Leer and Rooth (4) reported on additional observations made during this dive. In the last dive of the season, Dr. James Trumbull (5) became the first geologist to view directly a deep canyon in the Atlantic continental slope.

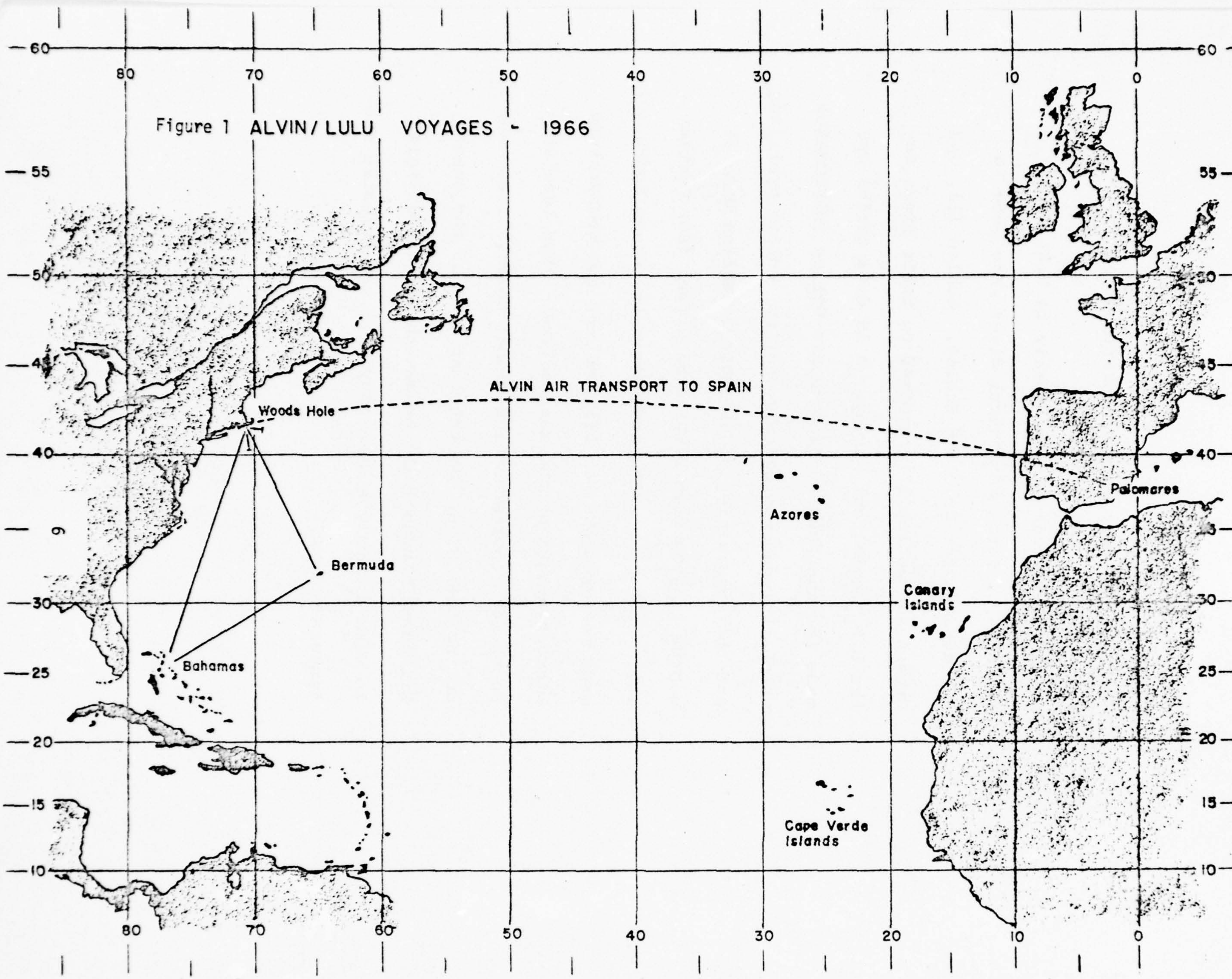


Figure 1 ALVIN/LULU VOYAGES - 1966

1967 - After several test and certification dives, 1967 began with four more dives for NAVOCEANO which included both geological and engineering work. In July John Milliman, Frank Manheim, Richard Pratt and E. F. K. Zarudzki (6, 7, 8) made a series of dives on the Blake Plateau and on the continental shelf northeast of Cape Hatteras. Both geological and biological observations were conducted on these dives. K. O. Emery of W.H.O.I. and R. L. Edwards of Bureau of Commercial Fisheries (9, 10), followed with two dives on the continental shelf off Chesapeake Bay, exploring submerged beaches and dunes. In August dives by J. V. A. Trumbull and J. C. Hathaway (11, 12), in Oceanographer Canyon provided new information about the formation and age of this geographical feature. Later in August R. L. Wigley of the Bureau of Commercial Fisheries made a dive on Georges Bank obtaining samples and photographs. Wigley (13), and Wigley and Emery (14) published the results of this dive. During this period D. A. Ross (15) made a dive in Corsair Canyon surveying the area and collecting samples. This was followed

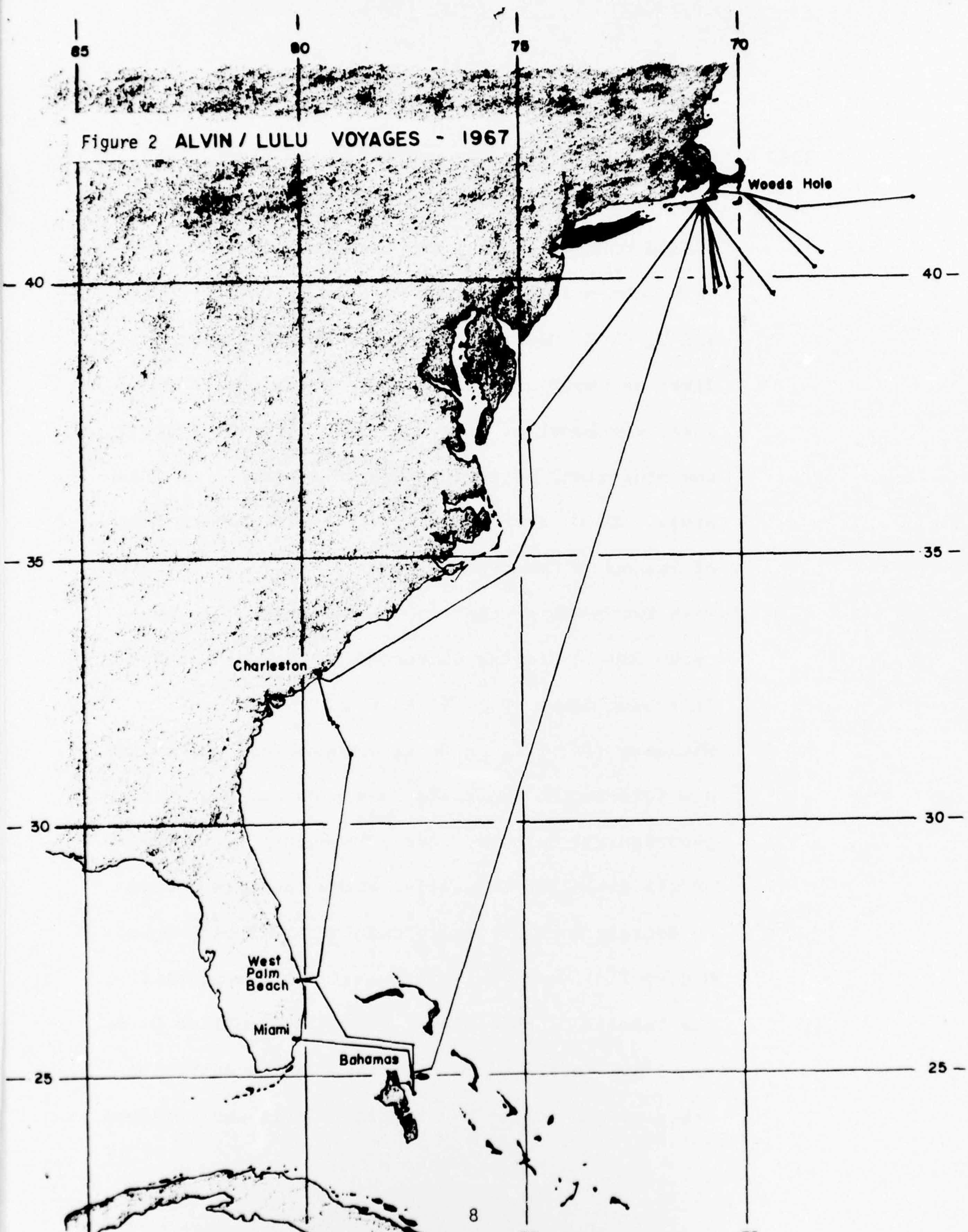


Figure 2 ALVIN / LULU VOYAGES - 1967
Woods Hole
Charleston
West Palm Beach
Miami
Bahamas
85
80
75
70
40
35
30
25

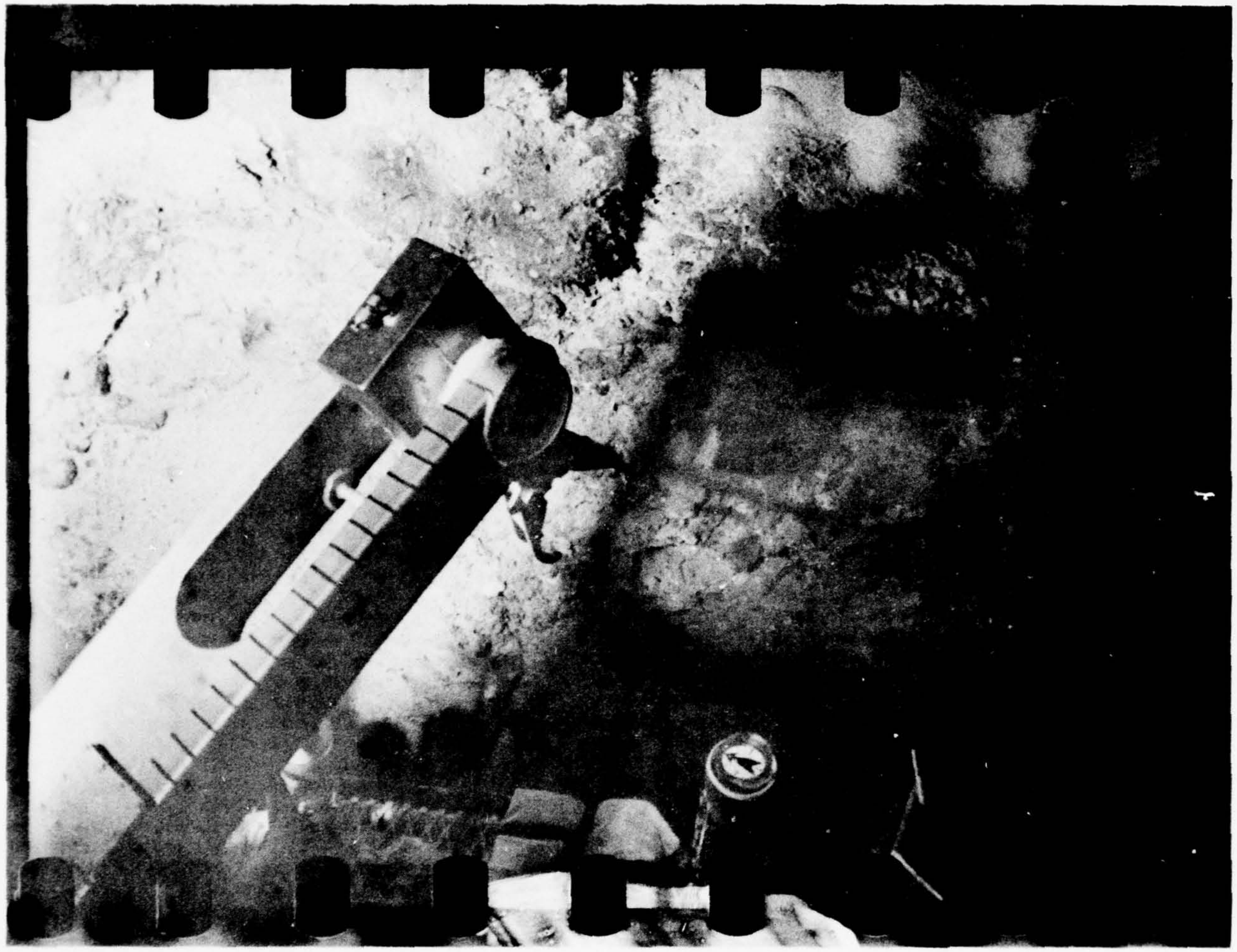


Figure 3 ALVIN's Manipulator Collects Geological Samples in Corsair Canyon, August 1967 (Ross)

by a series of biological dives by R. H. Backus, et al (16) in which the deep sound-scattering layer was studied. In October K. O. Emery and D. A. Ross (17) made four dives with the dual purpose of searching for the lost ALVIN manipulator and making geological observations. J. E. Sanders (of Hudson Laboratories), with K. O. Emery (18, 19) investigated the ocean bottom using side-scanning sonar in an area south of Cape Cod, to complete the year's diving season.

1968 - A series of dives was conducted in April to attempt observation of Right Whales for W. E. Schevill. Data obtained in these dives contributed to the study then being made by Schevill and Watkins (20) of naturally occurring sounds in the ocean. In addition to numerous test and engineering dives in May, Mr. John Hughes of the Massachusetts Department of Natural Resources made a dive to observe lobsters. Late in May three dives were made for Drs. Schlee and Hathaway for geological survey work. Two geological dives were made in June for D. A. Ross (21, 22) and J. Hathaway, and seven dives were made for plankton tows early in July by biologists Hessler, Sanders, Grice (23, 24), Teal, Scheltema and Smith. Two dives were made to Bear Seamount by K. Emery and J. Milliman. Uchupi, Phillips and Prada (25) utilized data taken on those dives in a paper describing the New England Seamount Chain. During this period Ballard and Emery (26) began preparation of a paper on the use of deep-submersibles by

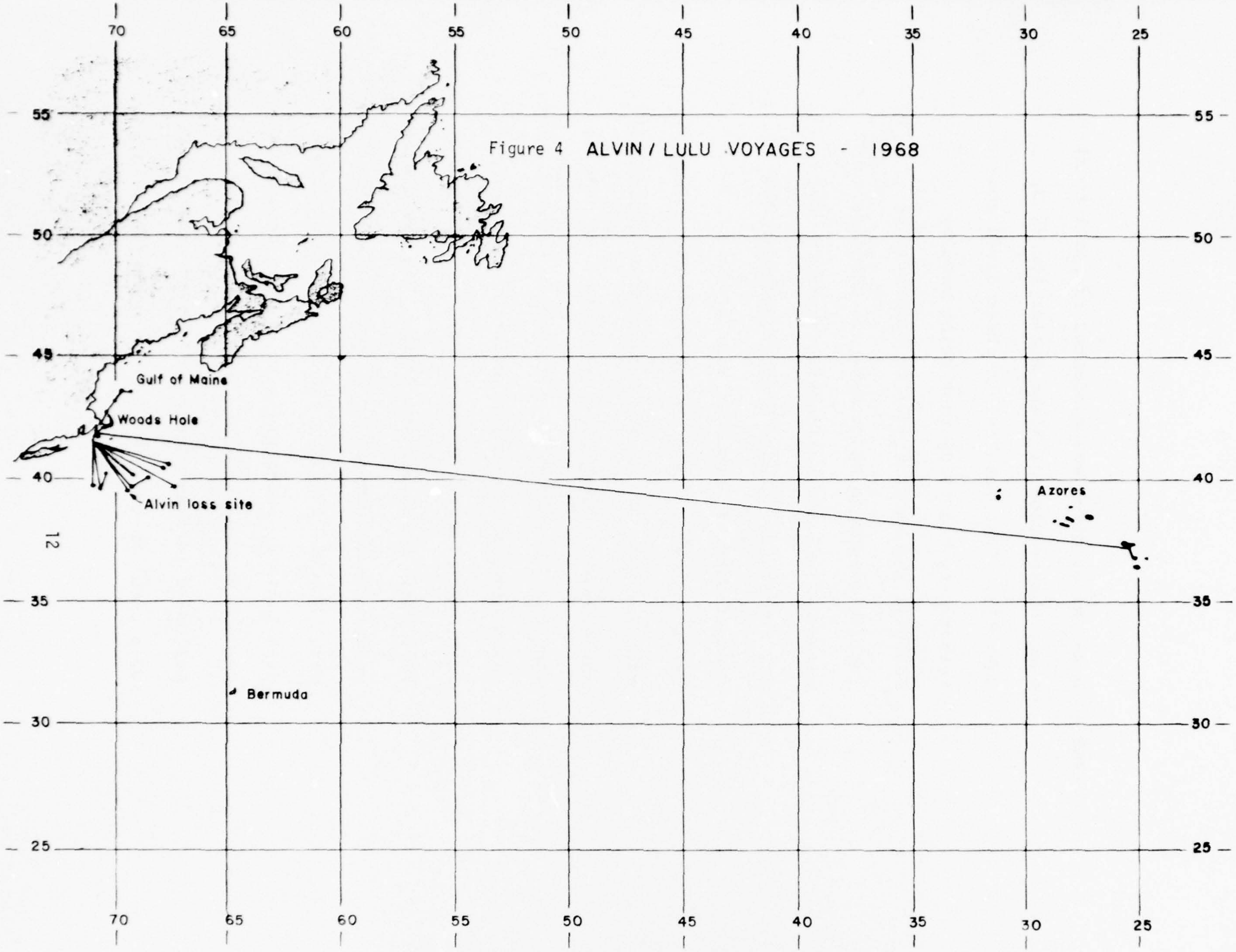


Figure 4 ALVIN / LULU VOYAGES - 1968

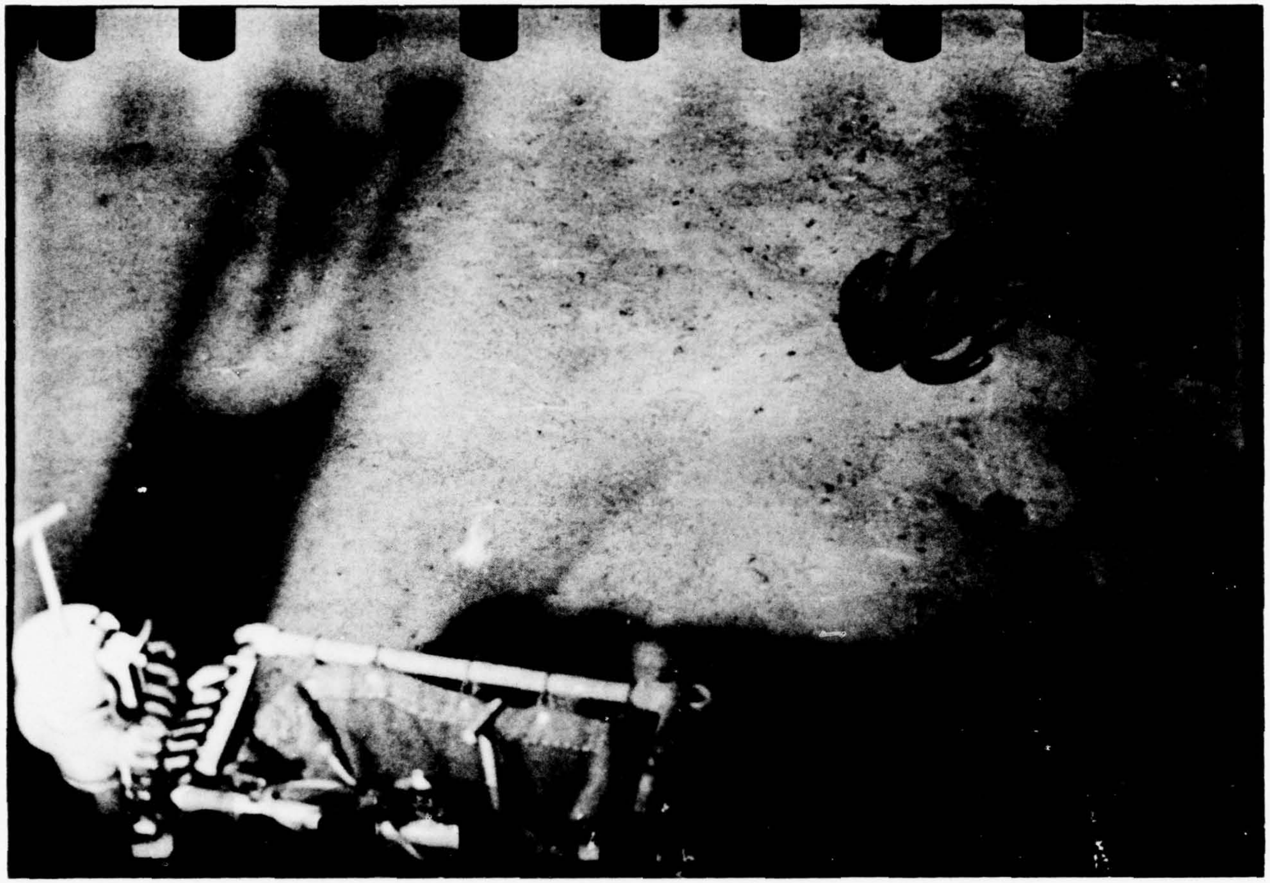
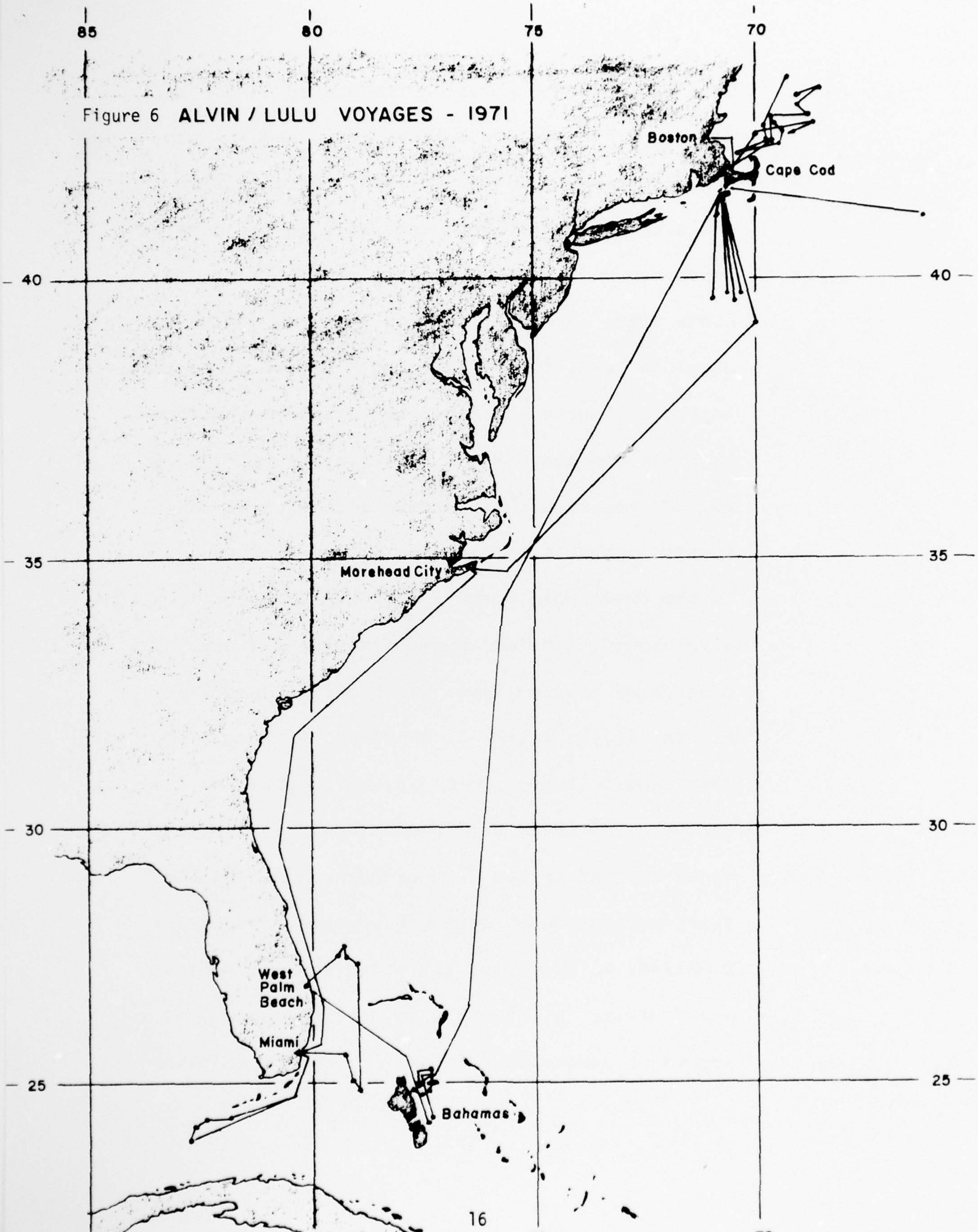


Figure 5 ALVIN Atop Seamount Mytilus, July 1968 (Emery)

scientists. All of August was spent conducting dives for the Navy. Three biology dives were made in October by scientists Backus, Foxton, Haedrich, Horn, Teal and Shores; observations and photographs were made of the deep scattering layer south of Martha's Vineyard.

1971 - The rebuilding of ALVIN was completed in May 1971, following its loss in October 1968, and its subsequent recovery in August 1969. At that time it was discovered that food materials in the crew's lunch box were in a surprisingly well preserved state after exposure for more than ten months to deep sea conditions. This led W.H.O.I. biologists to begin a series of experiments to substantiate this observation. H. W. Jannasch, et al (27, 28, 29, 30) reported their findings in several scientific journals. Following a series of test dives in the Woods Hole area, and a 6000 ft. certification dive about 100 miles south of Martha's Vineyard, a program of biology dives was begun on June 17th. F. Grassle, K. Smith, J. Craddock, R. Beamis, G. Rowe, and D. Bumpus participated in plankton tow and benthic survey experiments south of Martha's Vineyard, and in the Gulf of Maine. During the first week of July, Lehigh University researchers T. Nixon, A. Richards, J. Van Sciver, M. Perlow, and T. Terry (31, 32, 33, 34, 35, 36) conducted a series of penetrometer tests and bottom sediment

Figure 6 ALVIN / LULU VOYAGES - 1971



properties investigations, also in the Gulf of Maine. On July 18th a series of geology dives began in the Gulf of Maine. R. Ballard (37, 38) and D. Ross of W.H.O.I., Dr. L. King of Bedford Institute, and Dr. M. Kane of United States Geological Survey (USGS) obtained hard rock cores using the rock drill developed by W.H.O.I. engineers. They also surveyed the area, and obtained over 150 pounds of rock samples. Early in August Doctors Ruth Turner and John Teal (39, 40) conducted biology dives near Cape Cod. Later that month and during most of September the new submersible navigation system was tested. Early in October further Gulf of Maine geology dives were made by R. Ballard and R. Oldale (41) and a buoy line recovery was attempted for the Office of Naval Research (ONR). The remainder of October was used almost entirely for geology dives sponsored by the National Oceanic and Atmospheric Administration (NOAA) and ONR. D. Florwick, D. Lambert, G. Keller (42), J. Kofoed and G. Hood of NOAA, and Dr. C. Neumann (43) of the

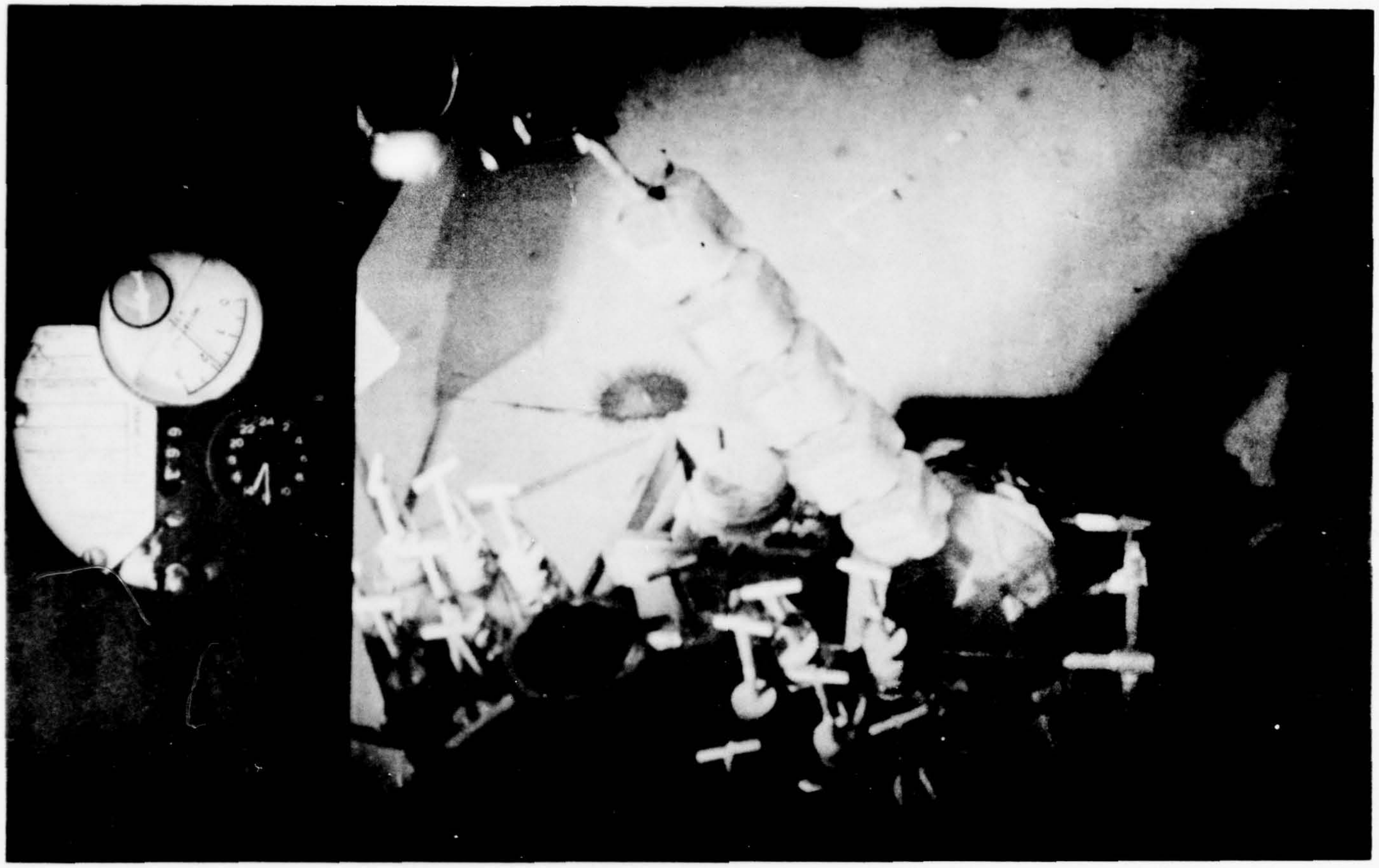


Figure 7 ALVIN's Manipulator Handles Rack of 20 Biological Sample Bottles for _In Situ_ Incubation of Deep Sea Microorganisms, June 1971 (Jannasch)

University of Maine participated in these dives in the area of the Straits of Florida. In November miscellaneous dives were made in the Bahamas for W.H.O.I. biology, ONR/AUTEC, and the underwater navigation program supported by the Advanced Research Projects Agency (ARPA). Drs. R. Ballard, G. Rowe (44,45) and J. Teal (46) were observers on a number of these dives. During December further ARPA navigation testing was done and magnetic studies were made by Dr. B. Luyendyk of W.H.O.I., including a successful test of a new magnetometer. David Williams and Andrew Barrs successfully tested a large rock drill capable of making cores three feet in length, and Dr. G. Grice (47) of W.H.O.I. and Dr. Mary Johrde of the National Science Foundation (NSF) ran plankton tows. Finally, a successful recovery of Naval ordnance hardware was made from a depth of 1545 meters.

1972 - The first four months of 1972 were spent completing the annual overhaul, and diving operations commenced in May. A total of 67 dives were made; 21 of these were for test, training, certification. In May, following the usual vehicle tests and a certification dive to 1833 m., scientific diving began with a series of tests of the large rock drill developed at W.H.O.I. under the ARPA program. Also sponsored by ARPA, Drs. G. Rowe and R. Haedrich (48) made two biology dives in the Gulf of Maine. These were followed by a series of four NSF biology dives by Carl Wirsen (49, 50), Drs. T. McLellen, P. Wiebe, K. Smith, R. Turner and F. Grassle. Drs. T. Terry (51), G. Keller (52), G. Rowe, and R. Ballard made dives in the Hudson Canyon late in June for geological and biological observations. These eight dives, funded by NOAA, were primarily for the purpose of sediment density determination and the installation of bottom current meters. Later, eight ARPA dives were made for geology and

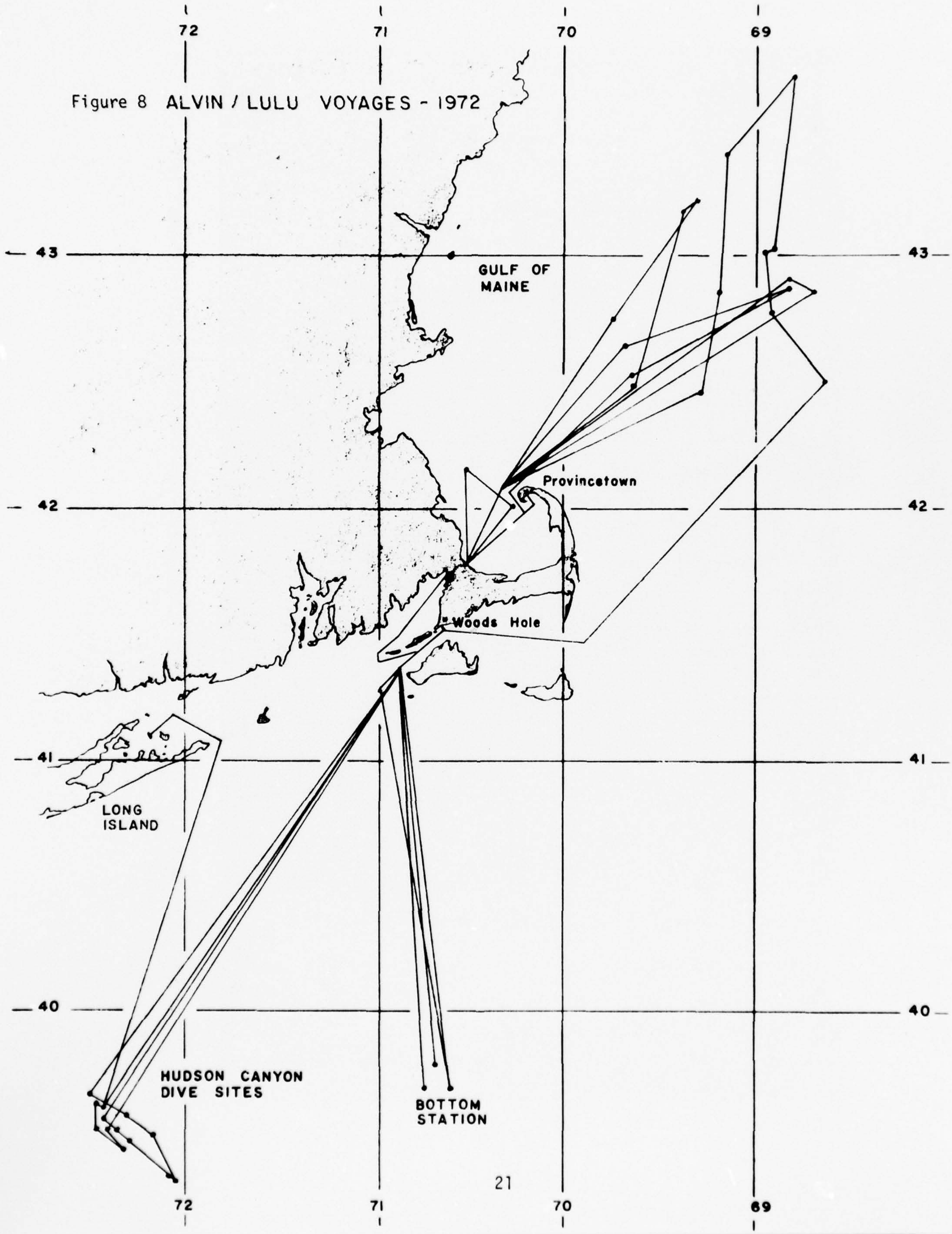


Figure 8 ALVIN / LULU VOYAGES - 1972
72
71
70
69
43
42
41
40
GULF OF
MAINE
Provincetown
Woods Hole
LONG
ISLAND
HUDSON CANYON
DIVE SITES
BOTTOM
STATION

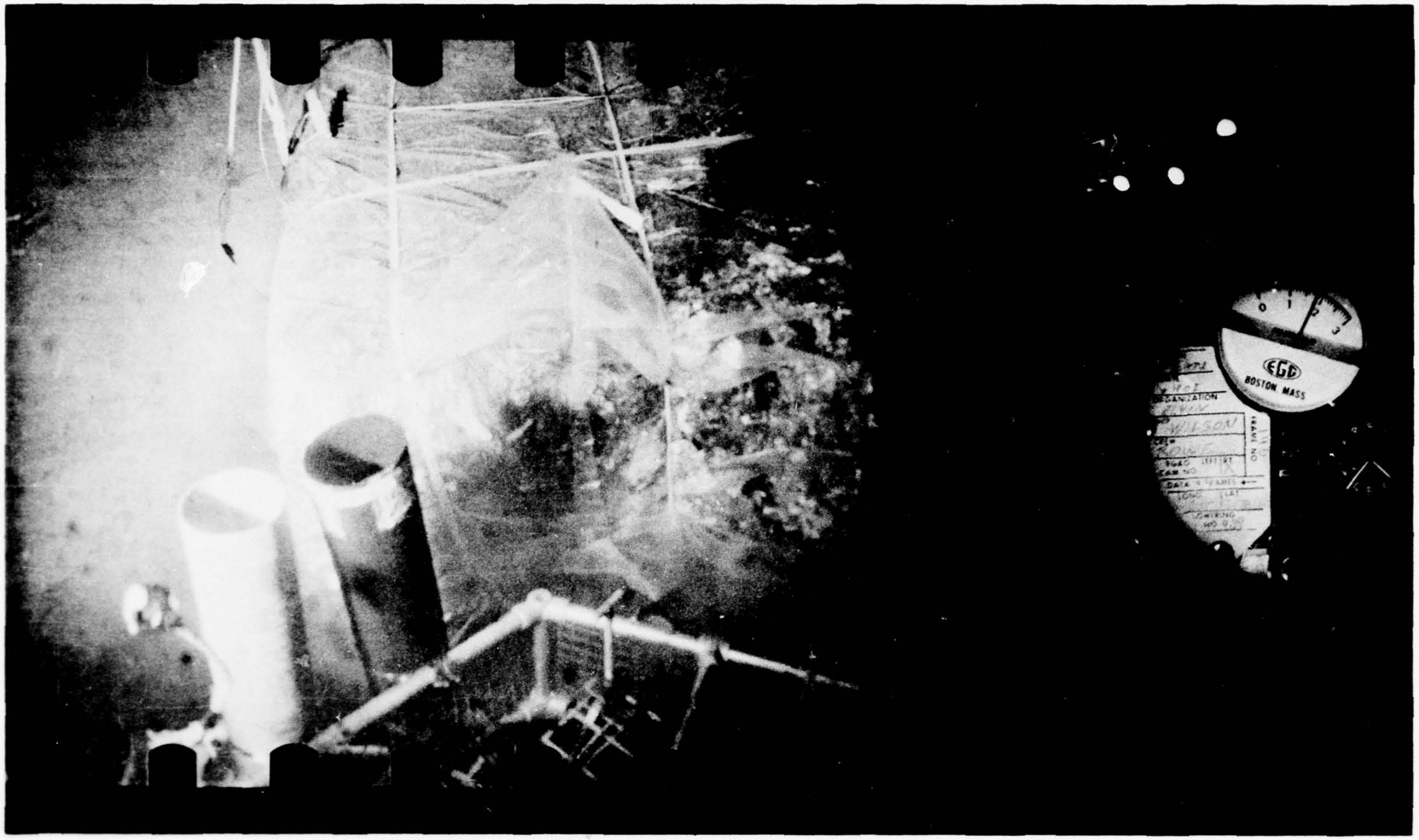


Figure 9 Inspection of Garbage Bale During Ocean Refuse Disposal Studies, August 1972 (Rowe and Clifford)

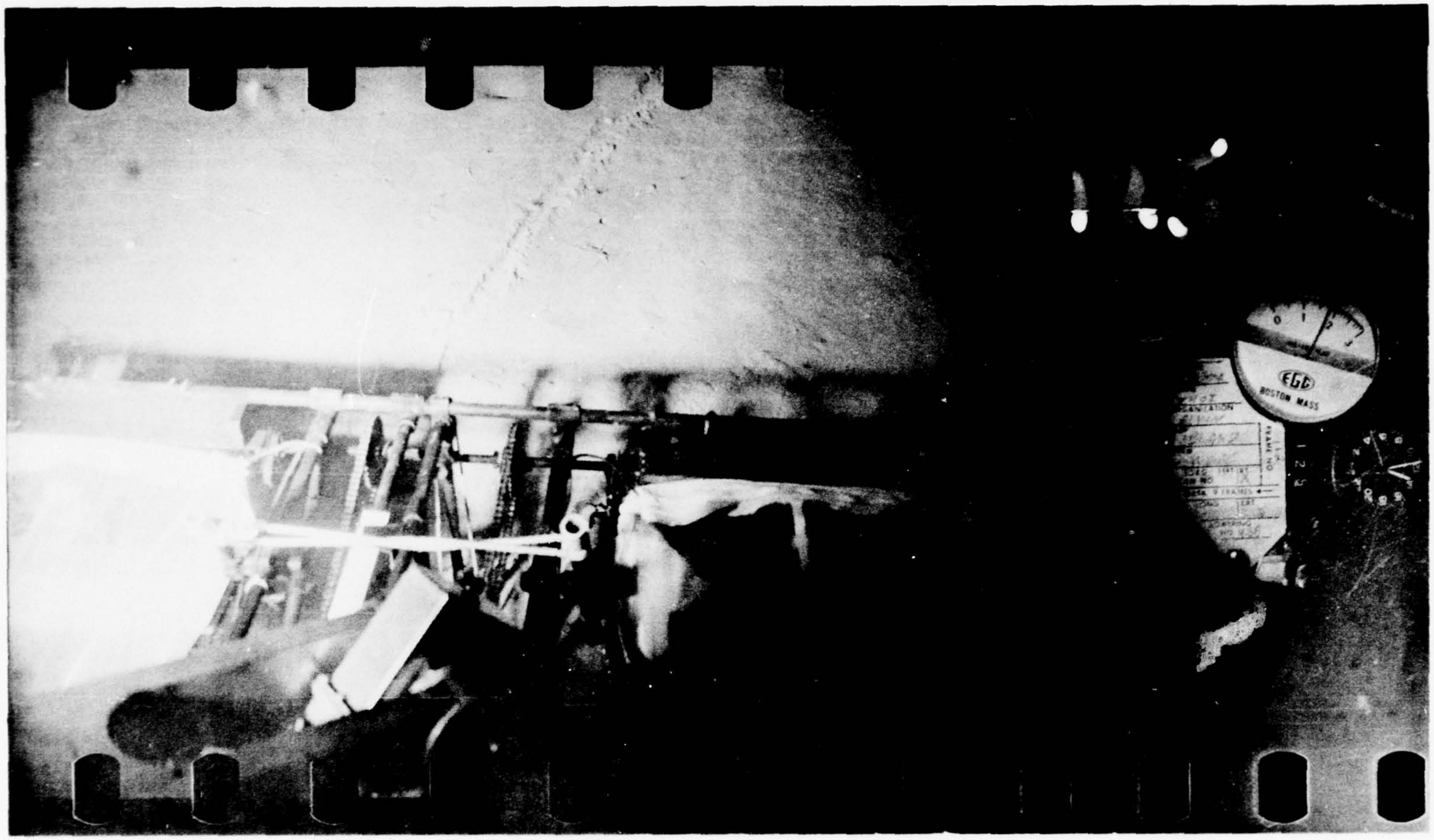


Figure 10 Towing Plankton Net at 1820 m., August 1972 (Wiebe)

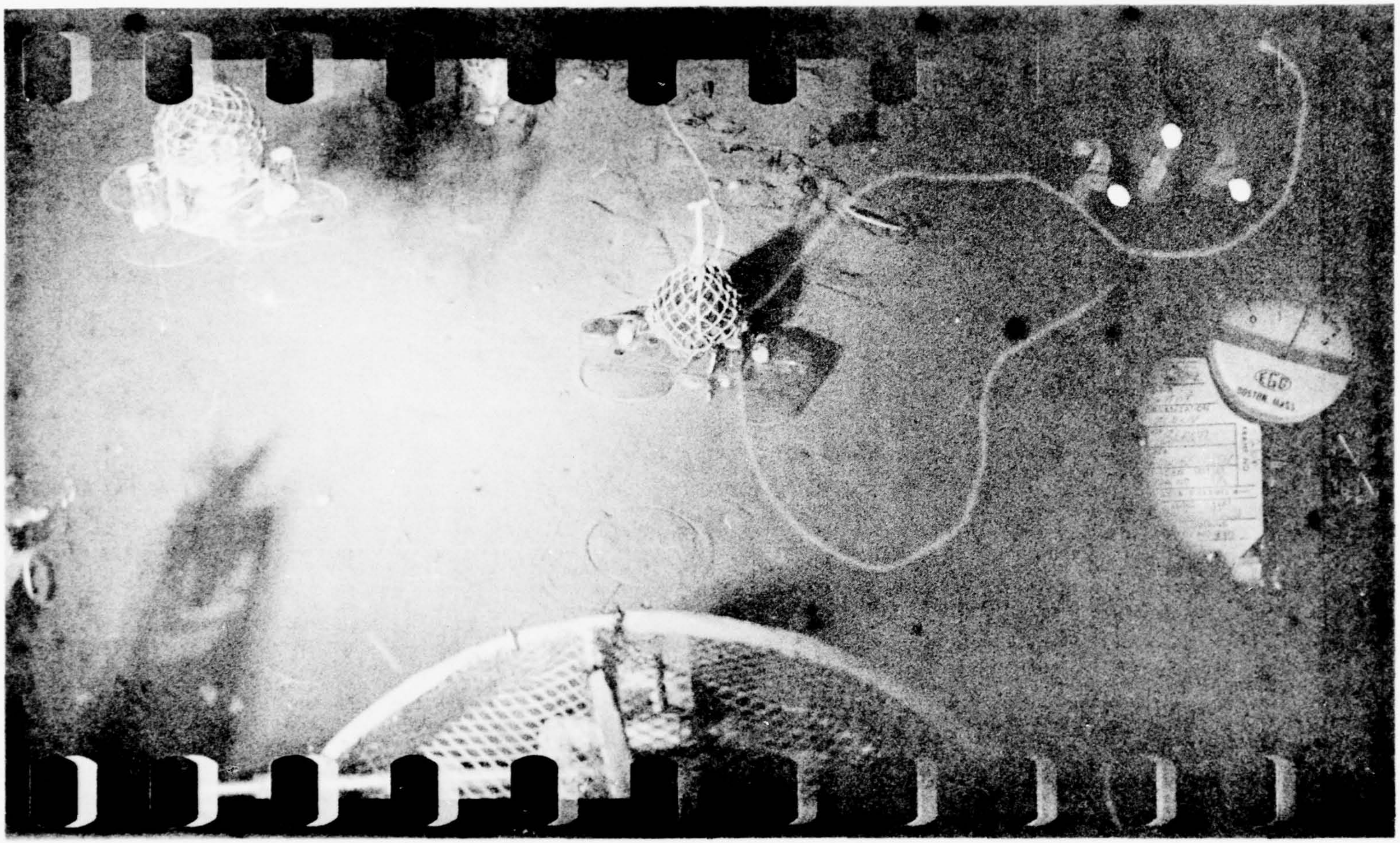


Figure 11 Biologists Recover Bell Jar Respirometers Used for *In Situ* Studies of Benthic Community Respiration, August 1972 (Rowe and Smith)

navigation experiments. Magnetometer and rock hammer trials were conducted by Dr. R. Ballard of W.H.O.I., and A. Malahoff and J. Carlmark of ONR. Late in July eight geology dives were made under NSF funding, all in the Gulf of Maine. Participating scientists were W. Bryan, L. King, R. Ballard, R. McMasters and G. Hayward. Rock samples were collected and various geological observations were made. ALVIN and LULU then returned to Woods Hole for about one week for minor repairs and routine maintenance. Early in August, six ONR-funded biology dives were made at a point about 100 miles south of Martha's Vineyard (bottom station). Scientists G. Rowe, D. Cohen, K. Smith, J. MacIvaine, P. Wiebe and C. Clifford planted bell jars and made plankton tows. The remainder of August was given over to ARPA geology and navigation work. Seven dives were made by investigators Bryan, Heirtzler, Ballard of W.H.O.I., and Bellaiche (CNEXO, France) in the Gulf of Maine. Ballard (53, 54) and Ballard and Uchupi (55) reported on the results of the geological observations. Hudson Canyon geology

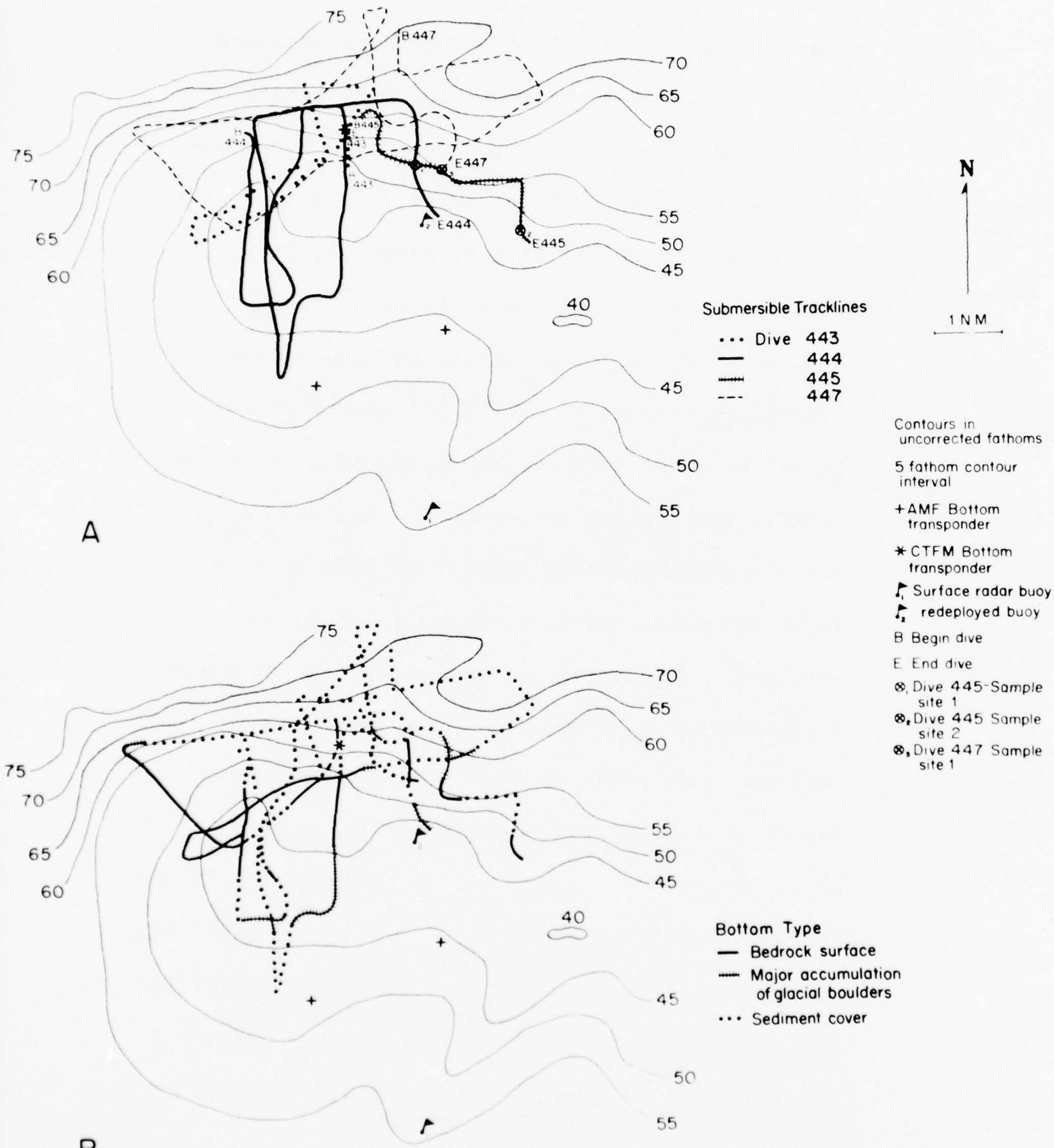


Figure 12 ALVIN Survey of Bedrock on Cashes Ledge, Gulf of Maine, August 1972 (Ballard)

dives were made in September by G. Rowe, G. Keller, N. Staresinic, D. Lambert, W. Van Sciver, and R. Swartz. Seven dives were devoted to current measurement, sediment density determination, and sampling (56, 57, 58). Five NSF-funded biology dives at the bottom station 100 miles south of Martha's Vineyard completed the scientific diving season. Observations were made and samples obtained by investigators H. Sanders, T. McLellan, F. Grassle (59), P. Holmes and G. Hampson, of W.H.O.I., and J. Drogou of CNEXO, France. The year 1972 saw the publication of a book by K. O. Emery and E. Uchupi (60) which presents a comprehensive treatment of the geological aspects of the western North Atlantic Ocean area. In November the major disassembly of ALVIN was begun, to prepare for the installation of the new titanium pressure hull.

1973 - The period November 1972 through June 1973 was set aside for the refitting of ALVIN with the new titanium pressure hull provided under Project TITANES. The operation of the rebuilt vehicle began in July with pressure tank tests at the Naval Ship Research and Development Center (NSRDC) at Annapolis, Maryland. Two unmanned tests, and one manned test, were made, all to the pressure equivalent of 12000 feet. The manned test constituted the required certification deep dive. Following the usual dockside tests in Woods Hole, further test and training dives were made, during August and September, in Provincetown harbor and nearby waters. Training and test dives continued into October in the Woods Hole and Provincetown areas. Similar diving activity was resumed in waters off West Palm Beach, Florida, during November and early December.

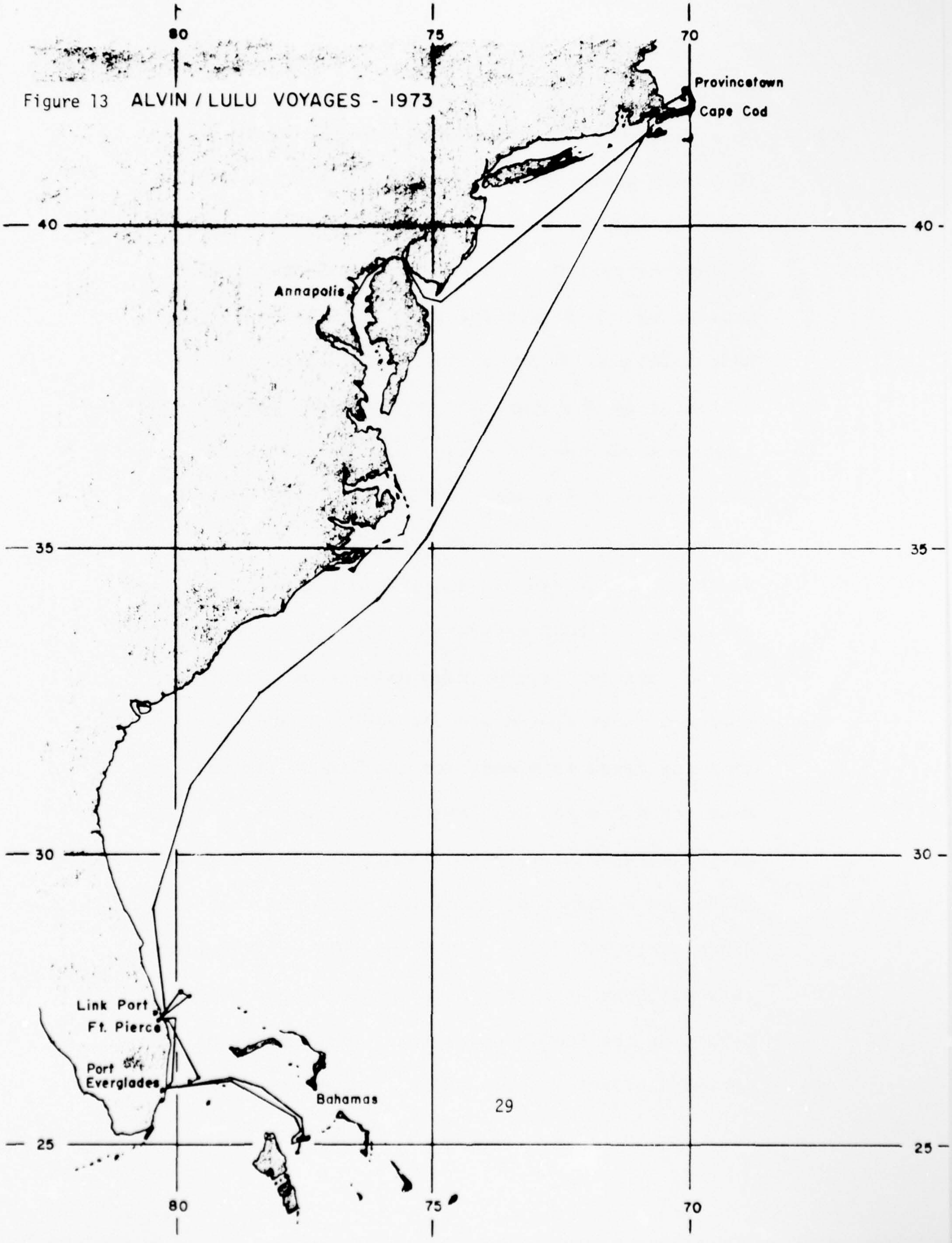
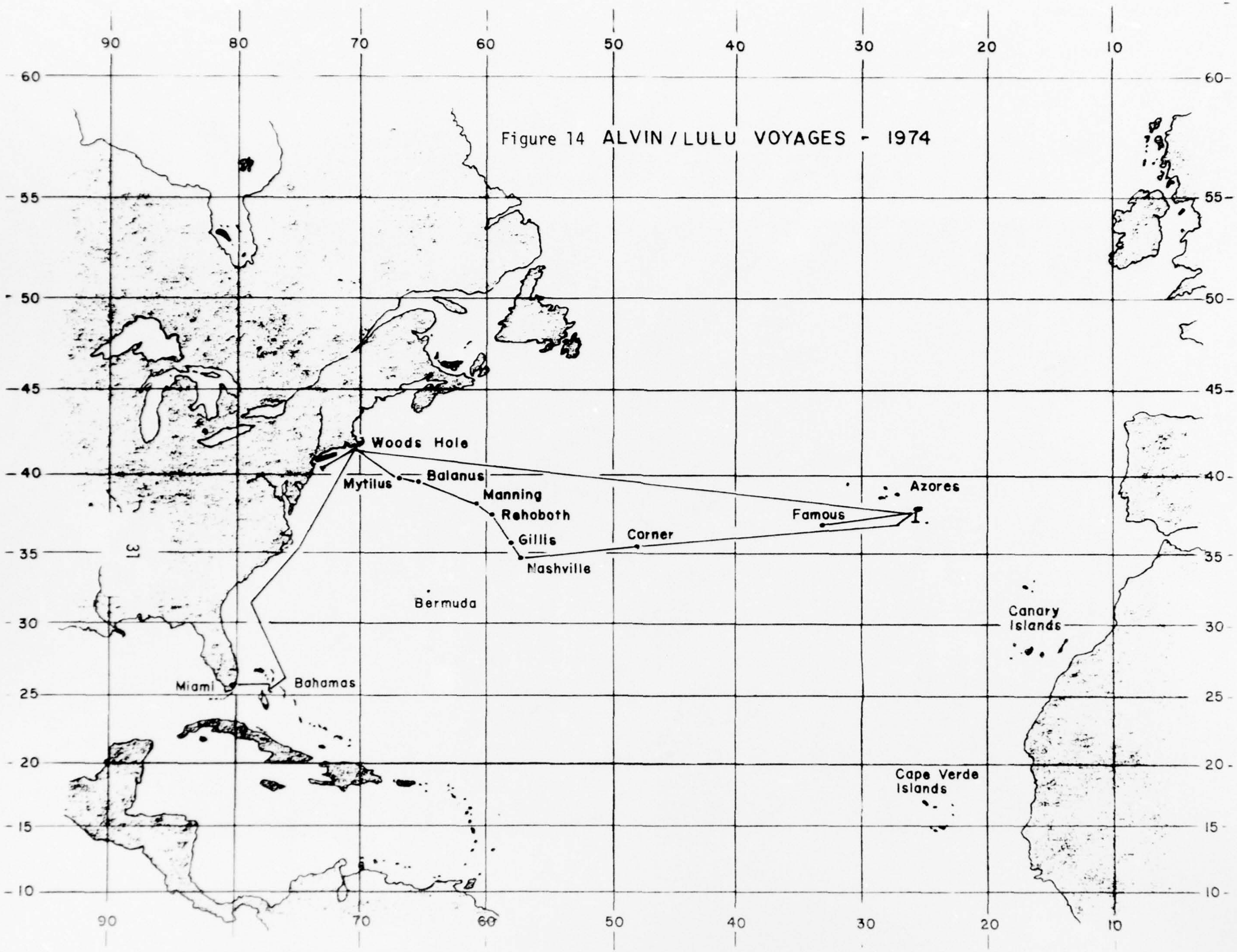


Figure 13 ALVIN / LULU VOYAGES - 1973
80
75
70
Provincetown
Cape Cod
40
Annapolis
35
30
Link Port
Ft. Pierce
Port
Everglades
Bahamas
25

1974 - On 1 January 1974, DSRV ALVIN embarked on RV LULU, was underway from Ft. Pierce, Florida en route to Nassau, New Providence Island, Bahamas. During the period 1 January through 9 March, six cruises were made operating out of Nassau and Andros Island. Work accomplished included current studies, biology, and recovery and inspection work for the U.S. Navy. During this period Carl Wirsen (61) conducted studies of the activity of marine bacteria at high pressures. P. Wiebe and K. Ulmer closed the doors of a sediment trap at a depth of 2000 meters prior to its recovery to the surface. Wiebe, Boyd and Winget (62) reported on this device and its use. In addition, training dives were made for the FAMOUS (French American Mid-Ocean Undersea Study) Program, and new penetrator installation configurations were tested on a number of dives including one to a depth of 10,000 feet. ALVIN and LULU arrived back in Woods Hole on 21 March and preparations were begun for the FAMOUS operation. These preparations included a short cruise off Provincetown, Mass. for

Figure 14 ALVIN / LULU VOYAGES - 1974



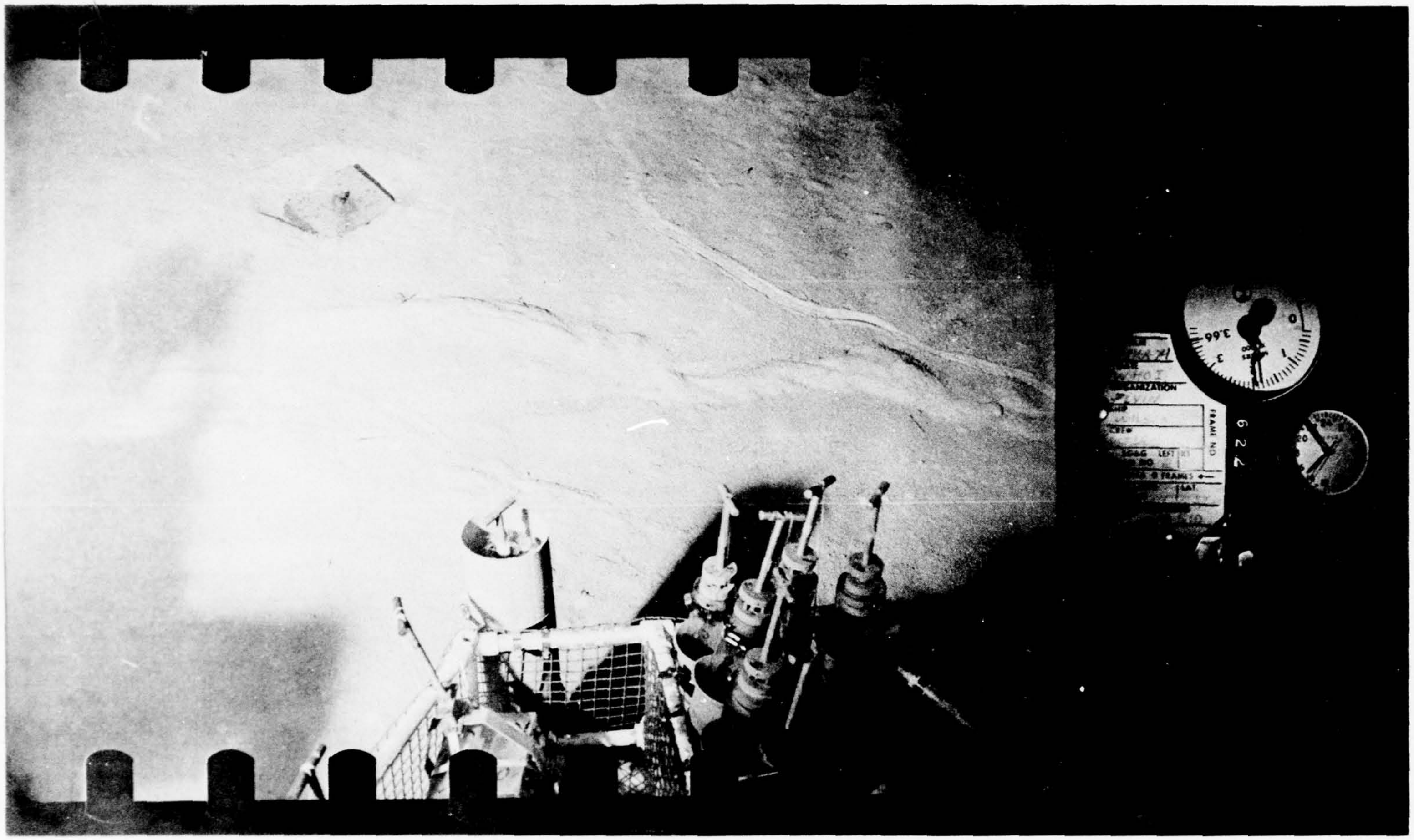


Figure 15 Inspecting Tracks in Sediment Near Bottom Station, Tongue of the Ocean, Bahamas, March 1974. One of ALVIN's Droppable Weights Can be Seen Nearby (Polloni)

Figure 16 Lava Formation Known as "Collapsed Blister Pillow" is Caused by Tectonic Activity on Rift Valley Floor of Mid-Atlantic Ridge, FAMOUS Program, 1974

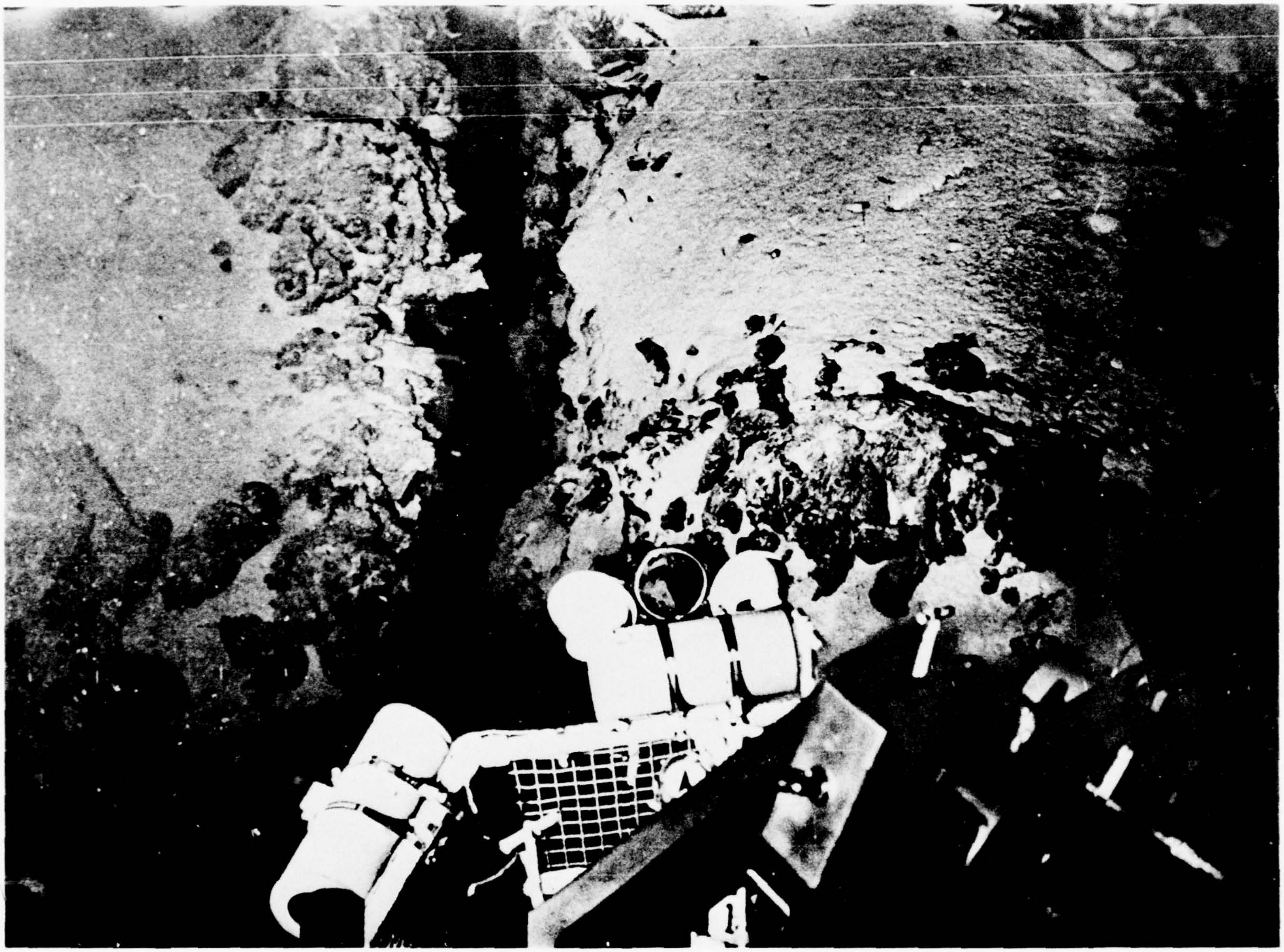


Figure 17 Camera Mounted on Top of ALVIN Looks Down Into Narrow Fissure Caused by Tectonic Activity Near Center of Rift Valley of Mid-Atlantic Ridge, FAMOUS Program 1974

shallow trials in May. On 6 June with ALVIN on deck and LULU towing astern, RV KNORR got underway for the Azores and Project FAMOUS. Upon arrival at Ponta Delgada, Azores, on 18 June, ALVIN was transferred to LULU. From 19 June until its return to Woods Hole on 3 September ALVIN made a total of 27 dives. Of these, 17 were for the FAMOUS project on the Mid-Atlantic Ridge. Anderson (63), Ballard, et al (64), Ballard (65, 66, 67, 68), Drake (69), Heirtzler (70), Heirtzler and Le-Pichon (71), Heirtzler (72), Heirtzler and Bryan (73), Heirtzler (74) and Moore (75) have published their findings covering a variety of Mid-Atlantic Ridge observations. In addition, Ballard and van Andel (76, 77), Bryan and Moore (78), Fenn, et al (79), Heirtzler and van Andel (80), Johnson and Atwater (81) and Williams, et al (82) have ALVIN-related FAMOUS contributions in press or in preparation at this writing. It was during Project FAMOUS that the ALVIN navigation (ALNAV) system, developed under a grant by the Advanced Research Projects Agency (ARPA) received its first full-scale utilization. The system was a major contributor to the success of the project. Following the FAMOUS activities, ALVIN made one dive to inspect a defective acoustic array for the Navy, one for the Deep Sea Drilling Project, one for vehicle test, and a series of seven dives for ONR during which each dive was made to a different seamount in the New England Seamount Chain. In September and October, two short cruises were made under NOAA sponsorship to the Hudson Canyon area, and to the W.H.O.I. bottom station south of Cape Cod. On 6 October after a year's total of 60 dives, ALVIN went into annual overhaul, scheduled for completion on 1 March 1975.

1975 - Scientific diving began in mid-April with four dives in the Tongue of the Ocean. These dives were made by scientists L. Cole, S. Garner, M. Rex, and Ruth Turner. Biological observations centered around a bottom station at a depth of 2043 meters. In the same location four geology dives were made by investigators N. James, R. Hooke, and W. Schlager (83). Four more biology dives followed; observers were J. Staiger (84), C. Messing, K. Sulak, and P. Colin. After a number of engineering dives which occupied the first two weeks of May, a series of five geology dives were made by observers G. Keller, W. Stubblefield, G. Lambert, P. Fox, and G. LaPiene. These dives, under NOAA funding, were made in an area just west of Great Abaco Island, Bahamas. Dive No. 569, one of this series, was the first ocean dive to a depth of 12000 feet. Two biology dives were then conducted by scientists J. Musick, C. Wenner, and D. Markle for NSF. Late in June investigators G. Keller (85), R. Cooper, J. Uzmann and D. Lambert made four dives for NOAA during which

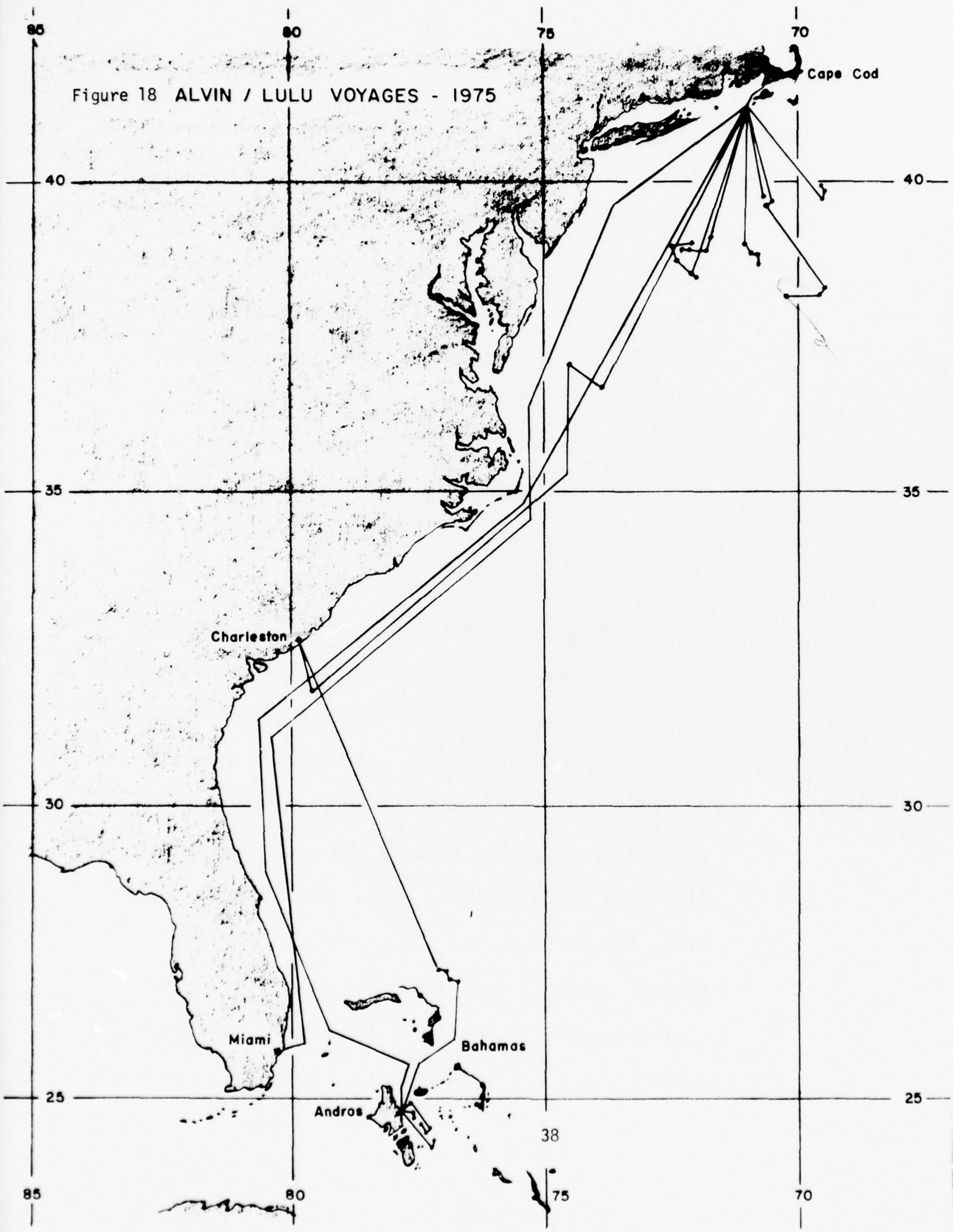


Figure 18 ALVIN / LULU VOYAGES - 1975
85
80
75
70
Cape Cod
40
35
30
25
Charleston
Miami
Bahamas
Andros

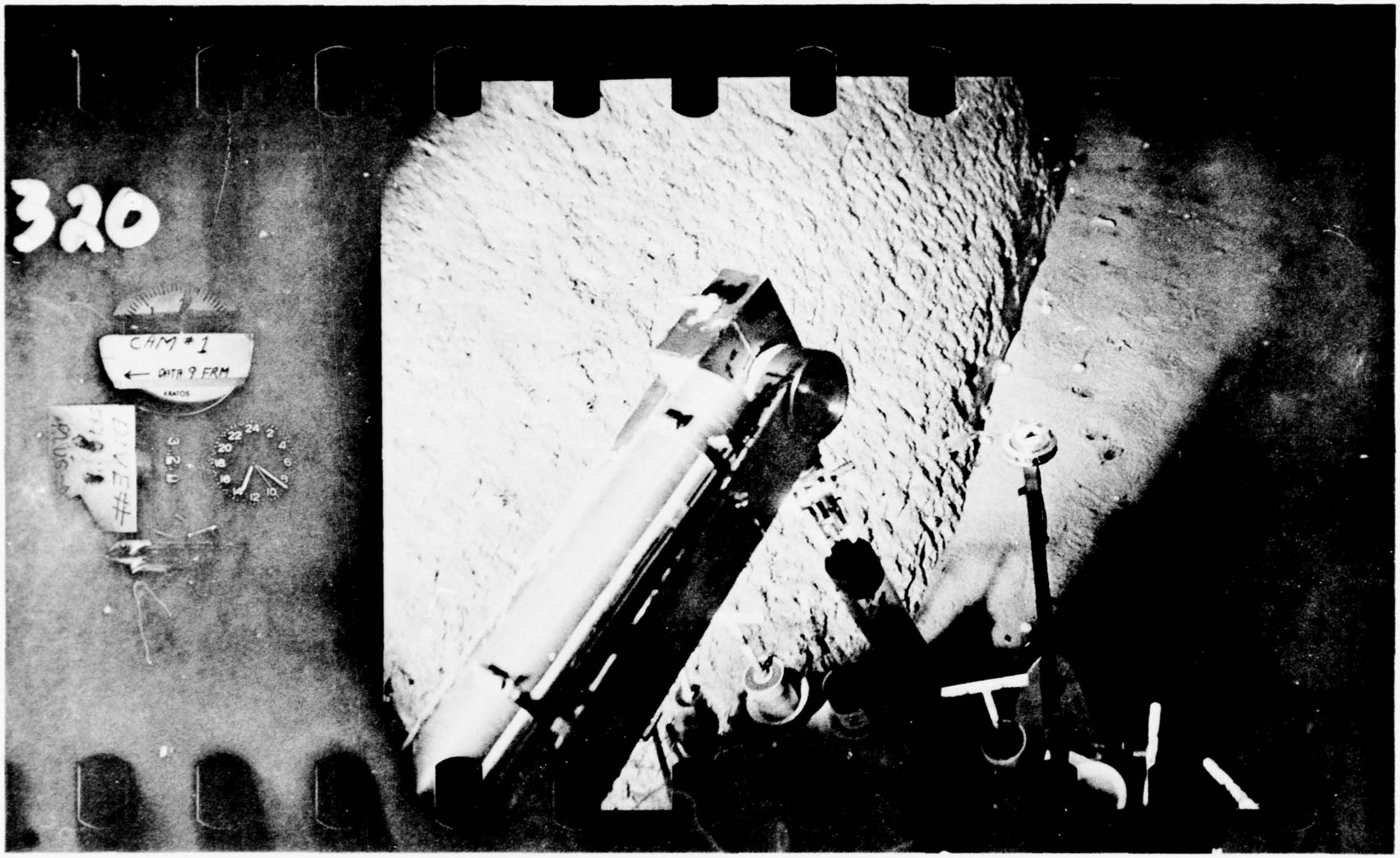


Figure 19 ALVIN Off Cape May, New Jersey at 2000 m. Inspects Intersection of Canyon Wall With Sedimentary Bottom

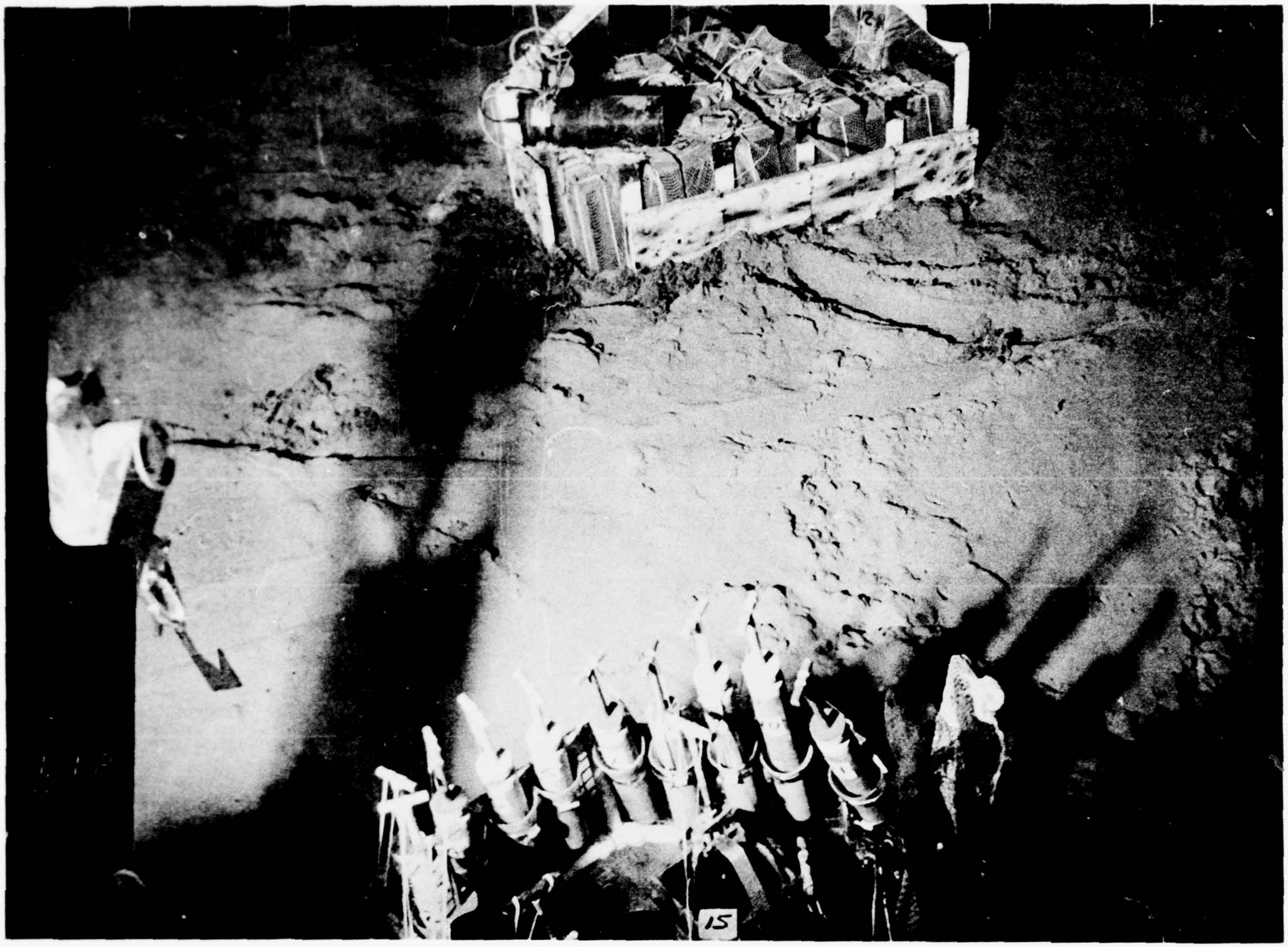


Figure 20 "Wood Islands" Introduced Into Deep Sea Environment for Studies of Wood Boring Bivalve Mollusks, September 1975 (Turner) biological and geological observations were made. Three biology dives followed in early July in which scientists K. Smith, C. Wirsen (86, 87, 88, 89) M. Rex, F. Grassle, and R. Carney took samples, recovered a prior-installed bottom station tower, and set two new towers. Later, ten biology dives were sponsored by NOAA in which investigators R. Dyer (90), D. Cohen, H. Clifford, D. Pawson, J. Musick, R. Gibbs, and C. Karnella located radioactive waste containers and made a survey of the dump site about 150 miles east of Cape May, New Jersey. Also during this series, biological characterization studies were conducted, and a scattering layer species count was made. Biology work continued during late August and early September with a series of eleven dives. These dives were made in the Hudson Canyon area. Activities included the emplacement of wood specimens, pingers, and mud boxes. In addition, core samples were taken and a sediment trap was recovered. W.H.O.I. scientists G. Rowe, R. Turner, P. Polloni, K. Smith, H. Sanders, N. Staresinic, and R. Harbison made these dives, accompanied by D. Cacchione of the U.S.G.S. and A. Malahoff of ONR. Cacchione, Rowe and Malahoff (91) have reported on some of the work accomplished during this series, which brought the 1975 operating season to a close.

1976 - Test and training dives were made in Woods Hole and in the harbor at Guantanamo, Cuba, during which post-overhaul checkouts and certification testing were completed. Late in January, geological work funded by NSF began in the Cayman Trench. Scientists R. Ballard (92), J. de Boer, J. Fox, R. Wright, W. Sullivan, K. Emery, T. van Andel, J. Corliss and photographer E. Kristof participated in these 15 dives in which some 500 pounds of rock samples were collected. The St. Croix Range studies began in mid-March with observers Dill, Gardner, Sutherland, Ballew, Williams, and Kirkpatrick involved in inspections of underwater installations for the U.S. Navy. Early in April Dr. Bruce Heezen assisted by M. Rawson, W. Nesterhoff, and R. Lynde conducted a series of geology dives in waters off Puerto Rico and the Dominican Republic. Later, Dr. Ruth Turner made two biology dives in the Tongue of the Ocean. Further inspection and search activities for the U.S. Navy followed, and the spring operating season ended on 28 April with dive number 653.

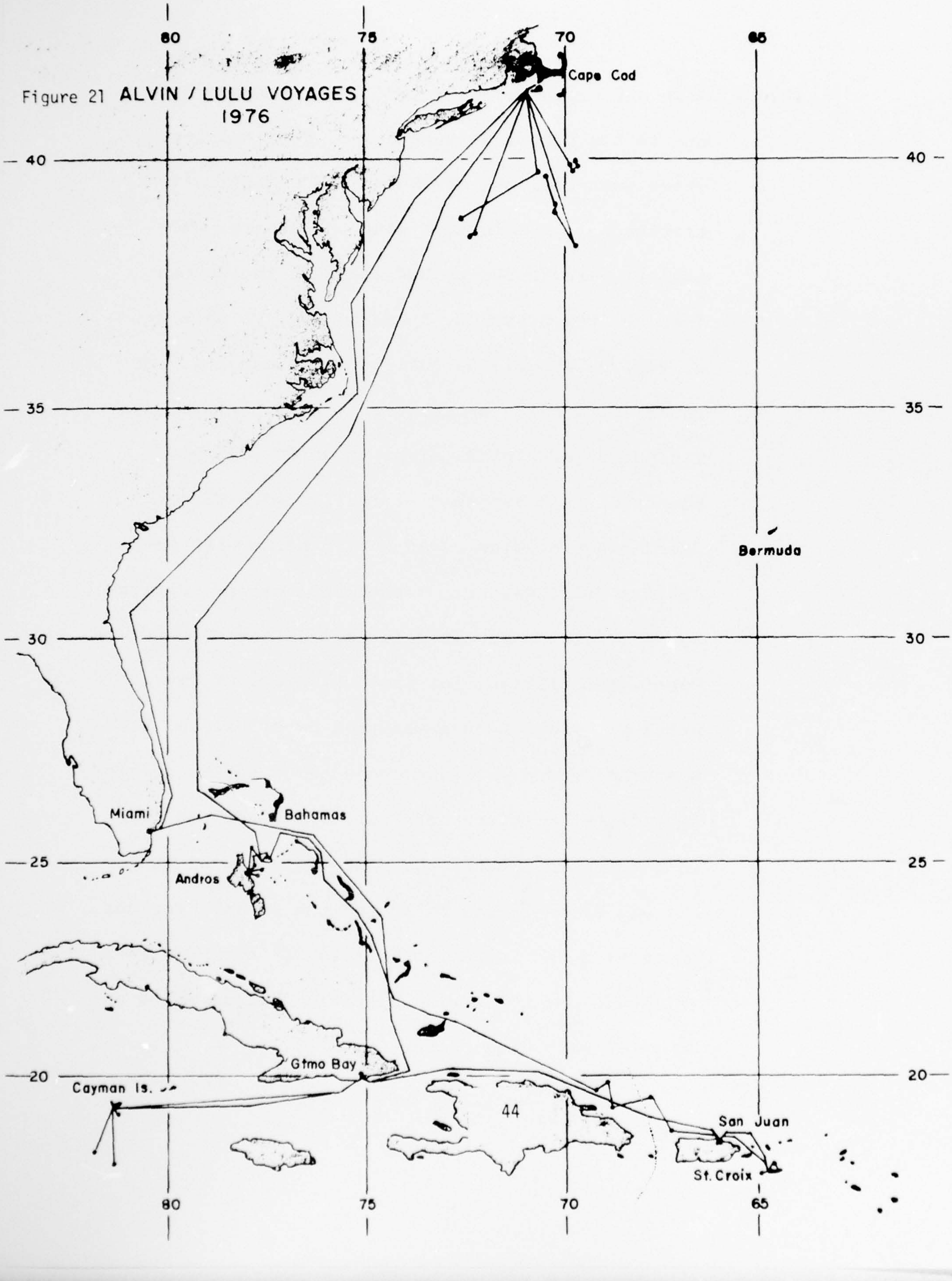


Figure 21 ALVIN / LULU VOYAGES
1976
80
75
70
65
40
35
30
25
20
Cape Cod
Bermuda
Miami
Bahamas
Andros
Gtmo Bay
Cayman Is.
San Juan
St. Croix

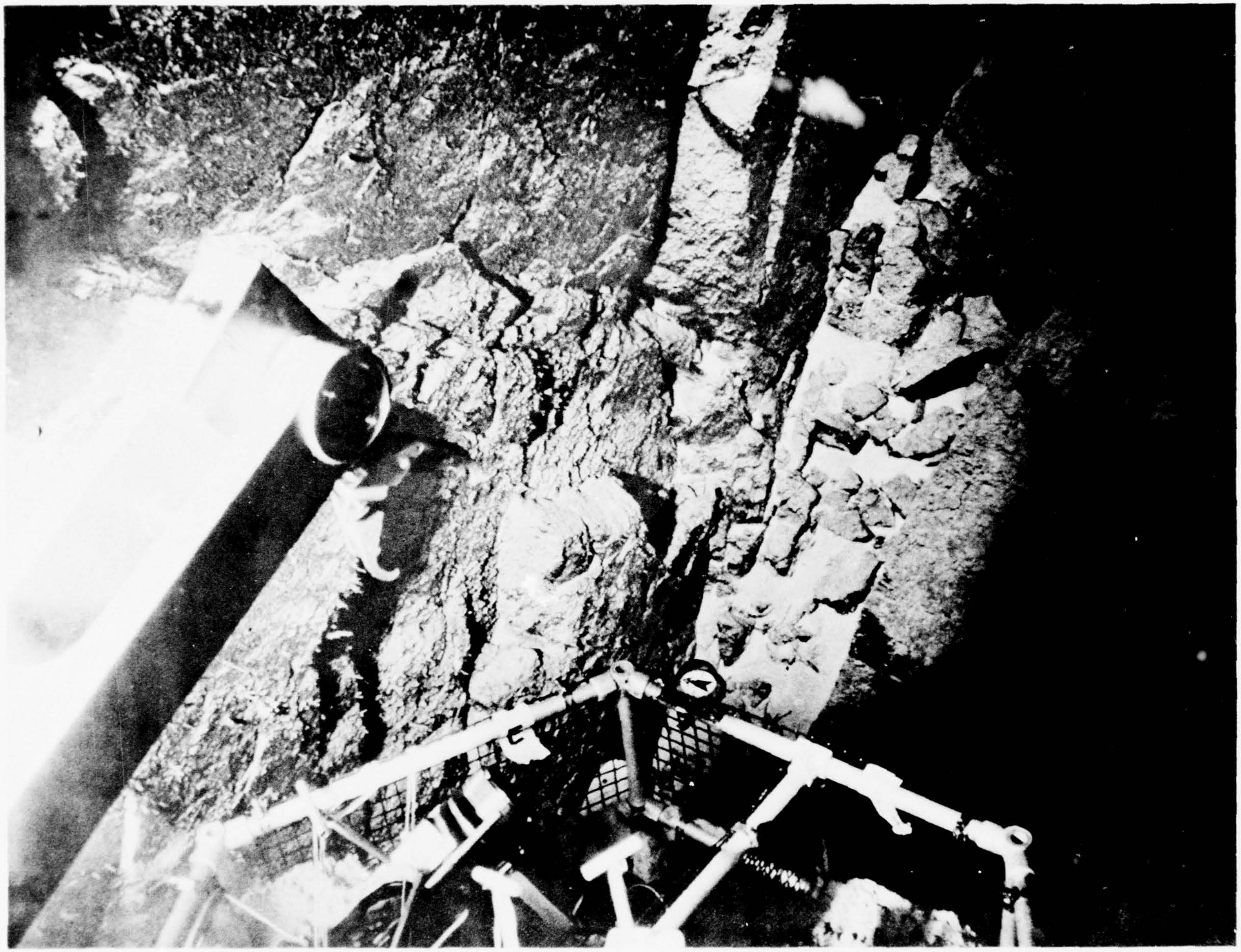


Figure 22 Near-Vertical Face of 6000 Foot Scarp in Cayman Trough Presented Scientists With a Window into Earth's Interior, February 1976

III. List of Scientific Publications

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IV. Summary of U.S. Navy Dives

U.S. Navy utilization of ALVIN began early in the life of the submersible. Almost as soon as the vehicle had been made operational and the personnel fully trained, engineers from the Navy Underwater Sound Laboratory were making dives in the Bermuda area for underwater acoustic studies. Cobb (1) reported on these activities conducted in August and September of 1965.

The loss of a nuclear weapon in the crash of a U.S. military aircraft off the coast of Spain in early 1966 brought ALVIN and LULU to the scene at the Navy's request. Working with Reynolds Metals' ALUMINAUT, ALVIN made 35 dives during the search. The weapon was found at a depth of 1900 feet, and the successful recovery operation took place on April 7, 1966.

Further Navy dives were made in the Bermuda area early in July 1966. Mullarkey and Cobb (2) presented the results of the ARTEMIS module inspection conducted during that period.

In late July 1966, R. Austin (3) of the Naval Underwater Weapons Research and Engineering Station participated in three ALVIN dives near Goulding Cay, Bahamas, to inspect and photograph an AUTEC cable.

Figure 23 ALVIN Locates Parachute in Search for Lost Hydrogen Bomb, April 1966

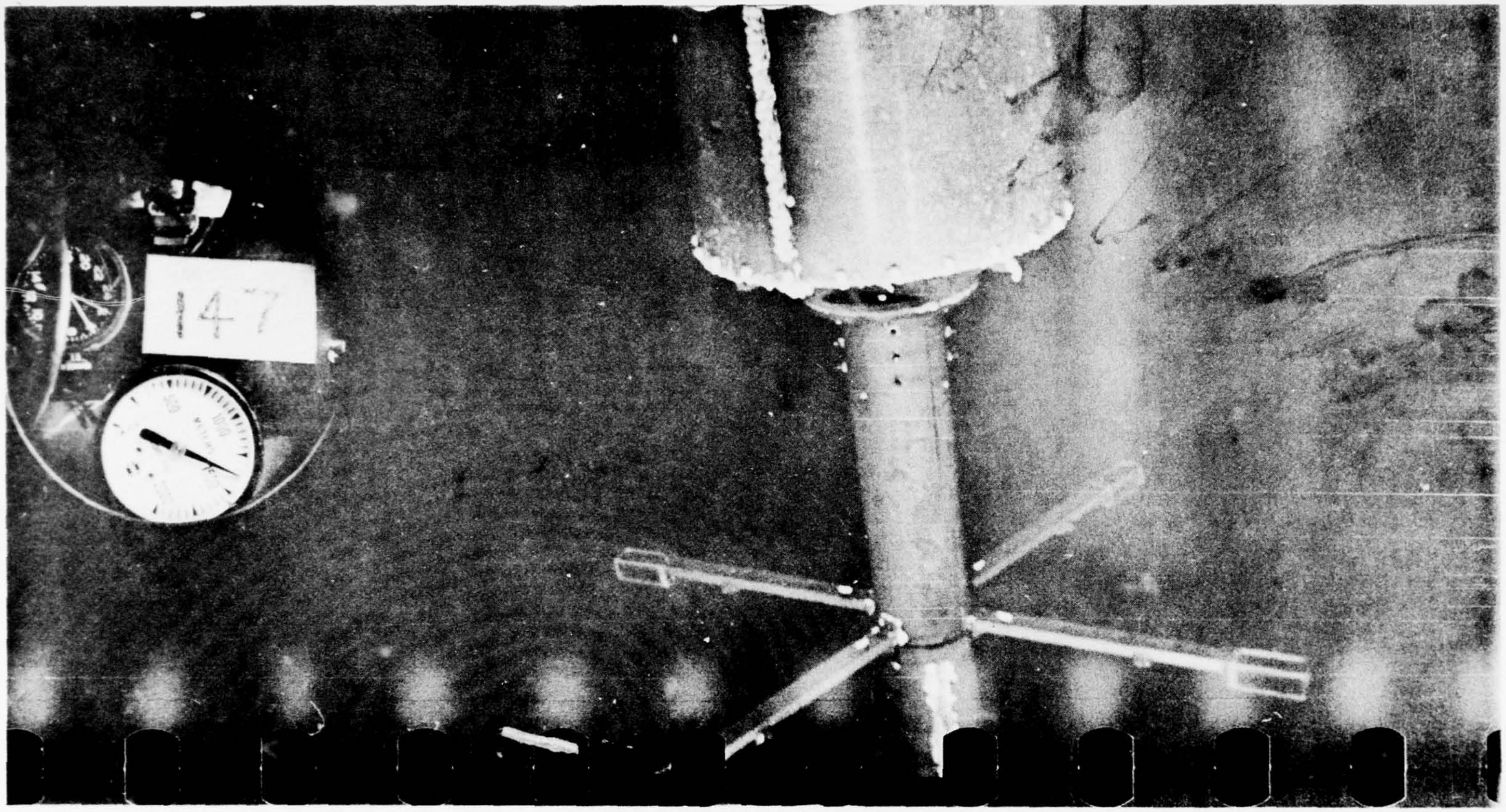

Figure 24 Photographic Inspection of Underwater Acoustic Equipment for U.S. Navy, July 1966

In August and September of 1966 the Tongue of the Ocean in the Bahamas was the scene of underwater acoustic studies by personnel of the Naval Oceanographic Office. Busby and Merrifield (4) and Breaker and Winokur (5) reported on the observations and measurements made during 15 ALVIN dives.

On October 24, 1967, D. Potter of the Navy Underwater Sound Laboratory accompanied by W. Marquet of W.H.O.I. made measurements of ALVIN's radiated noise when submerged. Howell and Gouzie (6) reported the results of this investigation.

Lt. Cdr. J. D. Donnelly (7) of the Office of Naval Research summarized ALVIN's scientific activities for the year 1967.

A seamount survey was conducted near the Azores during August and September of 1968. Navy Underwater Sound Laboratory personnel made 12 dives to survey the geological features of this Mid-Atlantic Ridge area. Ellinthorpe and Malone (8) have reported on these dives.

The loss of ALVIN occurred in October 1968, and the recovery was completed in August 1969. A 145 page report on the recovery operation was prepared by the Naval Ship Systems Command (9).

More recently, inspections, surveys, and recoveries of naval equipment have been conducted in the Tongue of The Ocean and nearby areas. The Naval Undersea Center, The Naval Facilities Command and the Naval Air Development Center participated in these dives, which utilized a portion of each diving season during the period 1974 through 1976.

J. M. Ford (10), Public Relations Officer at the Naval Ship Research and Development Center, summarized the rebuilding of ALVIN under Project TITANES, emphasizing the major role of NSRDC in the total program.

G. Reem (11) of Raytheon Corporation accompanied ALVIN and LULU to the AUTEC Range, Andros Island, in 1975. He has described three new systems that have improved ALVIN's capabilities: the Wide Angle Illumination System, the Modular Sonar, and the Self-Contained Ancillary Modular Platform.

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VI. Engineering Research and Development

Since the beginning of the manned deep-submersible program at Woods Hole, Institution engineers, as well as specialists from U.S. Navy laboratories and private industry, have contributed much to the design, testing and maintenance of ALVIN. As diving experience has accumulated, operational and safety requirements have become more clearly defined. In meeting these requirements ALVIN staff engineers have from the start been involved in programs of structural and instrumentation redesign to upgrade vehicle capability and increase safety.

There have been stress analysis and structural design studies required almost continuously during the life of the submarine ALVIN. Requirements for improved buoyancy systems, increased depth capability, a seawater variable ballast system, greater payload, better visibility and improved freeboard, to name a few, have generated challenging problems in these areas. Similarly, the need for greater reliability and flexibility in ALVIN's electrical systems, and the necessity for improved underwater navigation techniques, have presented ALVIN's electrical and instrumentation engineers with a variety of design and development tasks.

The following paragraphs present a brief description of some of the engineering work done in support of ALVIN. Space does not permit detailed discussion, nor does it allow coverage of all of the tasks undertaken. The list of technical reports following this section hopefully provides a comprehensive view of the total engineering effort.

Emergency Forebody Release

During the initial shallow water trials of ALVIN certain difficulties were experienced with the forebody release device. Actuating the release caused galling of the mating stainless steel threads of the main shaft. Also, it was seen that because the shaft projected several inches below the end of its main bearing, there existed a possibility for high bending stresses in the shaft extension. In 1965 a new forebody release was designed and built in an effort to eliminate these problem areas. The new design uses no threads on the actuating shaft, and dissimilar metals are employed for contacting surfaces. The one-quarter turn cam fits closely against the hull wall so that the possibility of shaft bending is minimized. Later, a full-size accurately machined model of the release device was constructed for laboratory testing. Resistance strain gauges, attached at various points on the model, provided data for force and stress determinations for a number of loading conditions. In another series of laboratory tests, full-scale side forces (as predicted by the earlier tests) were applied to an actual release shaft using a compression testing machine, and actuating torques were measured directly. The test results give increased assurance that the release device has adequate structural strength, and that the forebody, in an emergency, can be released with nominal effort.

Titanium Buoyancy Spheres

The original variable ballast and fixed-buoyancy spheres were fabricated from aluminum alloy. Close inspection after a period of use revealed that, despite the spheres' protective coating, a potential corrosion problem existed which could in time render them unsafe. Also, in collapse-pressure tests of four extra spheres, two of them imploded violently in a brittle-type failure. To correct this situation new buoyancy spheres were designed, and fabricated of titanium alloy 6Al-4V ELI. Seventeen spheres were obtained, 15 of which were installed in ALVIN. Two spheres were tested to destruction after careful monitoring of elastic and creep strains during the period of increasing external hydrostatic pressure. Test results indicated the minimum collapse pressure of the spheres to be 7500 psi.

Titanium Pressure Hull

Woods Hole engineers participated in the initial discussions relative to the structural design of the new titanium alloy pressure hull for ALVIN. Detailed design, fabrication and testing were done by various activities within the U.S. Navy. The new hull, fabricated from titanium alloy Ti-6Al-2Cb-1Ta-0.8Mo (Ti-621/0.8) has the same outside dimensions as the original HY-100 steel sphere. Two hemispheres were hot press formed from flat plate, machined outside and inside, and welded together. The hatch and viewports are located in thickened inserts designed to be welded into, and blend with, the basic spherical shell. The new wall thickness is nominally two inches, or about 50 percent greater than that of the steel hull. A final hydrostatic pressure test of the entire submersible with the new pressure sphere was conducted at the Naval Ship Research and Development Center (N.S.R.D.C.) Annapolis facility with Woods Hole personnel participating. A second hull identical to the one installed in ALVIN was intended to be tested to destruction. Tests of this duplicate hull were done at the N.S.R.D.C. Carderock Laboratory. They included three static pressurizations, ending with a 24 hour hold at 13,200 feet; 6000 cycles of pressure, varying between 300 and 12,000 feet; and a creep-strain test with 72 hour holds at 18,000 feet and 19,100 feet, and a 10 hour hold at 22,500 feet. Prior calculations based on sphericity measurements had led to a prediction of collapse at a pressure equivalent to 19,035 feet. The test was terminated after the 10 hour hold at 22,500 feet and the hull and all of its attachments were closely examined. No damage of any kind was detected in the hull, the electrical penetrators, the viewports or the emergency sphere release mechanism.

Titanium Electrical Penetrators

While the new pressure hull was being designed and built at the Mare Island Naval Shipyard, engineers of the ALVIN organization in Woods Hole had the responsibility for designing and procuring the electrical penetrators for the new sphere. The new penetrators were modelled after the stainless steel units previously used in the original steel pressure hull. Certain modifications were introduced, both to conform to

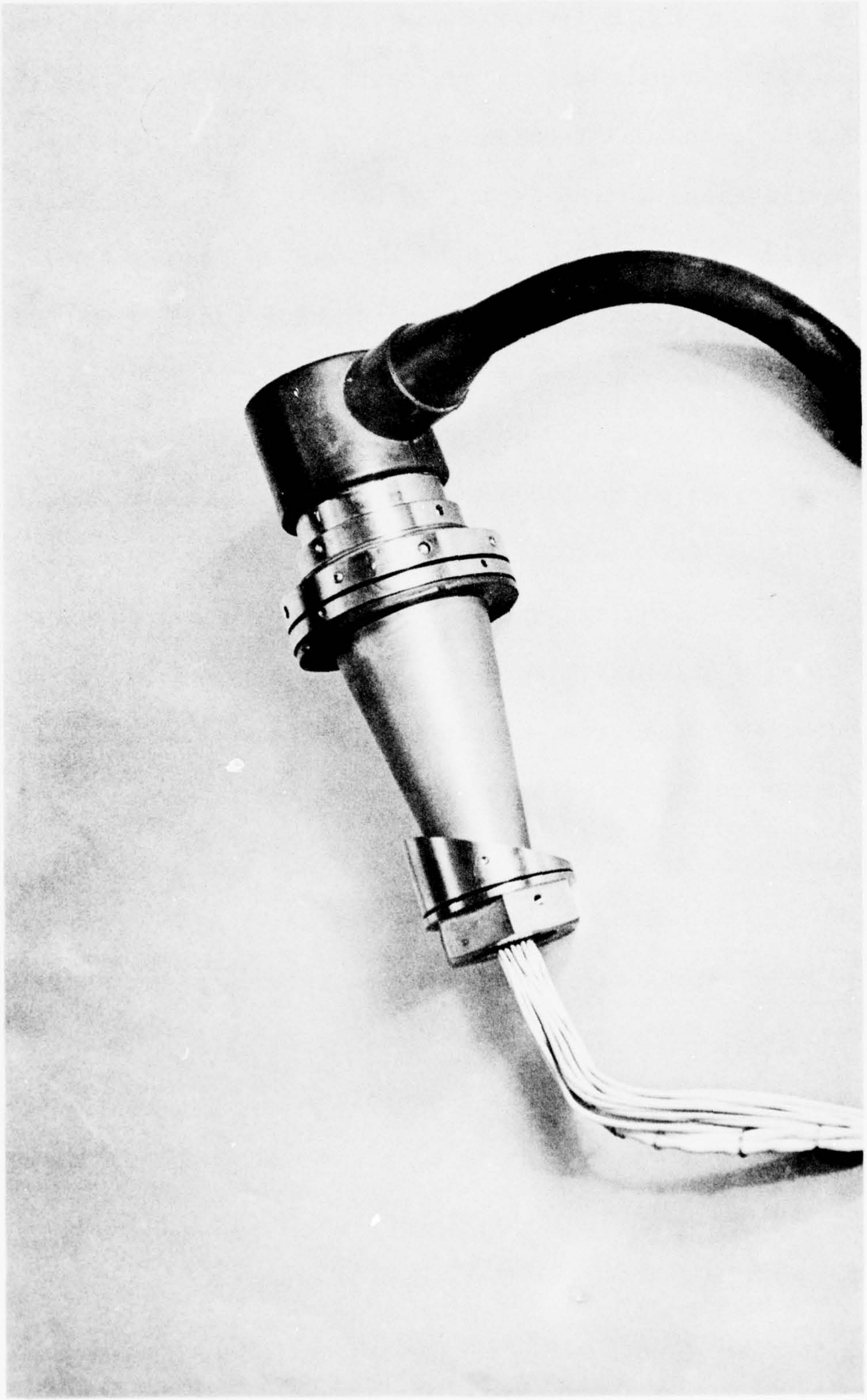

Figure 25 Titanium Through-Hull Electrical Penetrator

recently adopted U.S. Navy requirements, and to gain improved performance. Thus, the titanium penetrators have two separate pressure barriers instead of the original single barrier, the through-barrier contact pin design has been improved, and the outboard cables enter the penetrator at right angles to the penetrator axis. In addition, a 29 degree stub Acme thread is used for the inboard retaining fastening. This low-profile thread is recommended where heavy loads may be encountered but where space is limited. In the present application it provides a very strong thread with a minimum of reduction in neck diameter, with the result that maximum neck tensile strength is achieved. For the verification of mechanical and electrical design, two prototype penetrators were built and tested. Following the successful testing of these units an order was placed for 24 production penetrators. Because of the taper of the penetrator body ALVIN engineers were concerned about the possibility of a squeeze-out action caused by the hull wall compressive stress. Extensive testing was done, with laboratory models, and with the actual penetrators installed in the hull, at sea and during tank pressurizations. Dial gauges were used to measure possible penetrator movement and electric resistance strain gauges were employed to monitor thread neck stresses. All test results indicated that penetrator tensile loading due to squeezing action by the hull is very small or non-existent.

Submerged Navigation

In 1971 a program was initiated at Woods Hole to develop a submerged navigation system. Objectives were to provide real-time readout and graphic display of relative positions of a surface support ship and a submerged vehicle or instrument. A system has evolved in which these positions are determined relative to a network of two or more bottom-moored acoustic transponders. The primary test vehicles have been the submersible ALVIN and the support ship LULU. Each of these vessels carry precision clocks that are synchronized before each dive; these act as controllers for the system. At 15 second intervals ALVIN and LULU alternately transmit signals at 8.1 kHz to call the reference transponders. ALVIN also transmits at 12.5 and 13.5 kHz to send LULU slant range and depth information by telemetry. During tests in early 1974 it was noted that with ALVIN working very near the bottom, direct acoustic paths between submersible and transponders often were blocked

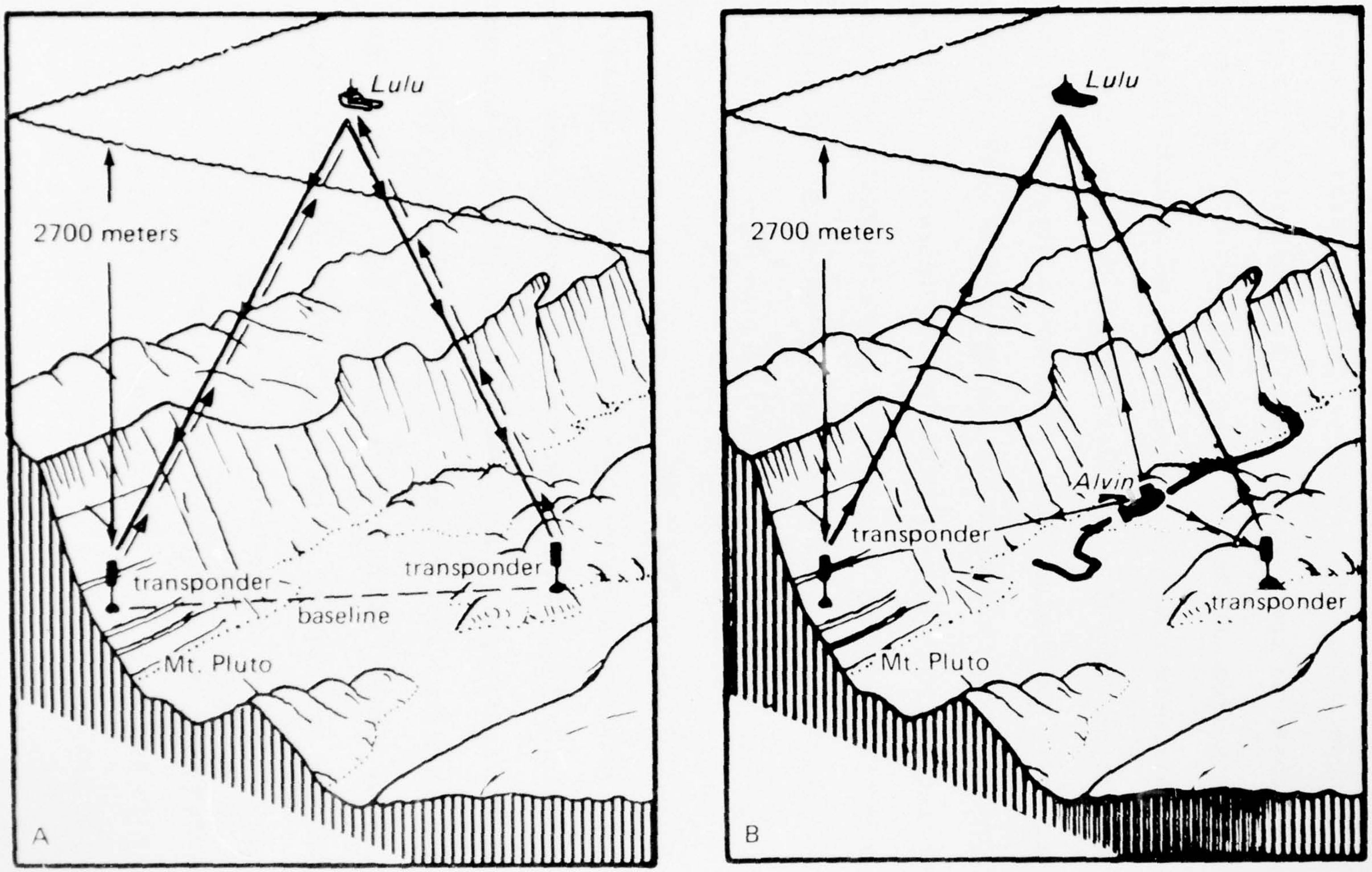

Figure 26 ALVIN-LULU Submerged Navigation System

by bottom topography. However, in those cases operators also observed that signals could be transmitted via reflection from the sea surface. The system's computer programs were consequently rewritten to include the capability to identify, and distinguish between, direct and surface-reflected signals. This new addition to the navigation system has extended its usefulness significantly. During the Mid-Atlantic Ridge FAMOUS operations it was found that bottom irregularities were so great that about one-half of the total number of bottom track positions were made possible by the new "surface bounce" technique.

Spherical Sector Viewports

Under an agreement between the Woods Hole Oceanographic Institution and the Naval Undersea Center in San Diego, California, that laboratory manufactured and tested six spherical sector acrylic plastic viewports intended for use in ALVIN. Because of their spherical shape the new windows are claimed to be structurally superior to the plane-surface conical windows presently in use. All six units were proof-tested at a pressure equivalent to a depth of 13,500 feet. Two were selected for severe testing; these will not be used in ALVIN. One of these was subjected to 30 consecutive cycles to a pressure equivalent to 13,500 feet. The other was pressurized to 45,000 feet (almost four times the operating depth of ALVIN) and held there for 100 hours without failure. Optically, the new viewports afford a much wider field of view than that provided by the plane windows, but viewed objects appear farther away. The plane windows show a more nearly life-size image and are preferred by ALVIN's pilots for normal operations. The spherical ports offer greater structural strength, and wide viewing that could be highly desirable in some situations. A design study is currently under way to develop an auxiliary lens capable of converting the spherical viewport's image into one which approximates that of the plane window. This extra lens, mounted inside the personnel sphere, will be for optional use, and removable by the viewer.

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ALVIN, a deep-submergence oceanographic research submarine, is owned by the Office of Naval Research of the U.S. Navy and operated by the Woods Hole Oceanographic Institution (W.H.O.I.). Completed in 1964, it began routine diving for scientific research in 1966. Since that time the submersible has made over 650 dives in many areas of the Atlantic Ocean including the Azores, Spain, the Bahamas, the Straits of Florida and the Gulf of Maine. Many of the dives have been for vehicle test and training purposes, and a significant number have been required by the U.S. Navy for various engineering and salvage operations. These activities are summarized briefly and a short list of related Navy reports is given. Extensive engineering research and development in support of the ALVIN project has been provided by personnel from W.H.O.I., U.S. Navy laboratories and private industry. Over 100 technical reports and papers have been produced as part of this effort and they are listed here. Nearly 300 dives have been completed for purely scientific purposes. These latter dives are described briefly in chronological order, and a list of 92 of the resulting scientific publications is presented.

1. ALVIN, 12,000 ft. research submersible
2. Deep submergence vehicle ALVIN
3. Bibliography, ALVIN-related science

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