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WHOI-82-41

TECHNICAL ACTIVITIES ASSOCIATED WITH AN EXPLORATORY ARRAY  
IN THE WESTERN NORTH PACIFIC

by

Keith F. Bradley

WOODS HOLE OCEANOGRAPHIC INSTITUTION  
Woods Hole, Massachusetts 02543

September 1982

TECHNICAL REPORT

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N. P. Fofonoff, Chairman  
Department of Physical Oceanography

Abstract

Operations activities of the Woods Hole Oceanographic Institution's Buoy Group for an exploratory array of deep-ocean moorings in the western North Pacific Ocean are described along with specific engineering notes associated with high-current deep moorings. The array, along 152° E. from 28° N. to 41° N., was in place for about two years. After one year the array was successfully recovered and redeployed. Brief summaries of each of three research cruises are provided. An Appendix lists details of the twenty moorings including positions, dates deployed and recovered, instrument types and depths and moored station numbers which are required for specific data retrieval by investigators. The initial scientific publication has been prepared by Schmitz, et al (1982).

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Technical Activities Associated with an Exploratory Array  
in the Western North Pacific

by

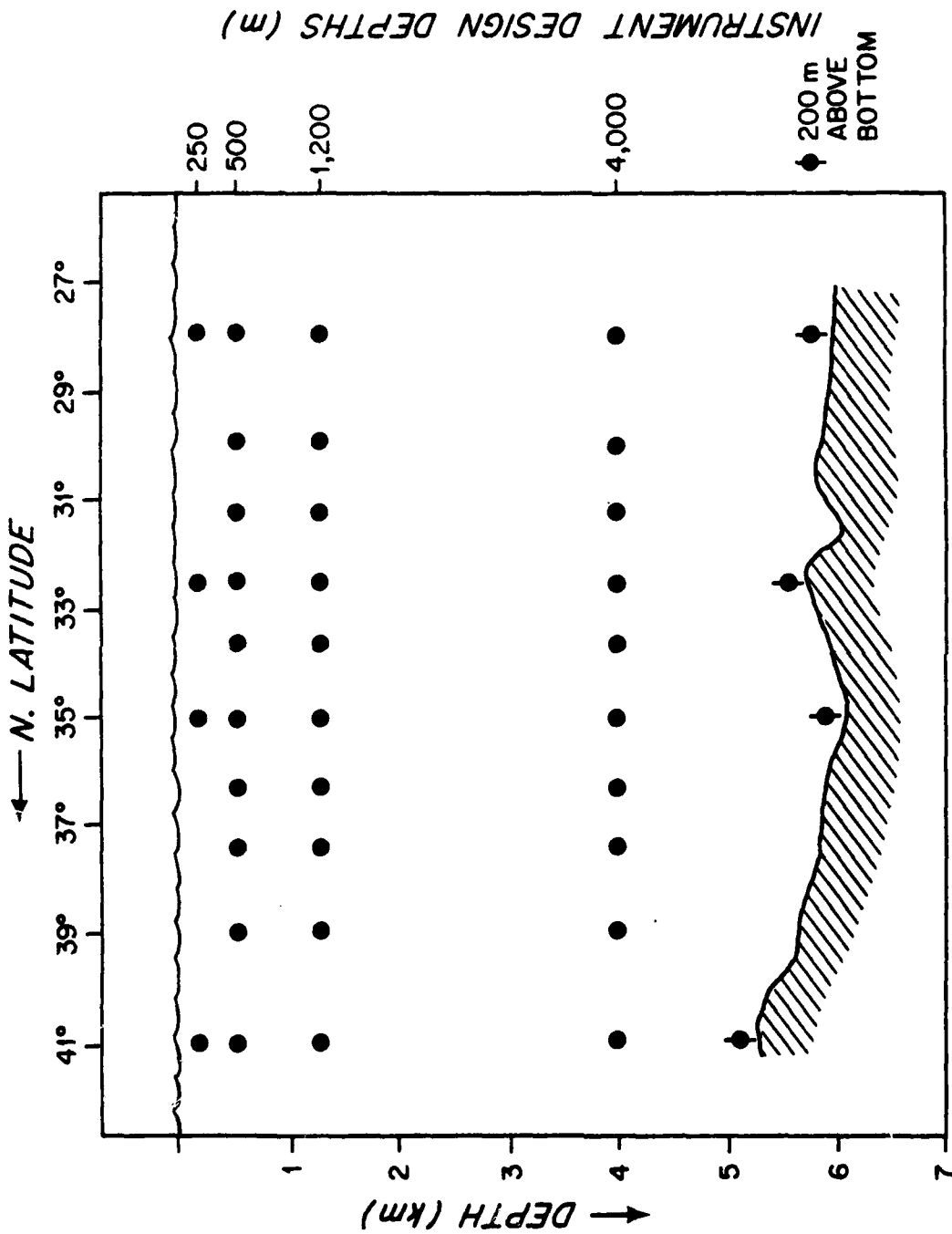
Keith F. Bradley

Introduction

An exploratory array of deep ocean moorings with recording current meters was designed under the guidance of Dr. William J. Schmitz, Jr. of the Woods Hole Oceanographic Institution (WHOI). This array, installed along 152° E. longitude from 28° N. to 41° N. latitude, was intended to be in one of the most energetic segments of the western North Pacific. In addition it was the first highly instrumented, long-term investigation of deep circulation using moorings set across the mid latitudes of the North Pacific Ocean.

The array included instrumentation from 250 meters below the surface to 200 meters above the bottom. Thirty-eight current meters were to be placed at discrete depths at ten mooring sites. The desired instrument placements along 152° E. are shown in Figure 1. The goal of a two-year record for long-term, low-frequency studies was accomplished using two settings of the array of one year's duration each. The initial deployment (cruise #1) in July of 1980 from the R/V THOMAS WASHINGTON was followed by a successful recovery and redeployment on the same ship (cruise #2) in May of 1981. The final recovery (cruise #3) was conducted from the R/V THOMAS G. THOMPSON in June of 1982.

In addition to the deployments and recoveries of the moorings each cruise conducted CTD lowerings at the mooring sites, at pre-selected sites between moorings and fifteen miles north and south of the array; and XBTs were



SECTION ALONG 152° E

Figure 1

Desired Current Meter Placements Along 152° E. for the Western North Pacific Array

launched at discrete intervals along the ship's track. On cruise #1 a CTD survey was conducted to the west of 152° E. in and out of a region of the Kuroshio Extension as defined by the 15° C isotherm at 200 meters depth. On cruise #3 an XBT survey was conducted north of the array.

At this time, analysis of the data from the second one-year deployment is under way. Current-meter performance was reasonable. A paper on the first one-year setting has been accepted by the Journal of Geophysical Research (Schmitz, et al, 1982).

#### Mooring Description and Design

Design parameters were developed by the principal investigator detailing the type of instrument required and the instrument-depth placement for each mooring site. For the first setting all instruments were Vector Averaging Current Meters (VACM) which record current speed and direction along with water temperature. In some positions VACMs were used which also record pressure changes due to vertical instrument movement caused by deflections of the mooring due to ocean currents. Nine of the thirty-eight instruments for the first setting were provided by the University of Miami. For the second setting some of the original WHOI current meters were turned around at sea, some fresh VACMs were installed and ten EG&G 850-style instruments (at the 4,000 meters level) were used. The type of instrument and its depth placement at each site for each setting is given in the Appendix. For the design process ocean depths at each site were estimated after a review of available topography charts.

For the individual mooring designs an interactive mooring-design computer program was used (labelled NOYFB [Moller, 1976]). The water depth is entered into the program along with the types and location of mooring components to be used (i.e., glass-ball flotation, type of mooring cable, anchor size, etc.). After a static (no-current) design is developed its performance with various given vertical current profiles is calculated using NOYFB. Current profiles used in design work included: 1) The MODE (Mid-Ocean Dynamics Experiment)/POLYMODE profile (Bradley, 1981); 2) an estimated design profile for the western North Pacific array; and 3) a worst-case survival profile for this array. The depths and speeds of these profiles are given in Figure 2. For the survival case computer analysis indicated that the combined static and dynamic anchor loading exceeded the dead weight horizontal holding power of the Buoy Group's standard 3,000 lb. (wet) cast iron anchors assuming a bottom friction coefficient of 0.5.

The solution was the use of a new specifically designed "MACE" anchor (Bradley, 1980) for all but the southernmost site where large currents were not expected. Simply using a larger anchor would necessitate a larger-diameter mooring cable to withstand launch tensions during an "anchor-last" launch. This in turn would require more flotation to optimize wire tension and total mooring performance. The added drag from the flotation and bigger wire would require a still larger anchor, etc. Research on bottom conditions at each site and model testing by Henri Berteaux of the WHOI Ocean Engineering Department resulted in the design of a cylindrical anchor with flukes added at each end. Figure 3 shows this anchor on deck before launch. Its central core is a stack of three 1,000 pound (wet) discs with a fluke plate added top and bottom. Total weight is approximately 3,400 pounds. (To

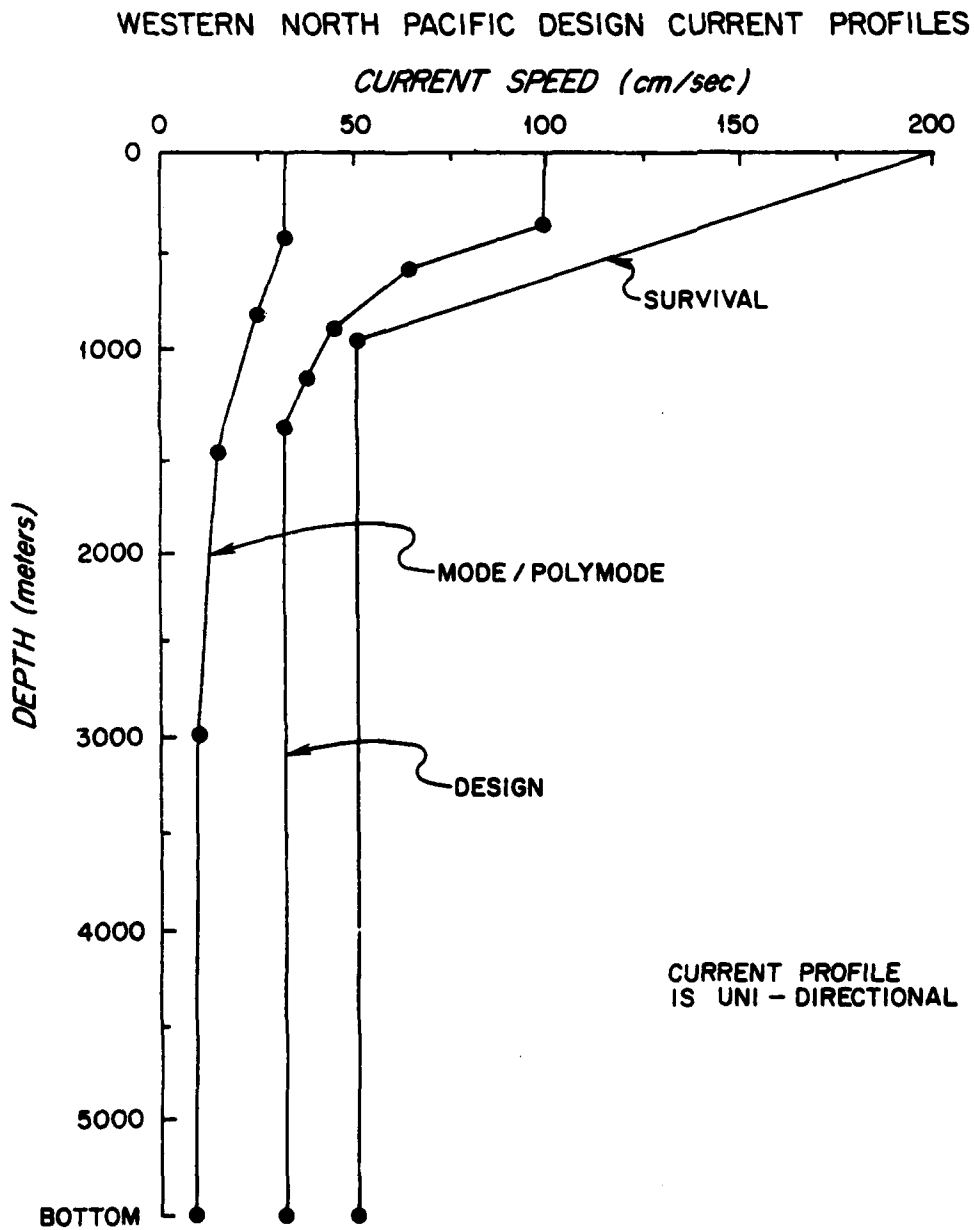


Figure 2

Current Profiles used to Design Moorings for the Western North Pacific Array

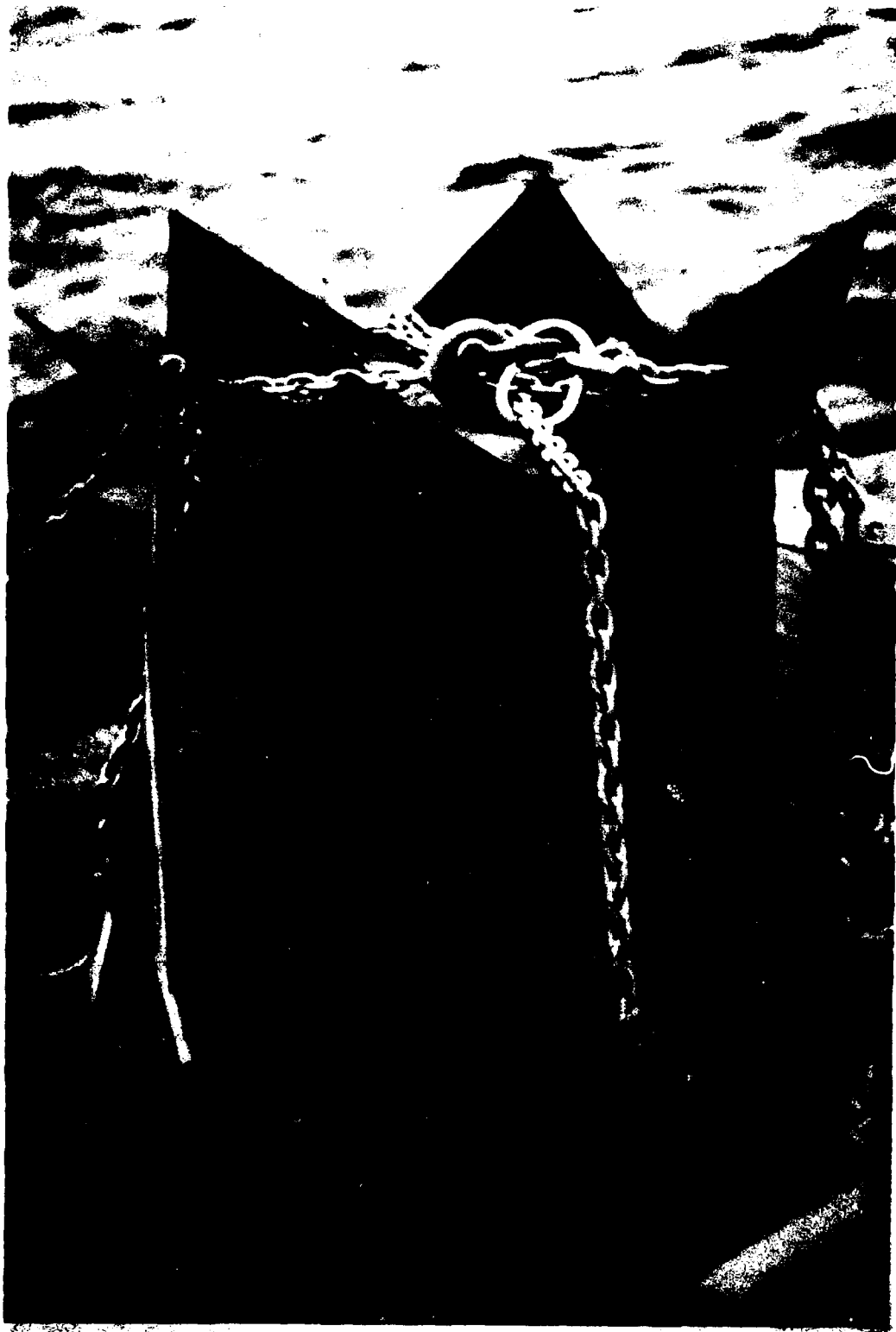


Figure 3

**MACE Anchor with Auxilliary Danforth Anchor attached**

provide inexpensive insurance a standard Danforth-style anchor was added.) Although bulky on deck the fluke plates stack neatly for shipping and are easily assembled to the core with the aid of a forklift truck at the departure port.

Two other engineering aspects of the project should be discussed: the use of a single large flotation sphere in high-current locations and the operational testing of Kevlar mooring cable. For many years the development of a light-weight, strong and reuseable yet less expensive cable has been an ongoing development program. Standard steel mooring cable of 3/16" diameter and 3 x 19 construction covered with a polyethylene jacket has proved to be a reliable long-term (greater than one year) mooring cable. However, it cannot be reused at its full initial strength after storage ashore, its weight places extra demand for flotation and it is relatively expensive compared to synthetics.

Kevlar mooring cable jacketed with Dacron for abrasion protection is a likely replacement. Due to its susceptibility to cutting it cannot be used above 2,000 meters of depth where active fish attack has been identified (Prindle, 1981). Moored Station 704 and its replacement mooring 718 used Kevlar cable (1/4" diameter, 6,000 pounds breaking strength) below 2,000 meters depth. After one year at sea on Moored Station 704 its strength had not diminished based on laboratory tensile testing and it will be reused on later deep-ocean experiments. Incidentally, some longer lengths of steel wire from the first setting were reused on the second array setting. The Kevlar line besides being less expensive than steel (\$1.30 versus \$2.53 per meter in 1982) reduced the buoyancy requirements from a similar all-wire mooring by fourteen glass spheres (Moored Station 718 versus 721) indicating added

potential savings in shipping, handling and inventory costs.

The Kuroshio Extension, somewhat analogous to the Gulf Stream in that it has a well-defined area of high-current surface water whose axis moves geographically with time, passes through the central portion of the array. The high currents expected would add stress to a mooring and depress instruments substantially due to the tipping of the mooring by drag forces. To help alleviate this and to further develop high performance moorings a large (five-foot diameter) syntactic foam sphere was incorporated into one of the central moorings that had a static instrument depth only 250 meters beneath the surface (Moored Station 699 and its replacement, 724).

Figure 4 is a detailed drawing of Moored Station 698 using all glass flotation with the top instrument at 500 meters, while Figure 5 is a similar drawing of Moored Station 699 with the sixty-inch sphere for top flotation and a top instrument depth of 250 meters. These represent two separate design philosophies. Station 698 (with all glass-sphere flotation) was called a "Floppy Moor" - below 1,200 meters the mooring is very stiff while the top has less tension, sacrificing instrument depth change in order to maintain fairly static deeper instrument placement. When the high near-surface currents of the Kuroshio are not present the upper group of instruments return to near design depth. A constant-tension glass-sphere mooring would exhibit poor performance in high currents at both upper and lower instrument depths. On the other hand the sixty-inch sphere design concept was to maximize the total mooring tension in an attempt to keep all instruments near the design static depth. The drag coefficient of a smooth sphere and the cross sectional area of the sphere is less than those of an equivalent cluster of seventeen-inch glass spheres; total tilt of the instruments and mooring, instrument depth

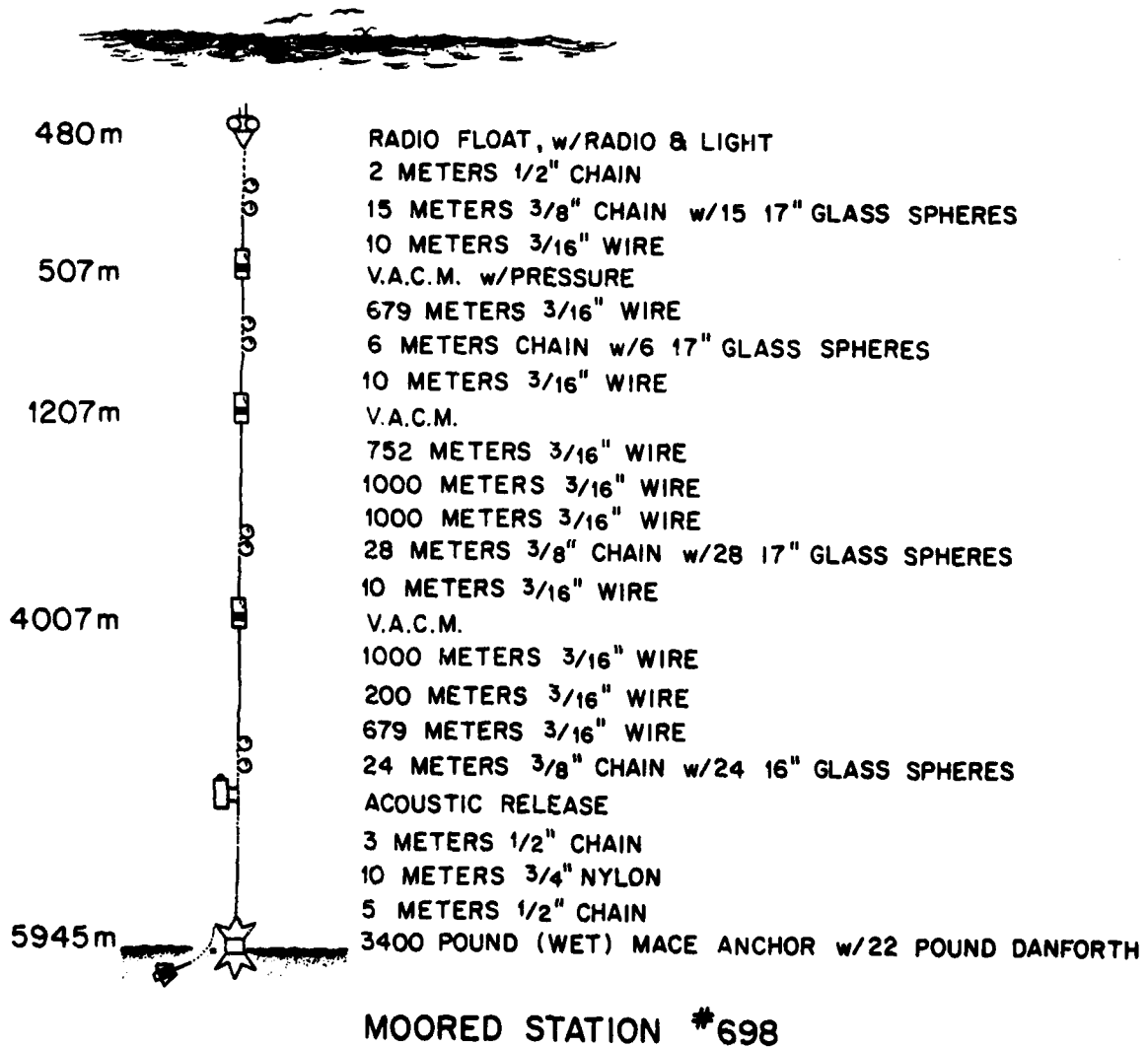
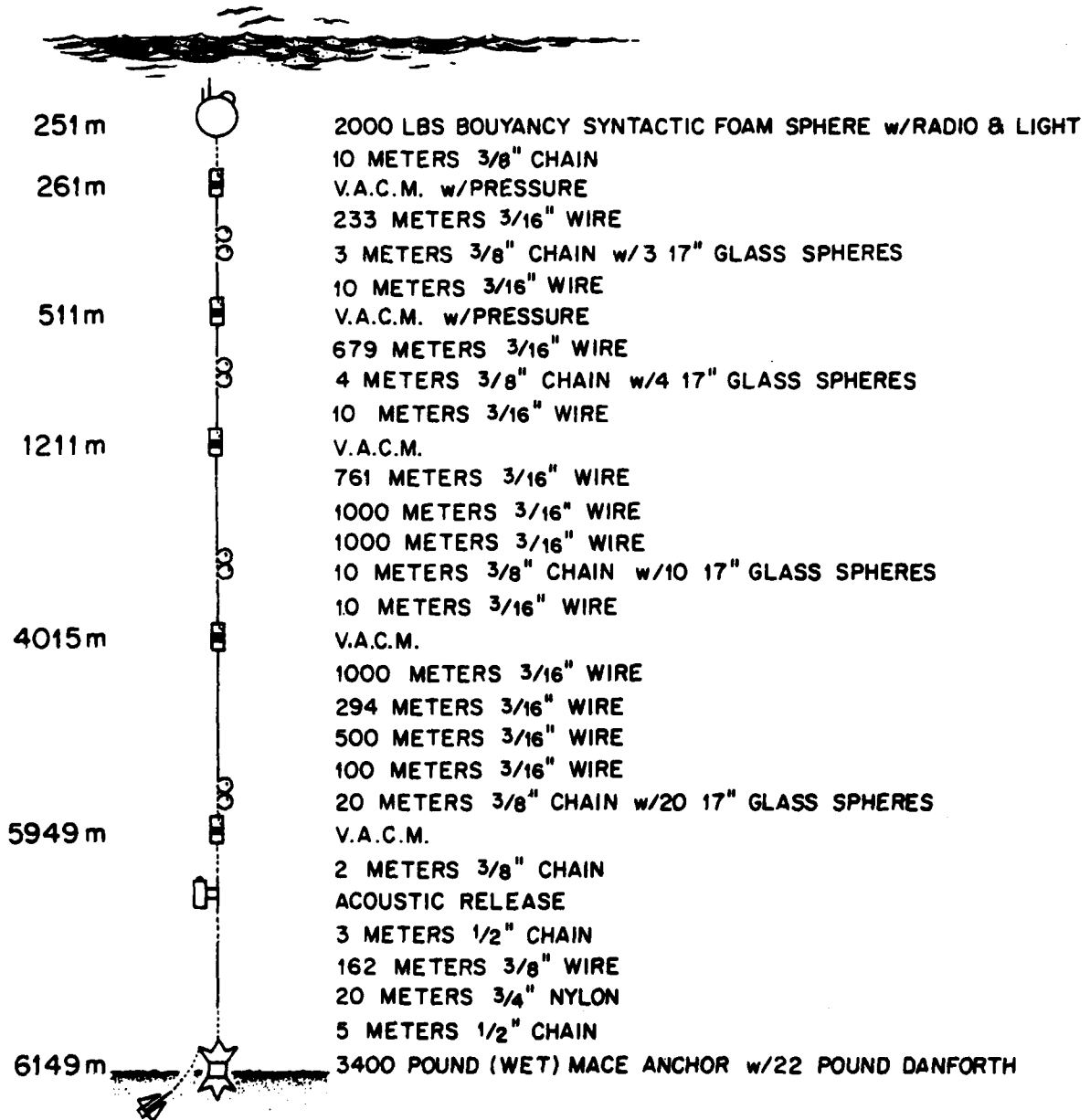


Figure 4

Western North Pacific Array Mooring #4. An Example of the "Floppy Mooring" Concept



**MOORED STATION # 699**

Figure 5

Western North Pacific Array Mooring #5. Constant Tension Mooring with Large Syntactic Sphere Main Flotation

change and drag at the anchor are reduced.

Data recovered from the first setting appears to validate the computer-generated analysis of both of these designs. Peter Clay of the WHOI Ocean Engineering Department has analyzed pressure and current speed/direction data from these two moorings. Maximum current profiles for the first setting didn't approach the design survival current profile and only at depths of 2,000 meters and more exceeded slightly the array design profile (35 cm/sec versus 30 cm/sec). Currents nearer the surface were generally less than the array design profile. Maximum mooring excursions did not appear simultaneously but current speeds corresponding to these excursions were similar. Maximum dip for the floppy design was 396 meters while for the large sphere it was 206 meters. Keep in mind that the floppy moor instrument's static depth is 500 meters compared to 250 meters for the large-sphere instrument and the large-sphere mooring reacted to higher currents nearer the surface. In addition over the length of deployment the sphere mooring maintained a fairly steady state depth level while the glass sphere mooring exhibited peaked responses to varying current profiles. Clearly the concentrated buoyancy of the large sphere provided superior performance in a near-surface high-current regime.

#### General At-Sea Operations

The shipboard procedures for deploying and recovering deep-sea intermediate moorings are described by Heinmiller (1976) in detail. The general deployment technique is to determine the actual depth at the launch site, compute and make the necessary changes to the adjustable sections of the mooring, move the ship at least a water-depth distance downwind and/or down current, turn around and begin deployment. The top of the mooring is payed

out as the ship heads back to the mooring site. If the mooring is all in the water (except the anchor), the mooring string is towed into position. If the site is approached before all components are in the water the ship is slowed so the launch site is not passed. At the designated site the anchor is launched and the mooring follows it down.

It is difficult to return exactly to the previously chosen position and depth. Because of this and the time required to make mooring adjustments the launch depth may be slightly different resulting in slight changes to the actual instrument depths compared to the desired design depth. The Appendix presents the designed instrument depths and the actual (zero-current) depth of the instrument as post-launch calculated using NOYFB, the actual depth and adjustments made to the mooring. The comparison of design to actual is an indication of just how accurate deployment can be. In general, accuracies of plus or minus ten meters are obtained (approximately 0.2% of water depth) for this array.

Navigation for the three cruises was primarily by satellite with occasional back-up from distant Loran-C stations. Ship drift during operations particularly in areas of the strong Kuroshio Extension current and the infrequency of satellite fixes prevented exact deployment positions at desired intersections (e.g. 152° 00' E., 35° 00' N.). During recovery operations the satellite system easily put the ship within acoustic listening range of the moorings.

All acoustic releases were tested before launch to a depth of 3,000 meters using a shipboard winch. They were tracked to the bottom on launch and later checked for acoustic performance before the ship left the area. One mooring, Moored Station 720 of the second deployment, was not recovered. When

the ship was at the recovery site no acoustic contact was made. A thorough acoustic and visual search around the area during excellent weather failed to locate the mooring. An electronics failure within the release is a likely cause of the loss.

Routine procedure for all three cruises was to conduct a full-depth CTD lowering at each mooring site and at selected intervals along 152° E. Difficulties occurred on each of the three cruises slightly limiting full coverage. Details, including data sources, are given in the three cruises summaries that follow.

XBTs were dropped routinely along the ship's track filling in between CTD stations. Some additional XBT work was done on cruises #2 and #3. Details and data sources follow in these cruise summaries.

Western North Pacific Array

WHOI Buoy Group Cruise Summaries

Cruise #1, R/V THOMAS WASHINGTON, RAMA Expedition, Cruise 4  
Yokosuka, Japan to Guam  
July 1, 1980 to July 21, 1980  
Chief Scientist, Keith F. Bradley

The science crew arrived at the U.S. Naval Station at Yokosuka, Japan on June 23, 1980 to unpack and prepare current meters, acoustic releases and mooring components before the ship's arrival. Previous contacts with the Naval Station through Office of Naval Research personnel had arranged Navy handling of shipped equipment and the use of electronics laboratory space provided by the Naval Mobile Technical Unit Seven. The Naval Supply Depot (NSD) provided assistance in securing all equipment sent by commercial carriers, Military Sealift Command and Military Airlift Command. All equipment arrived safely and its movement from warehouse to laboratory and to the ship was well coordinated by NSD.

The THOMAS WASHINGTON arrived in Yokosuka on June 25 completing RAMA Expedition Cruise 3 from Midway Island with Dr. Edward L. Winterer of Scripps Institution of Oceanography (SIO) the Chief Scientist. Off-loading and loading of Buoy Group equipment went smoothly. NSD provided trucks and a mobile dock-side crane. Nearly twenty tons of anchors were placed on the ship's after deck. Over 700 glass flotation spheres were placed on deck where space allowed; 200 of these were sixteen-inch glass spheres provided by the University of Miami and were placed on the forecastle by the dock-side crane. At sea these were hand-carried to the after-deck for launching; about twenty to twenty-five were used on each mooring. Two winches, forty miles of mooring cable, hardware, tools, etc. were also loaded on board.

The Naval Ship Repair Facility provided mechanical and welding assistance in securing large anchors and deck equipment to the ship. XBTs and service/calibration of the ship's launcher and recorder were provided by prior arrangement through the Naval Oceanography Command Facility, Yokosuka. CTD equipment and technicians were provided by SIO through a contract for Dr. P. P. Niller.

Table I lists the science crew that participated on Cruise #1. Atsunoba Misumi and Masao Numoto were observers from the Japan Marine Science and Technical Center who were to observe deep-sea mooring techniques since a number of Japanese research groups were starting or improving their own mooring programs. Robert Edwards from CSIRO, Australia was likewise seeking deep-ocean experience to extend his work from the Australian coast.

While the ship work was proceeding, current-meter and release checkouts were completed and equipment loaded. A technician from the University of Miami checked their nine VACMs and two acoustic releases but did not join the cruise. Keith Bradley and Henri Berteaux travelled to Tokyo to give a seminar on mooring techniques and the upcoming Kuroshio Extension mooring program to about forty Japanese scientists and engineers. Arrangements for this seminar and participation of the two Japanese observers were made by Shiro Imawaki of Kyoto University, who had participated in a 1975 Buoy Group cruise in the Atlantic, and Dr. Yoshio Horibe of the University of Tokyo.

When all port preparations were completed the ship sailed on July 1. On the evening of July 2 continuous magnetometer tows and bathymetry began. These are done on all SIO cruises except when station work or other towing operations are underway. SIO technicians maintain the equipment and monitor

its operation. The Buoy Group provided personnel for the watches and assistance in deployment and retrieval of the tow fish. About 1,600 nautical miles of data along the ship's track were collected; it is available from Mr. Stuart Smith, SIO, LaJolla, California 92093.

On July 3 a test CTD lowering to 1,600 meters was carried out preceded by a 1,600 meter lowering of a weight only to check the condition of the cable and the level-wind system. Some evidence of poor level-winding was apparent but it was decided to proceed with deeper stations hoping that problems of bad layers further in on the drum would be relieved after rehaul from a deep cast. The first actual station (labelled CTD #2) was on July 4 at  $41^{\circ} 15' N.$  and  $152^{\circ} E.$ , north of the first mooring site at  $41^{\circ} N.$  Robert Edwards conducted a short XBT review session for the assigned watch standers and XBT launches began on a schedule designed to provide data between mooring and CTD sites. CTD data is available from Dr. P. P. Niiler, Oregon State University, Corvallis, Oregon 97331 and XBT data is available from Dr. W. J. Schmitz, Jr., WHOI.

An acoustic release lowering of two releases to 3,000 meters depth was completed next. Generally, two releases at a time are lowered and their acoustic performances checked. Five more lowerings were conducted during the cruise. In the morning of July 3 CTD #3 was taken at the launch site of mooring #1 (Moored Station 695) followed by the routine launch and acoustic check of Station 695. By this time it was evident that the level-winding of the CTD winch was not working properly; in order to continue deep stations and not damage the wire it was necessary to assign two science personnel to the winch during each cast's rehaul to manually adjust the level-wind and to rewind poorly wrapped sections of the drum. This usually resulted in about

two extra hours added to each cast. The ship's engineers were not able to correct the problem at sea.

On July 6 the second mooring was launched (Moored Station 696) slightly to the east of  $152^{\circ}$  E. where a flatter bottom was found. On July 2 work included again XBTs, CTDs and the launch of Station 697. Between mooring launches the deck crew wound wire for the next mooring, moved anchors and prepared glass balls and hardware.

XBT #17 at  $35^{\circ} 14'$  N. showed that the  $15^{\circ}$  C isotherm was now below 200 meters depth indicating the defined northern edge of the Kuroshio Extension. Continuing south with CTDs and XBTs and launching Moored Station 699, the same isotherm came above 200 meters at XBT site #19 at  $34^{\circ} 12'$  N. on July 10. A mini-survey using XBTs and CTDs to 1,500 meters depth was conducted to the west as detailed in Figure 7. The stepped-pattern ship's track provided a good definition of the northern  $15^{\circ}$  C isotherm west to  $151^{\circ}$  E. The western limit was chosen based on available ship time for the survey. CTD #13 was taken at  $36^{\circ} 30'$  N. to the north of the isotherm and #14 at  $36^{\circ} 15'$  N. to the south, both along  $151^{\circ}$  E. CTD #15 was about in the center of the core; XBTs along  $151^{\circ} 15'$  E. defined the southern boundary. CTD #16 was taken to the north and #17 to the south of the  $15^{\circ}$  C isotherm at 200 meters depth. The ship then returned to the array line along  $152^{\circ}$  E. and once again proceeded south with XBTs, CTDs and mooring launches. On July 13 gale-force winds forced the ship to stop operations for three hours; rough seas shortened CTD #19 to 4,200 meters.

On July 17 at CTD Site #27, which is the site of the southernmost mooring, a second bolt failed on the CTD wire drum (one had failed on a previous cruise) causing the drum flange to move outward hitting the winch

frame. The cable was slowly rehailed; had a third bolt failed the drum would have jammed and the CTD could not have been rehailed with the winch. A decision was then made to attempt the final scheduled CTD station (#28) at  $27^{\circ} 45' N.$  but only to 1,500 meters. This would provide data to at least the level of the current meter measurement at 1,200 meters. If the drum failed the CTD could be recovered using the ship's crane and hand-coiling the cable on deck. No problem occurred with the drum and upon completion of CTD #28 the ship headed to Guam launching the eleven remaining XBTs at fifteen mile intervals.

There was warm tropical weather on the transit to Guam compared to the grey, cool and foggy weather on the transit to the northern mooring site from Japan. Upon the ship's arrival at the Naval Station on July 21 NSD again provided shore support, trucks and a crane. Airfreight of electronic test gear and shore storage of mooring equipment was coordinated through NSD. Cruise #2 for the recovery of the first setting and deployment of the second was already scheduled on the R/V THOMAS WASHINGTON departing from Guam the following year. Guam Naval storage of mooring supplies and equipment greatly reduced shipping expenses.

The ship's track for Cruise #1 is shown in Figure 6 and for the mini-survey in Figure 7.

Western North Pacific Exploratory Array - Cruise 1

R/V THOMAS WASHINGTON, RAMA - 4

July 1, 1980 to July 21, 1980

Science Crew List

Captain Albert Arsenault

1. Keith F. Bradley	Chief Scientist	WHOI
2. Alfred J. Ciesluk	Mooring Supervisor	WHOI
3. William H. Ostrom	Mooring Technician	WHOI
4. John B. Reese	Mooring Technician	WHOI
5. Scott E. WorriLOW	Release Technician	WHOI
6. Samuel T. Simkins	Current Meter Technician	WHOI
7. William H. Horn	Current Meter Technician	WHOI
8. Henri O. Berteaux	Design Engineer	WHOI
9. William M. Parks	CTD Technician	SIO
10. Ronald G. Patrick	CTD Technician	SIO
11. Robert J. Edwards	Observer	*
12. Atsunobo Misumi	Observer	**
13. Masao Numoto	Observer	**

\* Commonwealth Scientific Industrial Organization (CSIRO),  
Cronulla, Australia

\*\* Japan Marine Science and Technical Center, Yokosuka, Japan

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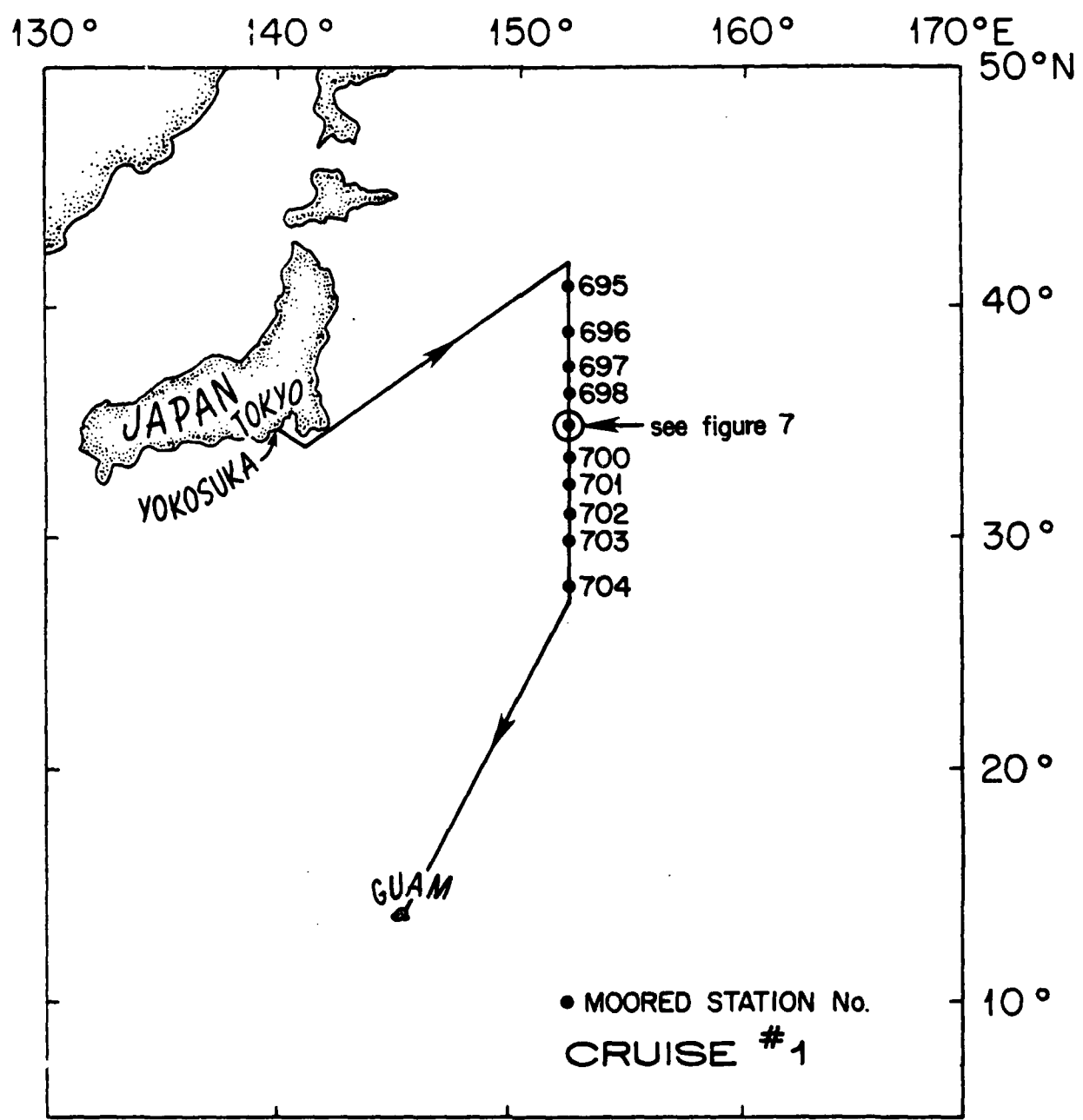


Figure 6

Cruise Track R/V THOMAS WASHINGTON, RAMA-4, July 1 to July 21, 1980

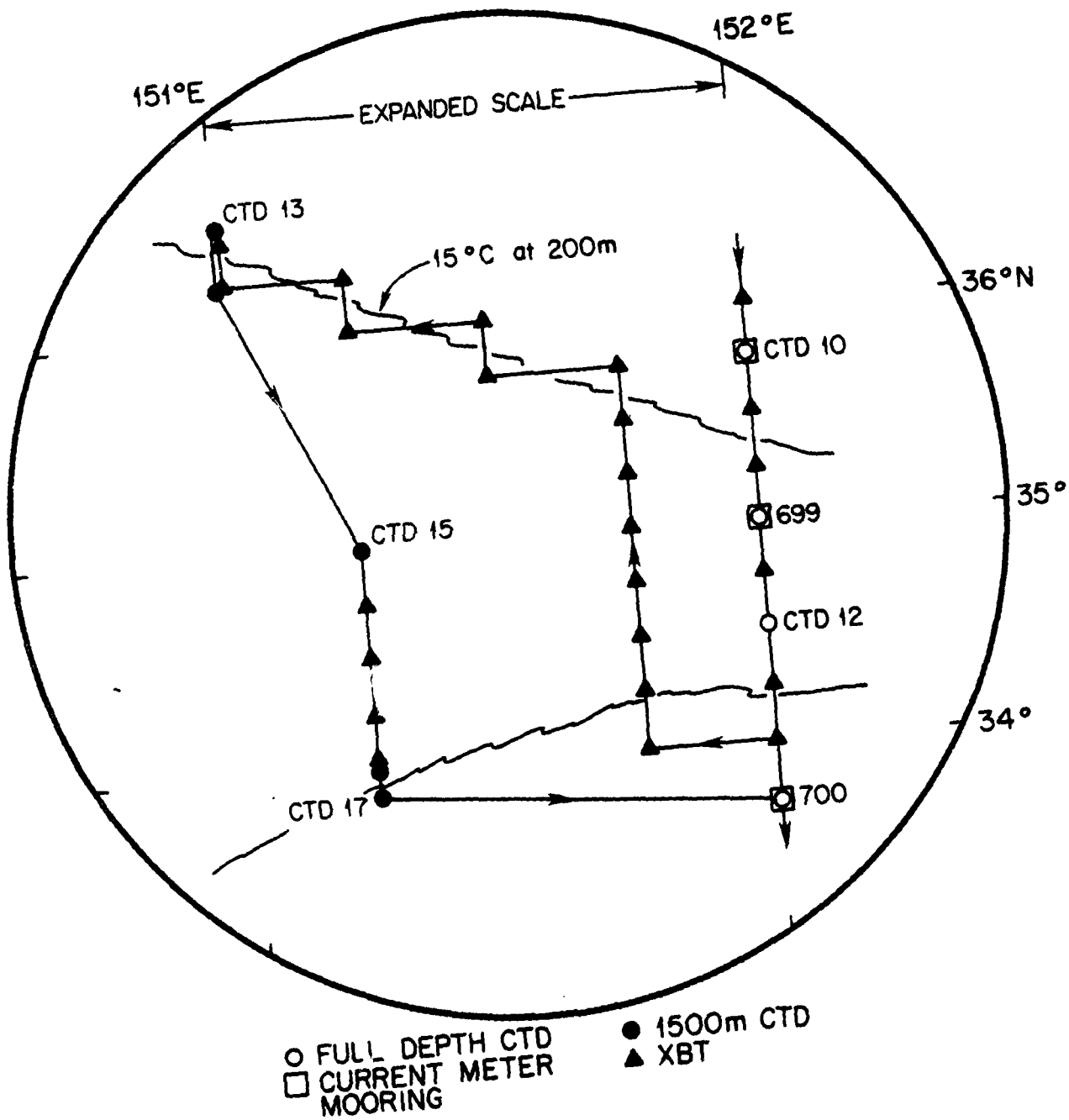


Figure 7

Detail of CTD and XBT Survey of Kuroshio Current on R/V THOMAS WASHINGTON Cruise

Cruise #2, R/V THOMAS WASHINGTON, RAMA Expedition, Cruise 13  
Guam to Adak, Alaska  
May 10, 1981 to June 3, 1981  
Chief Scientist, Alfred J. Ciesluk

The purpose of the second Kuroshio cruise was to recover and reset with fresh instruments the ten-mooring array set the previous year and to repeat the twenty-two CTDs made along the array at that time. Moorings had not been recycled at sea before on this scale so the cruise was to be a learning experience as well. The turnaround plan was to reuse those parts of each mooring recovered in good condition, except current meters and releases. All acoustic releases and all but ten of the thirty-eight current meters were to be replaced with units sent from Woods Hole.

Final preparations for the cruise began in Guam on May 1, 1981, four days before the R/V Washington would arrive from its previous leg. Equipment for the trip - 150,000 pounds of CTD and mooring hardware and instruments - had arrived in several shipments the month before. (CTD work on this cruise was done by the Woods Hole group whereas in 1980 it had been done by the Scripps group.) Included with the shipments were five complete moorings which were to be set by the Buoy Group during the R/V WASHINGTON's leg leaving Adak after the Kuroshio cruise. For economy in shipping the Adak moorings were sent with the Kuroshio equipment to Guam where they were brought aboard the ship.

As in 1980 the base of operations in Guam was the U.S. Naval Station. Arrangements had again been made through the Office of Naval Research for the Navy to furnish an air-conditioned laboratory on the Naval base where current meters, releases and CTD computers were assembled and

prepared for sea. Fifteen current meters for the Adak moorings were done at the same time. The Navy also helped load the ship by contributing heavy vehicles, a mobile crane, and welders.

It took eight days to complete the instrument preparations ashore and to ready the ship for sea, one day longer than planned. As a result the scheduled sailing was advanced one day from May 9 to 10. Typhoon Holly which passed within 200 miles of Guam on May 3 was partly responsible for the delay. As a precaution and to meet Navy regulations most of the Woods Hole equipment on the pier waiting to be moved aboard ship had to be returned to the forty-foot shipping containers it had arrived in to avoid being damaged by the expected high winds. The equipment remained in the containers for the next thirty-six hours. Delaying the preparations further, on May 9, the day the ship was to have sailed, most of the fifty reels of mooring wire rope which had already been secured on the fantail and main deck had to be restowed in an already crowded main hold so the ship's stability requirements could be met. Moving the wire occupied most of the day, spoiling any chance of the cruise beginning on time.

The ship departed at midday on May 10. Transit to the southern end of the array took four days which was uninterrupted except for a trial CTD cast to 1,000 meters taken the day after leaving port. The CTD system functioned satisfactorily during the test cast. Two releases to be used later with the first two redeployed moorings were also tested to 3,000 meters while the ship was stopped. Continuous magnetometer and bathymetry recordings were started shortly after leaving Guam. These data are routinely collected aboard Scripps Institution ships. Besides these data, the two individuals from Naval Underwater Systems Center (NUSC) conducted an independent XBT survey taking

XBT stations approximately every twenty nautical miles along the length of the array.

At 5 AM on May 14 the ship reached the first CTD station at  $27^{\circ} 44'$  N.,  $152^{\circ}$  E. lowering the CTD to the prescribed depth just above the bottom was routine but at the start of the upcast the winch pump lost hydraulic pressure and the CTD dropped to the bottom before a hand brake could be set. The pump failure was serious. Examination indicated repair would take at least twenty-four hours.

With the winch out of commission, the ship's crane was used to recover the CTD wire. By gripping the CTD wire with a wire grab the crane was able to pull aboard about seven meters of wire at a time. In this way the entire CTD wire was recovered in ten hours. Fortunately the CTD instrument itself was undamaged despite having been dragged across the bottom for several hours.

With the CTD back aboard the ship continued to mooring #10 (Moored Station 704) fifteen miles further north. The release responded immediately and recovery of the mooring was routine. However, some wire rope was ruined. As encountered when the subsequent moorings were recovered, those long pieces of wire rope next to large glass-ball clusters formed great wuzzles before they could be got aboard. Because of wuzzles only forty percent of the wire in the array was reusable.

Mooring #10 was redeployed as Moored Station 717 eleven hours after it had been recovered. Similar periods were taken between recovery and redeployment for most of the moorings. That much time was needed to inspect and replace mooring hardware intended for reuse, wind new wire rope to replace ruined sections, and recycle VACMs. One VACM per mooring was reused.

A CTD cast with the rebuilt winch pump was taken after mooring launch. The CTD winch operated normally for the remainder of the cruise with the exception of its level wind which needed frequent adjustment as it had during the 1980 cruise.

After completing mooring and CTD work at site 10, the ship steamed to mooring #9 (Moored Station 703) taking the planned CTD casts on the way. During recovery of mooring #9 a section of wire rope parted with half the mooring still in the water. Because it was nighttime and visibility was further reduced by heavy rain it took six hours to find the mooring again. A piece of wire rope had apparently kinked and parted during recovery when stressed by hauling coupled with ship's heave. A CTD station followed recovery of the second half of the mooring. This pattern of recovery, a CTD cast and then relaunching the mooring was repeated at all the remaining mooring locations. Releases, one for each of the two upcoming moorings, were also tested at depth in pairs between recovery and relaunching at every other mooring site.

Mooring and CTD work northward through the recovery of mooring #5 was uneventful. When relaunched, mooring #5 (Moored Station 723) broke in half. One of the long wire sections had kinked while the mooring was streamed and later snapped at the kink when the anchor was launched. The top half of the mooring immediately floated to the surface but the mooring's release had to be fired to recover the lower half.

The section of wire rope that parted was one that had been recycled. Although it wasn't immediately obvious, wire rope recovered in otherwise good condition was twisted along its length. During launch if a twisted section of wire rope was allowed to slack it tended to kink. Tension maintained during

the launch of mooring #5 apparently had been inconsistent enough to allow some sections of wire to go slack and kink.

Mooring #5 was relaunched a second time keeping payout tensions higher and more consistent. This procedure was successfully repeated for all the remaining mooring launches.

The launch failure of mooring #5 included loss of its MACE anchor. Since there were no spare MACE anchors to complete the mooring turnarounds, one of the five Adak mooring anchors was borrowed. Lost with the anchor for which there was no substitute was the 162 meter shot of 1/4" wire rope which had separated the anchor from the release. This piece's function in the mooring was to position the deepest current meter exactly 200 meters from the bottom. Of the moorings that remained at this point only mooring #1 was similar (see instrument depth requirements, Fig. 1). It was decided to redeploy mooring #5 the second time with the 162 meter shot intended for mooring #1 and use whatever was available of sufficient strength to make up 162 meters for mooring #1. Unfortunately only 126 meters of odd shots of rope and synthetic line could be found for mooring #1 so its bottom current meter was deployed closer to the bottom than the 200 meters planned.

Mooring and CTD work after leaving mooring site 5 lasted another seven days. Weather which was pleasant although often rainy south of 35° N. worsened as the ship continued north. Heavy seas were common over most of the northern half of the array and during the six-day transit to Adak. The ship arrived at Adak on the morning of June 3, 1981.

The ship's track for this cruise is shown in Figure 8. Table II lists the science crew that participated on Cruise #2.

Western North Pacific Exploratory Array - Cruise 2

R/V THOMAS WASHINGTON, RAMA - 13

May 10, 1981 to June 3, 1981

Science Crew List

Captain Curt Johnson

1.	Alfred J. Ciesluk	Chief Scientist	WHOI
2.	R. David Simoneau	Mooring Technician	WHOI
3.	John B. Reese	Mooring Technician	WHOI
4.	Roderigue A. LaRochelle	Release Technician	WHOI
5.	Joseph R. Poirier	Current Meter Technician	WHOI
6.	William H. Horn	Current Meter Technician	WHOI
7.	Marvel C. Stalcup	CTD Technician	WHOI
8.	Mary E. Raymer	CTD Technician	WHOI
9.	Robert E. McDevitt	CTD Technician	WHOI
10.	Peter R. Clay	Buoy Engineer	WHOI
11.	Jerome P. Dean	Electronics Engineer	WHOI
12.	Harold England	Guest Investigator	*
13.	Robert Hall	Guest Investigator	**

\* Naval Underwater Systems Center

\*\* Yale University

Table II

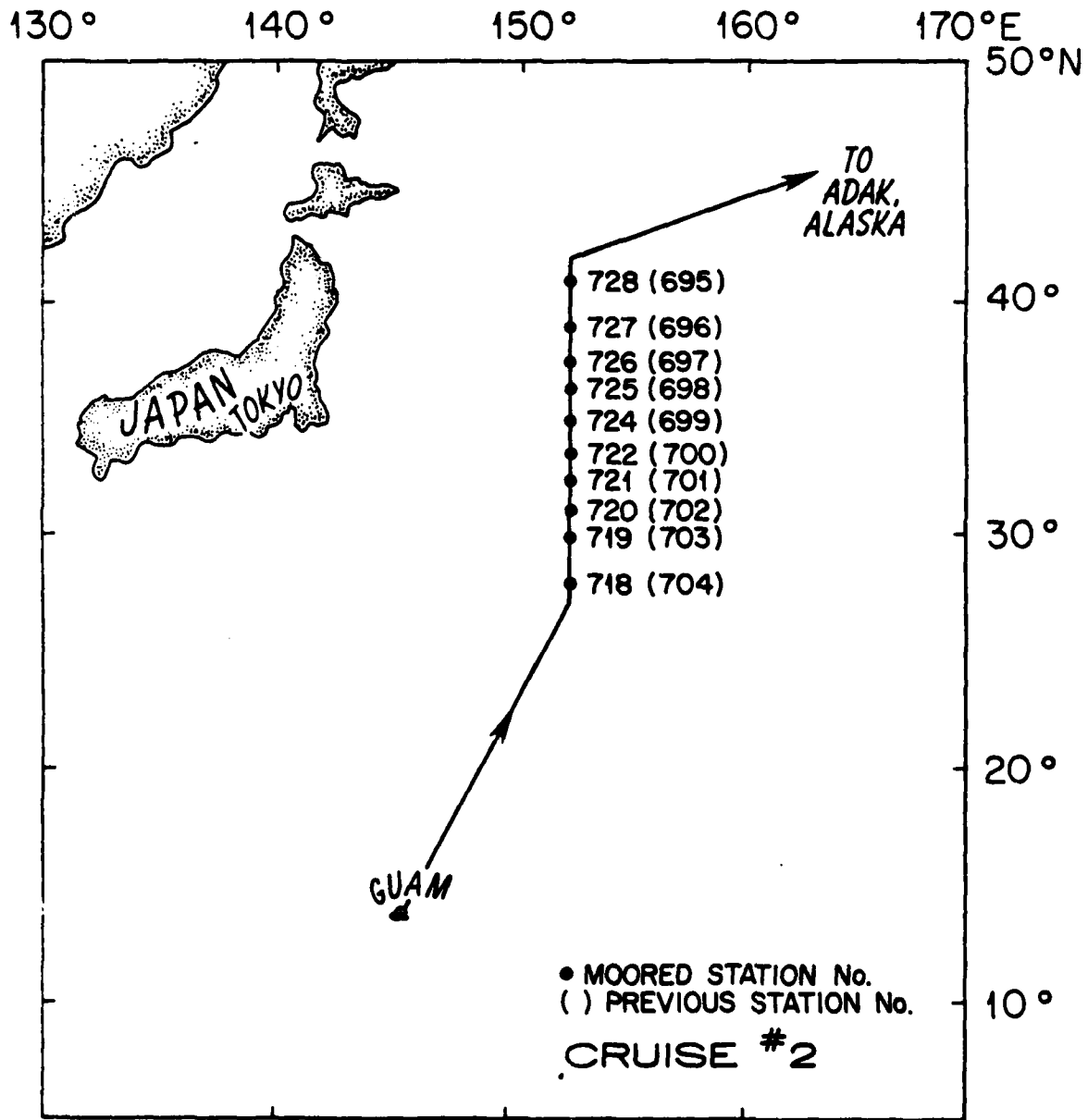


Figure 8

Cruise Track R/V THOMAS WASHINGTON, RAMA-13, May 10 to  
June 3, 1981

Cruise #3, R/V THOMAS THOMPSON, T.T. 167  
Guam to Hakodate, Japan  
May 22, 1982 to June 8, 1982  
Chief Scientist, Alfred J. Ciesluk

Final recovery of the mooring array was scheduled for the third Kuroshio cruise. The point of departure was again the U.S. Naval Station at Guam. The work of unpacking and assembling equipment began in Guam on May 17, 1982. The R/V THOMAS THOMPSON arrived two days later on May 19. By late afternoon on May 21 the ship was fully loaded and ready for sea.

On May 22 the R/V THOMPSON sailed from Guam. Because of problems with the CTD three test casts were taken en route to the array. Repairs to the CTD were necessary after the first two casts.

At most CTD stations the independent group from the University of British Columbia deployed their "camel" instrument to collect data for an independent experiment. The "camel" measures turbulence while free falling to as deep as 2,000 meters, then returns to the surface after releasing ballast. Launch of the "camel" was timed so it resurfaced just after recovery of the CTD.

Work at the array started on May 26 with the first formal CTD cast. Recovery of array mooring #10 (Moored Station 718) followed that afternoon. The weather from May 26 through the next two mooring stations was exceptional. A large high pressure system kept the skies clear and seas calm.

Mooring #10 had been reset the year before with sections of recycled wire rope. These were recovered in good condition, in appearance little different from the newer pieces in the mooring and showing little evidence of having been in the water that long. This was to be the case for all the recycled wire throughout the array. Mooring #10's one-year old

Kevlar sections were also recovered in good condition.

The CTD sensor unit, repaired satisfactorily for the first two array stations, malfunctioned during the third cast at 28° 30' N. Before reaching the next CTD station a single working CTD was assembled from parts taken from the two WHOI units aboard and a third belonging to the ship. This composite CTD did the job for the remainder of the cruise except for lack of capacity for direct oxygen measurements.

Lowpoint of the entire two-year experiment was the failure on May 29, 1982 of Moored Station 720 (mooring #8) to respond to acoustic commands. Repeated attempts to fire the mooring's release were all unsuccessful. On May 29 from 10 AM to after midnight each of the three release commands was sent to the release both from a position over the mooring and during two searches of the area. The first search was a box pattern with two-mile legs centered around the mooring position. At the midpoint and end of each leg the ship stopped to lower a transducer to signal the release. After completing this first search without any response from the release the ship returned to the mooring position for one more try there. When this was unsuccessful a final search was made with five stops on a five-mile radius course before abandoning the mooring.

Although mechanical failure of the mooring below the release or a failure of the release electronics cannot be ruled out, the evidence points to prematurely run down receiver batteries as the cause for the loss of Moored Station 720. Not until after this mooring had been deployed was it learned that two of the release's four receiver batteries had come from a specific manufacturing batch with a history of reaching end of life too soon. Adding to the likelihood of failure, these same two batteries had been used in

another release for two months just before the second Kuroshio cruise.

After abandoning Moored Station 720 the cruise continued routinely until the tenth CTD cast at  $33^{\circ} 11'$  N. on May 31. With 4,000 meters of wire out during the downcast at that station the CTD winch drum cracked in the middle. Signal from the CTD was lost simultaneously.

Fortunately the CTD came back up without the winch drum collapsing further. A resistance measurement of the CTD wire showed it had shorted 4,500 meters from one end. At 6,000 meters in length, this wire was the longer of the two CTD wires aboard. A second wire was 4,400 meters long and lay on a drum in the ship's main hold making the only choice at this point an exchange of the two drums, an operation which took four hours. Once the backup drum and wire were in place and adjusted the aborted CTD cast was started again. For no reason at all, on this first cast with the backup wire the CTD jumped the outboard sheave and jammed with only a thousand meters out.

Freeing the wire was simply done by stopping off and disassembling the sheave, but on inspection the outer wire strands were found ruined. Rather than risk further CTD operations with this bad spot in the wire it was decided to recover and cut off the top thousand meters. This was quickly done leaving only 3,000 meters of good wire. All CTD stations north of  $33^{\circ} 49'$  N. were then taken to a depth of 3,000 meters only and were not the bottom casts planned.

Weather was a factor in the transfer of the CTD wires. Had the seas not been as calm as they were on May 31 that operation might not have been possible. Poor weather and heavy seas arrived the next day and continued through most of the remainder of the cruise. Besides being affected by heavy seas the recoveries of moorings 5, 6 and 7 were made more difficult by heavy

rain squalls which limited visibility to often less than one-quarter of a mile. Because the radios of each of these moorings failed to turn on after surfacing, finding the moorings on the surface was a time-consuming and uncertain operation.

On June 4 also, heavy weather adversely affected recovery of mooring #2. Before the top cluster of glass balls and VACM could be brought aboard they worked under the ship and fouled in the ship's propeller. Attempts to free the mooring failed until eight hours later when the wire rope separating the VACM from the glass balls chafed through sending the VACM to the bottom. Once the VACM broke free the rest of the mass tangled in the screw quickly unravelled. The mooring below the top VACM had been recovered during the period when the top of the mooring was still fouled.

After the recovery of mooring #2 the cruise was relatively uneventful. When Kuroshio work was finished the ship continued north where a dense XBT survey was taken across the Oyashio Current by the independent group from NUSC for an independent experiment of theirs. The southern edge of the Oyashio was encountered at approximately  $42^{\circ} 05' N$ . The survey extended as far north as  $42^{\circ} 30' N$ . With the Oyashio survey done the ship steamed directly to Hakodate, arriving there in the late afternoon of June 8.

The ship's track for this cruise is shown in Figure 9. Table III lists the science crew that participated in Cruise #3.

Western North Pacific Exploratory Array - Cruise 3

R/V THOMAS G. THOMPSON  
May 22, 1982 to June 8, 1982

Science Crew List

Captain Francis Bean

1.	Alfred J. Ciesluk	Chief Scientist	WHOI
2.	R. David Simoneau	Mooring Supervisor	WHOI
3.	John B. Reese	Mooring Technician	WHOI
4.	Scott E. Worrilow	Current Meter Technician	WHOI
5.	Samuel T. Simkins	Current Meter Technician	WHOI
6.	Roderigue A. LaRochelle	Release Technician	WHOI
7.	Robert E. McDevitt	CTD Technician	WHOI
8.	Nancy Galbraith	CTD Technician	WHOI
9.	Toshiko Turner	CTD Technician	WHOI
10.	Ed Mellinger	Computer Technician	WHOI
11.	Kim Crocker	Guest Investigator	*
12.	Robert Hall	Guest Investigator	**
13.	James Muom	Guest Investigator	***
14.	Ronald Ninnis	Guest Investigator	***

\* Naval Underwater Systems Center (NUSC)

\*\* Yale University

\*\*\* University of British Columbia

Table III

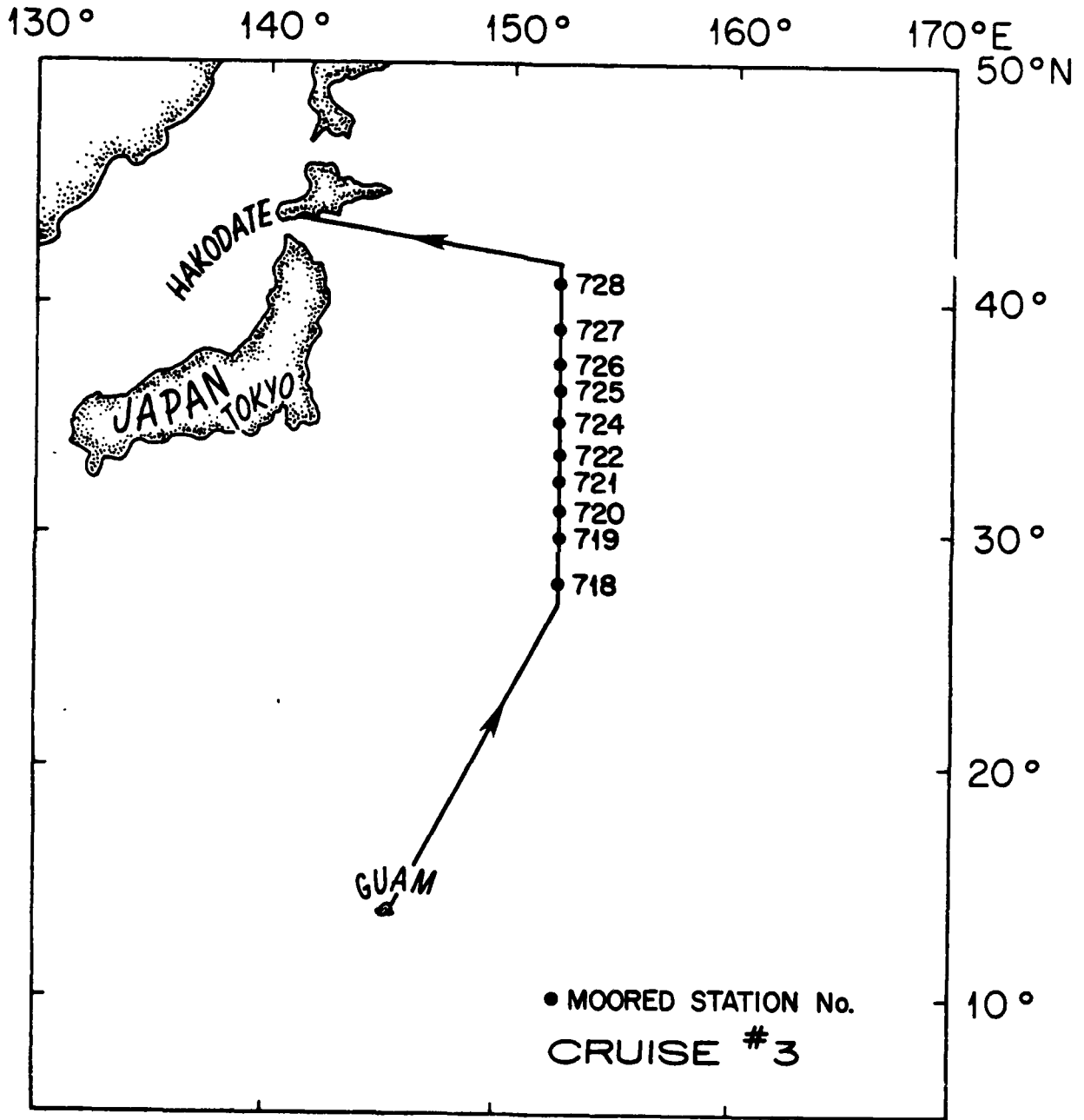


Figure 9

R/V THOMAS G. THOMPSON, T.T. 167, May 22 to June 8, 1982

ACKNOWLEDGMENTS

The ship's officers and crew of the R/V THOMAS WASHINGTON and R/V THOMAS G. THOMPSON should be recognized for their fine work, interest and enthusiasm on the three research cruises. Office of Naval Research personnel provided invaluable support in arranging use of Naval personnel and facilities overseas and in assisting with military transport of equipment. The Naval personnel of NSD and SRF at Yokosuka, Japan, Guam and Adak, Alaska worked with each cruise making large logistic operations run smoothly. The shipboard technicians and observers all contributed their effort and knowledge for successful, pleasant cruises. Alfred J. Ciesluk, Chief Scientist on the second and third cruises, contributed two cruise summaries for this publication. Finally, the Woods Hole Buoy Group Operations section provided the manpower and professional at-sea knowledge required for a successful large-array field program.

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APPENDIX

WHOI Mooring Summary

Western North Pacific Exploratory Array  
(Kuroshio Extension Program)

\*

VACM = Vector Averaging Current Meter  
VACM-P = VACM with Pressure Sensor  
850 = EG&G Current Meter

Station Number	Latitude & Longitude	Dates Set and Recovered	Days Duration	Instr. Type	Instr. Design Depth (m)	As-Launched Zero-Current		Remarks
						Depth (m)	Ocean Depth (m)	
695	40° 59:1 N. 152° 01:1 E.	5-VII-80 27- V-81	327	VACM	250	240	5,278	Mooring #1 of array, first setting
				VACM-P	500	490		
				VACM	1,200	1,190		
				VACM	4,000	3,990		
				VACM	5,078	5,078		
696	38° 58:3 N. 152° 04:0 E.	5-VII-80 25- V-81	325	VACM-P	500	495	5,664	Mooring #2 of array, first setting
				VACM	1,200	1,195		
				VACM	4,000	3,995		
697	37° 30:1 N. 152° 01:8 E.	6-VII-80 24- V-81	323	VACM-P	500	501	5,842	Mooring #3 of array, first setting
				VACM	1,200	1,201		
				VACM	4,000	4,001		
698	36° 17:8 N. 152° 02:5 E.	8-VII-80 23- V-81	320	VACM-P	500	507	5,945	Mooring #4 of array, first setting
				VACM	1,200	1,207		
				VACM	4,000	4,007		
699	34° 58:8 N. 152° 01:9 E.	9-VII-80 21- V-81	317	VACM-P	250	261	6,149	Mooring #5 of array, first setting. Main floatation is 60" foam sphere
				VACM-P	500	511		
				VACM	1,211	1,211		
				VACM	4,000	4,015		
				VACM	5,949	5,949		

Summary, Continued

Station Number	Latitude & Longitude	Dates Set and Recovered	Days Duration	Instr. Type	Instr. Design		Ocean Depth (m)	Remarks
					Depth (m)	As-Launched Zero-Current Depth		
700	33° 46:0 N. 151° 59:4 E.	12-VII-80 20- V-81	313	VACM-P	500	478	5,952	Mooring #6 of array, first setting
				VACM	1,200	1,178		
				VACM	4,000	3,979		
701	32° 29:0 N. 152° 10:3 E.	13-VII-80 19- V-81	311	VACM-P	250	250	5,728	Mooring #7 of array, first setting
				VACM-P	500	500		
				VACM	1,200	1,200		
				VACM	4,000	4,000		
				VACM	5,528	5,540		
702	31° 16:0 N. 152° 04:7 E.	14-VII-80 17- V-81	308	VACM-P	500	506	5,952	Mooring #8 of array, first setting
				VACM	1,200	1,206		
				VACM	4,000	4,006		
703	30° 02:1 N. 152° 00:8 E.	15-VII-80 16- V-81	306	VACM-P	500	494	5,966	Mooring #9 of array, first setting
				VACM	1,200	1,194		
				VACM	4,000	3,994		
704	27° 59:6 N. 151° 56:5 E.	17-VII-80 14- V-81	302	VACM-P	250	251	6,078	Mooring #10 of array, first setting. 5 kHz location pinger at 1,200 meters. Kevlar test
				VACM-P	500	501		
				VACM	1,200	1,202		
				VACM	4,000	3,984		
				VACM	5,878	5,890		

Summary, Continued

Station Number	Latitude & Longitude	Dates Set and Recovered		Days Duration	Instr. Type	Instr. Design Depth (m)		As-Launched Zero-Current Depth (m)		Remarks
		Recovered	Set			Depth (m)	Depth (m)	Depth (m)	Depth (m)	
718	27° 59' 3 N. 151° 53' 6 E.	15-	V-81	377	VACM-P	250	247	6,057	Mooring #10 of array, second setting. 5 kHz location pinger at 1,200 meters. Kevlar test	
		26-	V-82		VACM-P	500	497			
					850	1,200	1,198			
719	30° 03' 1 N. 152° 02' 8 E.	17-	V-81	377	VACM-P	500	502	6,005	Mooring #9 of array, second setting	
		28-	V-82		850	1,200	1,202			
					VACM	4,000	4,002			
720	31° 15' 8 N. 152° 03' 5 E.	18-	V-81	-	VACM-P	500	496	5,931	Mooring #8 of array, second setting. No acoustic contact with release at recovery	
		Lost			850	1,200	1,196			
					VACM	4,000	3,996			
721	32° 28' 1 N. 152° 06' 6 E.	19-	V-81	377	VACM-P	250	265	5,756	Mooring #7 of array, second setting	
		30-	V-82		VACM-P	500	515			
					850	1,200	1,214			
					VACM	4,000	4,015			
722	33° 49' 8 N. 151° 59' 4 E.	20-	V-81	377	VACM-P	500	498	5,952	Mooring #6 of array, second setting	
		31-	V-82		850	1,200	1,198			
					VACM	4,000	3,999			

Summary, Continued

Station Number	Latitude & Longitude	Dates Set and Recovered	Days Duration	Instr. Type	Instr. Design Depth (m)	As-Launched Zero-Current		Remarks
						Depth (m)	Ocean Depth (m)	
723								<i>Cable parted at anchor drop due to kink in it</i>
724	34° 57' 17 N. 152° 00' 17 E.	22- V-81 1- VI-82	376	VACM-P VACM-P 805 VACM-P VACM-P	250 500 1,200 4,000 5,958	255 505 1,204 4,004 5,958	6,158	Mooring #5 of array, second setting. Main flotation is 60" synthetic foam sphere
725	36° 16' 10 N. 152° 00' 18 E.	24- V-81 2- VI-82	375	VACM-P 850 VACM	500 1,200 4,000	496 1,196 3,996	5,938	Mooring #4 of array, second setting
726	37° 28' 13 N. 152° 04' 14 E.	24- V-81 2- VI-82	375	VACM-P 850 VACM	500 1,200 4,000	486 1,186 3,987	5,828	Mooring #3 of array, second setting
727	38° 57' 17 N. 152° 06' 16 E.	26- V-81 4- VI-82	375	VACM-P 850 VACM	500 1,200 4,000	522 1,222 4,023	5,680	Mooring #2 of array, second setting. VACM at 500 meters lost on recovery
728	41° 02' 13 N. 152° 01' 11 E.	28- V-81 5- VI-82	374	VACM-P VACM-P 850 VACM-P VACM	250 500 1,200 4,000 5,156	287 537 1,237 4,037 5,126	5,356	Mooring #1 of array, second setting

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<p>Woods Hole Oceanographic Institution WHOI-82-41</p> <p>TECHNICAL ACTIVITIES ASSOCIATED WITH AN EXPLORATORY ARRAY IN THE WESTERN NORTH PACIFIC by Keith F. Bradley, 40 pages, September 1982. Prepared for the Office of Naval Research under Contracts N00014-76-C-0197; NR 083-400; N00014-79-C-004; NR 083-102; N00014-75-C-0152; NR-083-005.</p> <p>Operations activities of the Woods Hole Oceanographic Institution's Buoy Group for an exploratory array of deep-ocean moorings in the western North Pacific Ocean are described along with specific engineering notes associated with high-current deep moorings. The array, along 152° E. from 28° N. to 41° N., was in place for about two years. After one year the array was successfully recovered and redeployed. Brief summaries of each of three research cruises are provided. An Appendix lists details of the twenty moorings including positions, dates deployed and recovered, instrument types and depths and moored station numbers which are required for specific data retrieval by investigators. The initial scientific publication has been prepared by Schmitz, et al (1982).</p>	<p>1. Kuroshio</p> <p>2. Current meters</p> <p>3. 152° E.</p> <p>I. Bradley, Keith F.</p> <p>II. N00014-76-C-0197; NR 083-400</p> <p>III. N00014-79-C-004; NR 083-102</p> <p>IV. N00014-75-C-0152; NR 083-005</p> <p>This card is UNCLASSIFIED</p>	<p>Woods Hole Oceanographic Institution WHOI-82-41</p> <p>TECHNICAL ACTIVITIES ASSOCIATED WITH AN EXPLORATORY ARRAY IN THE WESTERN NORTH PACIFIC by Keith F. Bradley, 40 pages, September 1982. Prepared for the Office of Naval Research under Contracts N00014-76-C-0197; NR 083-400; N00014-79-C-004; NR 083-102; N00014-75-C-0152; NR-083-005.</p> <p>Operations activities of the Woods Hole Oceanographic Institution's Buoy Group for an exploratory array of deep-ocean moorings in the western North Pacific Ocean are described along with specific engineering notes associated with high-current deep moorings. The array, along 152° E. from 28° N. to 41° N., was in place for about two years. After one year the array was successfully recovered and redeployed. Brief summaries of each of three research cruises are provided. An Appendix lists details of the twenty moorings including positions, dates deployed and recovered, instrument types and depths and moored station numbers which are required for specific data retrieval by investigators. The initial scientific publication has been prepared by Schmitz, et al (1982).</p>	<p>1. Kuroshio</p> <p>2. Current meters</p> <p>3. 152° E.</p> <p>I. Bradley, Keith F.</p> <p>II. N00014-76-C-0197; NR 083-400</p> <p>III. N00014-79-C-004; NR 083-102</p> <p>IV. N00014-75-C-0152; NR 083-005</p> <p>This card is UNCLASSIFIED</p>
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