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Free Vehicles and Deep-Sea Biology

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SYNOPSIS. A free vehicle is a timed and weighted device released from a ship in a free fall to the ocean bottom. Instruments carried on the free vehicle have been built to take biological samples, sediment samples, water samples, and photographs, and to measure currents, tides, and temperature. The instrument then returns to the surface where it is recovered by the ship. A free vehicle system for biological sampling in the deep sea is described in detail. It consists of a mast assembly, flotation, hookline and traps, and a magnesium release attached to weights. Different types of magnesium links used include a rod, a wire on pliers, and a series of diamond-shaped beads that drop through a hole after dissolving. A deck plan for launching the free vehicle and its retrieval at sea are described.

INTRODUCTION

A free vehicle is a timed and weighted device released from the ship in a free fall to the ocean bottom. It may be designed (1) to capture benthic organisms, as a baited free vehicle long-line or a baited free vehicle trap, (2) to collect water and/or bottom samples, or (3) to carry down instrumentation for various physical or chemical measurements in the benthic environment. The free vehicle and the weights which carry it to the ocean floor must be attached to each other by a timing device programmed to release the weights at any desired time. The free vehicle then returns to the surface where it is recovered by the ship. The major advantage of the free vehicle is that it obviates the necessity of lowering equipment into the deep sea on long, slowly moving cables operated from shipboard by heavy, expensive winches. This means that the ship can accomplish different tasks in other areas during the time the free vehicle is down. Other advantages of this technique include low price, expendable nature of equipment, rapid launch and recovery, the fact that it can be operated from almost any small or large vessel, and flexibility of schedule provided by different release times.

The concept of a free vehicle (autonomous instrument, free falling instrument, boomerang, pop-up) is not new, although most advances have been made since 1960. One of the earliest designs involved an oil-filled balloon and kite arrangement to lower seismographs and bombs to the bottom of the sea (Ewing and Vine, 1938). In this way, it was hoped to avoid the effect of unnecessary cable movement on the sensitive seismographs. The kite was included to aid in stringing the instruments over a length of one mile on the bottom. Recall from the surface by sound wave signals was envisioned to avoid recovery during storms. Although Lifesavers, ice, and bags of sugar had been used for short term, shallow release mechanisms, Van Dorn (1953) was the first to develop a practical release for use in the deep sea. This method involves electrochemical deterioration of a magnesium rod. Dissolution times of the rods are independent of temperature, salinity, and pressure within normal ocean ranges. Isaacs and Schick (1960) have used this magnesium link type of release with a number of free vehicles packaged with different kinds of instruments.

USES OF FREE VEHICLES

Free vehicles have now been used successfully to trap bottom creatures, photograph them, hook them for biochemical studies, measure bottom currents, sample bottom water, record deep-sea tides and temperature, and collect sediment samples.

A pyramid-shaped benthic trap has been described (Schick *et al.*, 1968) for free vehicle use. This single-chambered trap rests on the bottom and catches crawling invertebrates as well as fish. The three-chambered fish trap (Hubbs and McConnaughey, 1970) separates the catch by size into different chambers to avoid smaller animals being eaten by larger ones. Plastic elliptical lobster traps have been very successful in catching sablefish (*Anoplopoma fimbria*) in the deep sea (Phleger *et al.*, 1970). These can be attached in series on the free vehicle line or situated on the bottom. A larger fish trap (6 m^3) has been tested recently with free vehicles by us.

Sea floor photography by free vehicle has revealed high concentrations of fish and invertebrates (Sessions *et al.*, 1968) at depths up to 6100 m. Photographs of large benthic sleeper sharks (*Somniosus pacificus*), 5.5 to 6.7 m in length, have elicited much interest among marine biologists (Schick *et al.*, 1968). All attempts to obtain specimens of these monsters have failed to date.

Recent biochemical studies of free vehicle-hooked deep benthic fish have yielded new information. A massive accumulation of free cholesterol has been discovered in swimbladders of rattails (*Coryphaenoides* sp.) and other fish caught at great depths (Phleger and Benson, 1971). Sphingomyelin and phosphatidylcholine are intimately associated with this cholesterol in the swimbladder (Patton and Thomas, 1971). Pressure and temperature studies on enzymes in these deep fish have been performed (Hochachka *et al.*, 1970).

Deep ocean circulation has been measured by savonius rotors attached to free vehicles (Schrader, 1965*a*; Schick *et al.*, 1968). Knauss (1965) recorded a steady current of 17 cm/sec in the central Atlantic Ocean and speeds of 0-21 cm/sec in the deep Atlantic, but the current meter was probably nonlinear below 3 cm/sec. Isaacs *et al.* (1966) used savonius rotors calibrated to below 0.5 cm/sec at 4 km depth off Baja California, Mexico. Net currents of 2.2 cm/sec were measured as well as fluctuating motions of 1.7 cm/sec ascribable to surface tides. Using the same system, Swartzlose and Isaacs (1969) recorded an unusual deep ocean circulation event, or underwater storm, in the same region. A vertical array of current meters between 3 and 1000 m above the ocean floor measured 7-34 sudden shifts in current direction. The current meter at 1000 m measured an increase in current speed of 450% (to 18 cm/sec). Snodgrass (1968) has successfully measured pressures of deep-sea tides by self-contained instrument capsules to an accuracy of 1 mm. Temperature changes are measured to a few millionths of a degree, and water currents with speeds between 0.1 and 10 cm/sec. Return of the capsule to the surface is accomplished by solenoid release or exploding bolt, triggered by accoustical commands from the ship.

Sholkovitz (1970) has built a free vehicle water sampler to measure chemical gradients in the 2 m above the bottom. Ten bottles are situated at 20 cm intervals. These remain on the bottom three hours before sampling, to ensure flushing with bottom water.

An umbrella sediment trap is described for free vehicle use by Schick *et al.* (1968). An eight-hour magnesium release is attached to open the trap on the bottom, and closing is accomplished by a chain, attached to a gear paddle, which pulls the trap shut after a certain interval of time. This has been used successfully by Berger and Soutar (1967) to collect data on planktonic foraminifera productivity. Evidence was collected for one-month life spans in contrast to previously reported one-year life spans. A free corer to collect sediment samples has been described (Moore, 1961). A Van Dorn magnesium rod releases the encased sediment-filled core barrel from the casing and weight, which are abandoned in the mud. Sachs and Raymond (1965) developed and tested a similar unattached sediment sampler. Of 50 tested in deep water, 46 were recovered and 41 contained samples. It took 15 minutes for round trip of the vehicle.

DESCRIPTION OF THE FREE VEHICLE TECHNIQUE

Introduction. The free vehicle consists of a number of components which can be modified to fit the needs and budget of the individual. The purpose of this section is to describe each component separately as well as the technique of launching the free vehicle from a ship. The type of free vehicle that we and our colleagues at Scripps Institution of Oceanography have used most successfully is shown in Figure 1. It is shown resting vertically on the bottom. When the magnesium link dissolves, the floats carry everything except the weights to the surface, where location is indicated by such devices as bright flags, radar screens, radios, and blinking lights. A similar free vehicle was used on the 1970 *R/V Alpha Helix* cruise to the Galápagos Islands.

The mast assembly. This consists of bright flags, a radio and antenna, two floats, and a plastic pole (3.7 m length) with a 2-kg stabilizing weight tied to the bottom. A radar reflector may be attached to the top of the pole. Blinking lights (with pressure-activated switches) are useful for night recoveries and can be seen up to a distance of 15 km. Radio and lights cost $300 and $50 respectively at Scripps Institution of Oceanography. A radio direction finder is helpful in locating equipment (the cost is $500).

Radio transmitters (built by Erich Duffrin) are one watt, and operate at citizen band frequencies (27 mega-hertz). The signal can be transmitted up to a distance of 15 km. Battery power is conserved while underwater, because the radio is connected to a pressure activated switch, which allows surface operation for

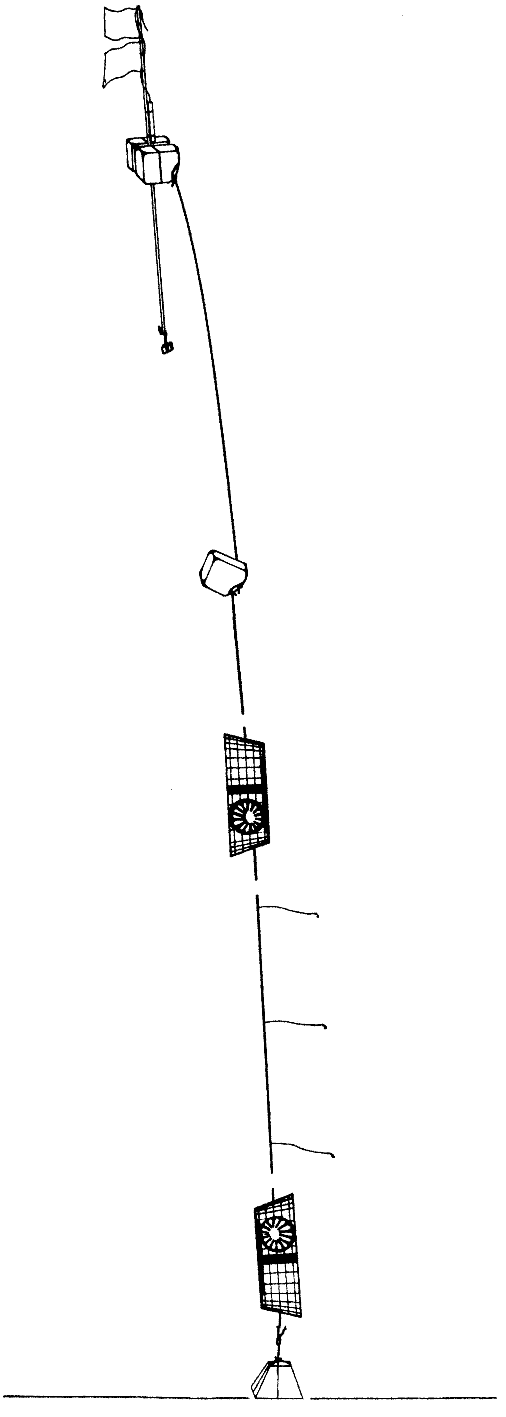

FIG. 1. The free vehicle vertical hookline-trap combination. The top shows the plastic mast supported by Isopar-M oil-filled jerry jugs with radio and flags. Fifteen meters of handling line connect to the secondary float, below which are traps and hookline. The free vehicle is held on the bottom by a 27-kg weight. The release is located between the lower trap and the weight (from Phleger *et al.*, 1970).

a day or longer. The radio is encased in a cylindrical aluminum pressure bomb, which is attached by metal clamps to the plastic mast. The aerial is taped to the upper half of the mast. In addition to the advantage of locating the free vehicle, radios inform the ship when it has surfaced. This aids in rapid recovery of gear. Valuable fish hooked on the setline may be eaten by surface sharks if the free vehicle sits at the surface too long. Blue sharks (*Prionace glauca*) are a problem off the California coast. They eat specimens and often hopelessly entangle the line. Sea birds as well as sea lions, sea elephants, and passing fishermen are attracted to the floating fish, distended with expanded swimbladder gases.

Bright flags are important for visual sighting from the ship. International orange, bright yellow, and green can be seen 8 km away on a clear day. It is important to make sure the flag is not wrapped around the mast before launching the equipment. Radar reflectors, available at some Navy surplus stores, are an added means of detection. Rough seas interfere with detection of these screens, but they are useful on calm days.

Two 5-gallon carboys are attached to the mast by steel clamps. These are filled with a lightweight oil (described below). It is best to clamp the floats securely to the mast (Fig. 1) to help ensure that the mast assembly floats upright in the ocean. The 2-kg stabilizing weight tied to the bottom of the pole also keeps the mast in a vertical position. These free vehicles can stand erect in 30 knot winds and high seas, while other arrangements, with loosely fastened floats, may lie horizontally under such conditions. This makes visual sighting almost impossible and reduces the effectiveness of the radio.

Plastic pipes (30 by 2.5 cm) are used for masts. These are flexible and light.

Flotation. Many different flotation or buoyancy techniques can be used. Glass spheres are effective (Knauss, 1965; Raymond, 1968) but are expensive ($30 to $50 per float), have pressure limits, and are fragile. Styractene floats (Schick *et al.*, 1968) are even more expensive. Five-gallon polyethylene carboys filled with gasoline (Hubbs and McConnaughey, 1970) are inexpensive ($12 per float) and provide 5.2 kg of flotation each. Precaution must be taken to avoid combustion of the gasoline aboard ship, however. It is usually necessary to construct special easily jettisoned racks for storage of these floats on deck.

Isopar-M, manufactured by the Humble Oil and Refining Co., is a convenient bouyancy oil. This lightweight vehicle oil provides 5-kg bouyancy at the surface per 5 gallons and is less flammable than gasoline. It is an odorless, relatively high boiling (78°C), isoparaffinic solvent, with low skin irritation effects. Compressibility data (tabulated at 0°C) show a decrease in volume of 1.2% at 2000 psi and 5.5% at 10,000 psi. The cost is $1.24 per gallon if ordered in a 55-gallon drum. Five-gallon plastic carboys (jerry jugs) with large strong handles (for rope attachment) are used to hold the oil. The cost is $3.50 per jug.

In addition to the two floats attached to the mast assembly, there is also a secondary float (Fig. 1). For the hookline and plastic trap combination, one secondary float is sufficient. If other heavy instruments are used, it is necessary to provide more flotation in this position. Secondary floats can be tied loosely together in a bundle, whereas primary floats are clamped securely to the mast.

Handling lines. Fifteen meters of handling line (polypropylene, 1.25 cm diameter) separate the mast assembly and secondary floats. The purpose of the handling line is to allow separate launching and hauling aboard of the mast assembly (with fragile radios, etc.) and secondary float. This is especially useful when working from a large rolling ship with high freeboard. Another advantage of the handling line is that it can be seen at the surface between the primary and secondary floats to facilitate retrieval of equipment (described below). It is advisable to have 7.5

m of handling line between the secondary float and the instrument (hookline, traps, etc.). This allows the secondary float to be taken aboard the ship before the instrument.

Hookline and traps. The hookline (polypropylene, 0.6 cm diameter) and traps are situated (Fig. 1) between the secondary float and magnesium release. The hookline, or vertical setline, usually consists of 30 hooks spaced at one meter intervals on plastic leaders which are 30-60 cm in length. Squid bait is commonly used on size 8-0 or 9-0 hooks. With one or two traps on the hookline, 30 hooks, and extra line above and below the gear, the total length is 45 m.

Hooks and leaders can be permanently attached to the hookline or clamped on each time the gear is used. If hooks are permanently attached, the 45 m hookline is stored in a plastic tub (60 cm diameter, 45 cm deep). Cardboard boxes can be used, but they get wet each time the line is recoiled after a set, and must be replaced. The plastic tub is provided with enough slots on the rim to accommodate all hooks, and the line is coiled in the tub. Hooks are always baited before launching the free vehicle. Clamp-on hooks are probably more efficient, especially during retrieval of the gear, when large numbers of fish must be hauled aboard rapidly.

Many variations of this arrangement are possible. More hooks can be used (60-100); the traps can be eliminated, or the hooks can be eliminated. Eight plastic elliptical traps were tied in series at three-meter intervals in one experiment (Phleger *et al.*, 1970) off southern California, and yielded an average of 3.1 sablefish per trap. While free vehicle fishing for rattail fish off the Galápagos Islands, we found that hooklines were more effective than traps. Hubbs and McConnaughey (1970) use a hookline trap combination with the three-chambered trap located on the bottom. The catch includes organisms confined to the bottom (invertebrates and hagfish) as well as fishes that are likely to swim above the bottom. A horizontal hookline may be more effective in catching certain types of fish that stay close to the bottom. This can be used in combination with a trap (Fig. 2) and includes a wooden kite (paravane) to help spread the line

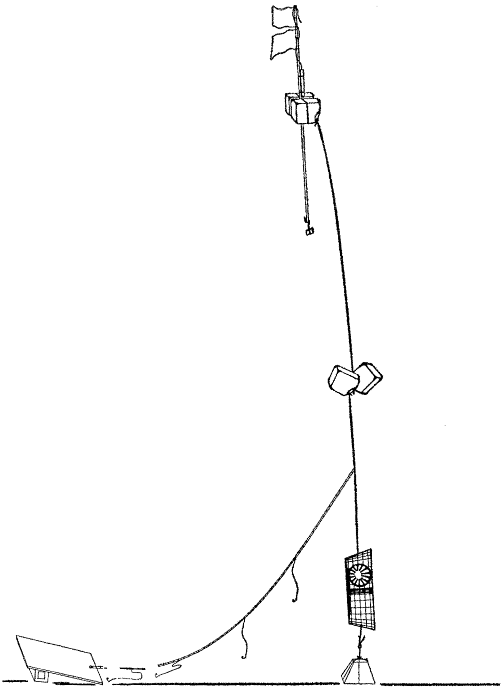

FIG. 2. The free vehicle horizontal hookline-trap combination. The top shows the plastic mast supported by two Isopar-M oil-filled jerry jugs with radio and flags. Fifteen meters of handling line connect to the secondary floats, below which is the trap and horizontal hookline. The trap is held on the bottom by a 27-kg weight, attached to a magnesium release. The horizontal hookline, with 30 hooks (spaced at 1 m intervals, not all shown in diagram), is spread out by a kite (paravane) attached to a magnesium link (not shown) and a 14-kg weight. This technique was developed by R. R. McConnaughey at Scripps Institution of Oceanography.

out on the bottom. The kite is constructed of plywood with dimensions of 100 by 60 by 1 cm.

Any instrument can be placed on the free vehicle between the secondary float and the release. Examples include current meters, cameras, sediment traps, and monster traps. Care must be taken to provide adequate flotation (at the secondary position) to hoist the instrument back up to the surface after the release has dissolved.

Release mechanisms. Anything that dissolves in sea water relatively independent of normal ocean temperature and pressure differences is a candidate for a release mechanism. Candy "Lifesavers" are used with good results in shallow water (75 m)

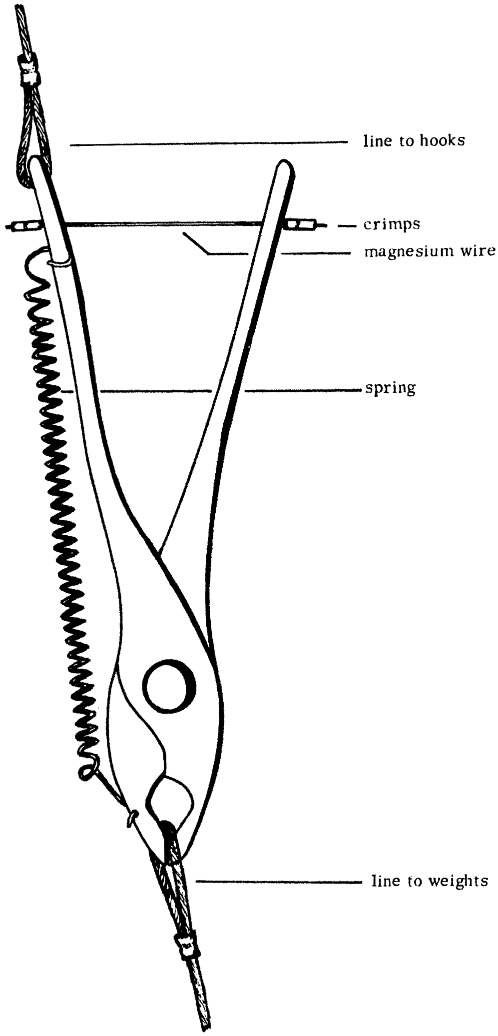

FIG. 3. A scale diagram of the wire-plier release mechanism. The magnesium wire has a diameter of 0.15 cm. When it dissolves in seawater, the spring insures that the pliers will snap open to release the weights (from Phleger *et al.*, 1970).

off La Jolla, California. In this simple device, the hookline, with two hooks, is tied between the candy and a corked bottle which is used as a float. A brick, tied to the candy, is used as the weight. These remain on the bottom about ten minutes before popping up to the surface with the catch. Instead of a brick with candy linkage, a bag of sugar can be used as the weight.

For the deep sea, it is better to use something that dissolves more slowly than sugar. Magnesium fulfills this requirement. It is necessary to make sure this metal is clean before use, and to provide an electron acceptor of some sort. The wire-plier release (Fig. 3) is an example of a device which is inexpensive, simple to construct, and works remarkably well in the ocean. One of the major benefits of this technique is that there is almost no strain on the wire itself. Only slight modification of a pair of pliers is necessary. Holes are drilled to accommodate a short length of thin (0.15 cm) magnesium wire. Another larger hole is drilled for attachment of the hookline. Grinding the handles of the pliers exposes the metal so it can act as an electron acceptor. After use in the ocean, the handles should either be well sanded or acid soaked in 0.1 N HCl for four hours. It is necessary to grind the grasping portion of the pliers for a snug fit, to insure that the line to the weights will remain attached. Inclusion of a spring on the pliers is optional, but it helps the pliers open when

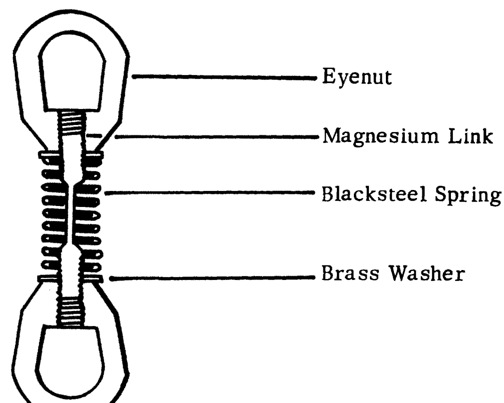

FIG. 4. A diagram of the magnesium rod or link release (from Schick *et al.*, 1968). The hookline is attached to the upper eyenut and the ballast is attached to the lower eyenut. Galvanized or black steel eyenuts with 0.9 cm thread diameter are used. A 0.9-cm diameter magnesium rod (alloy AZ31B) is used. The length of this rod is 6.3 cm and the length of the narrow center portion is 2.5 cm. A no. 68 black finish steel spring (4.4 cm length) is used with two 0.9 cm brass washers.

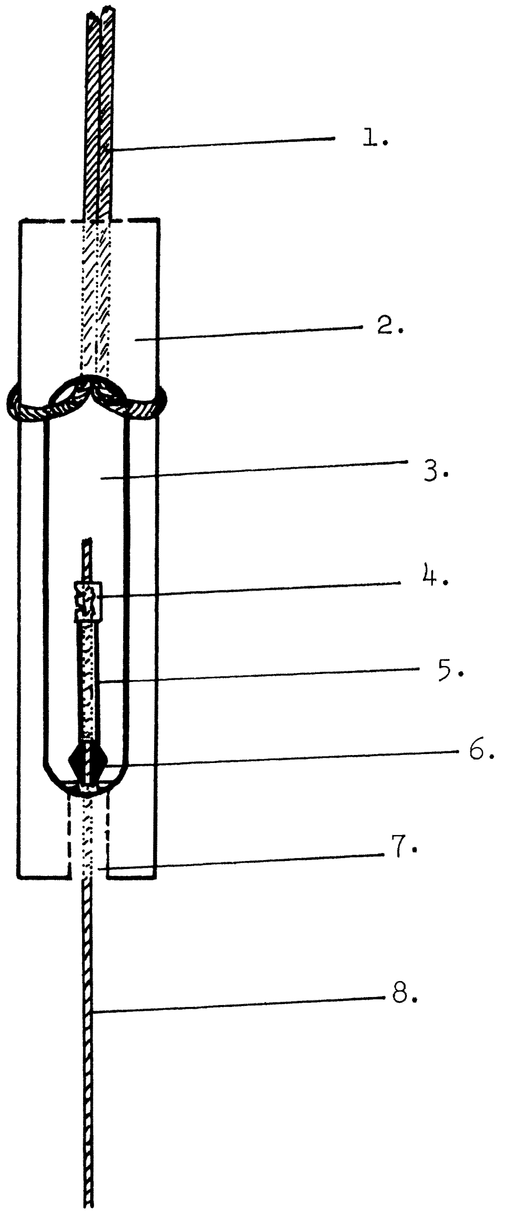

FIG. 5. The magnesium bead release. Short time. (1) 1/8" holding rope. (2) 3/4" micarta tube (tube diameter above Mg bead is 1/2"). (3) 1/2" slot milled through tube. (4) Brass crimp. (5) 5/8" long, 3/16" diameter stainless tube. (6) Magnesium bead (3/8" long, 1/4" maximum width). Bead rests on 1/2" stainless steel flat washer drilled to 0.242" internal diameter. (7) 3/8" drill hole in micarta tube. (8) 3/32" nylon rope. Designed by A. Soutar.

the magnesium has dissolved. These releases open after about six hours in sea water.

The magnesium rod (Fig. 4) is another type of release that is widely used with free vehicles. Since the magnesium takes the strain of the weights, its diameter must be greater (usually not less than 0.3 cm) than the wire-plier magnesium link. This means that magnesium rods are longer term release devices (ten hours and greater). The black steel spring acts as an electron acceptor, and helps insure that the device will release when the magnesium has dissolved. Any convenient steel surface such as steel wool (tied loosely around the link), will act as an electron acceptor. Sea water also provides this function, but corrosion times are much longer. Eyenuts are screwed onto the link for attachment of the hookline and line to the weights. The upper eyenut is retrieved with the hookline, but the lower eyenut, spring, and magnesium link are lost. The spring can be saved if it is tied to the upper eyenut by a monofilament. Black steel eyenuts provide an electron acceptor surface when springs are not available. These and the springs must be cleaned (in 0.1 N HCl) after each immersion in sea water.

One of us (Soutar) has recently built and successfully ocean-tested a magnesium bead release (Fig. 5). A series of diamond-shaped magnesium beads are placed on a line to provide flexible release times. Each dissolving bead rests on a hole in the bottom of a small metal pipe. The bead drops through the hole when its diameter has decreased sufficiently by dissolving in sea water. Another bead, situated higher on the line then drops out of an oil filled hose to rest on the same hole and repeat the process. Bead release times depend on the diameter of the widest part of the bead, but can be as little as two hours in the ocean. A large number of beads can be stored on the same line in the oil filled hose, providing an endless amount of scheduling flexibility. As shown in Figure 5, with a 5/8" stainless tube as electron acceptor, the device will release in about four hours. Other electron acceptors will vary the time. For example, ten No. 4

stainless lock washers will provide a release time of about 12 hours. If more than one bead is used, the stainless washer should be replaced each time. If it is not, it will become progressively plated with a mineral precipitate and will eventually block the passage of the bead. For multiple timings, a 1/4 in. nylon nut drilled to 0.242 in. internal diameter and then tapered to 0.260 in. at the base can be used.

A number of other release devices have been designed for use with free vehicles. A magnesium pin release is described (Schrader, 1965*b*) which is similar in principle to the magnesium bead release. In the technique, a knife blade which acts as an electron acceptor rests on top of the uppermost pin in a series of pins. After the pin has corroded, the knife is supposed to fall (pulled by the attached weights) to the next pin below, etc., until all pins are corroded. This magnesium pin cascade was envisioned as a long term release mechanism because each pin should require about 66 hours to corrode. Tests of this device, however, have revealed corrosion of the knife blade before all pins have dissolved. This greatly prolongs the release time, and introduces variability into predicted times, making it an essentially useless instrument.

A pressure release has been designed (Schick and Isaacs, 1961) which makes use of a thin metal rupture disc (such as heavy gauge aluminum foil) to break a sealed partial vacuum. When the disc ruptures, the equalization of internal pressure causes a spring to open jaws which release the weights. This pressure release can be triggered electrically by an attachment which triggers an explosive charge which ruptures the disc.

Weights. Since the weights, or ballast, are left on the bottom after the release dissolves, anything can be used for this purpose, as long as it sinks the free vehicle. A calculation of flotation versus weights should be made in advance. Consideration of ballast buoyancy in ocean water is important. A compact, heavy scrap metal hook weighs about the same under water as above water, whereas large porous cement blocks weigh less in sea water than in air. Almost anything that sinks works well as a weight, as long as it is possible to tie rope tightly to it. Cement blocks are convenient to obtain and easily tied. Scrap metal is also used, but different sizes are difficult to store on ship board. Rocks can be collected from a beach and tied in gunny sacks to save the expense of cement blocks.

Launching the free vehicle. Before launching, a thorough check should be made of all components which have been prepared on deck. Special attention should be given to knots. A failure in one knot can cause loss of the whole free vehicle. Loose line ends from knots should be securely taped. The launching process for the free vehicle vertical hookline-trap combination is illustrated in Figure 6A-D. It is important that one individual take responsibility for proper preparation and launching of the free vehicle.

The ship should head slowly into the wind at a speed of one-half to one knot. The mast assembly is carefully lowered into the water from the ship's fantail by means of the handling line (A). When the mast has drifted sufficiently away from the ship to preclude line entanglement, the secondary float is dropped overboard (B). As the secondary float drifts away, the hookline is carefully payed out (C). Care must be taken to avoid tangling the line. Wire cutters should be available in case someone gets hooked. Communication with the bridge is essential in case it is necessary for the ship to slow down or stop. The use of clamp-on hooks greatly simplifies the hookline payout process. When the end of the hookline is reached, the weights are lowered into the water (D). No strain should be put on the magnesium release until the weights are underwater and sinking. The launching of the free vehicle is completed successfully only after the mast assembly has sunk and completely disappeared from view. Occasionally a release breaks prematurely, or a knot fails, and the weights sink to the bottom without the gear. This is why it is neces-

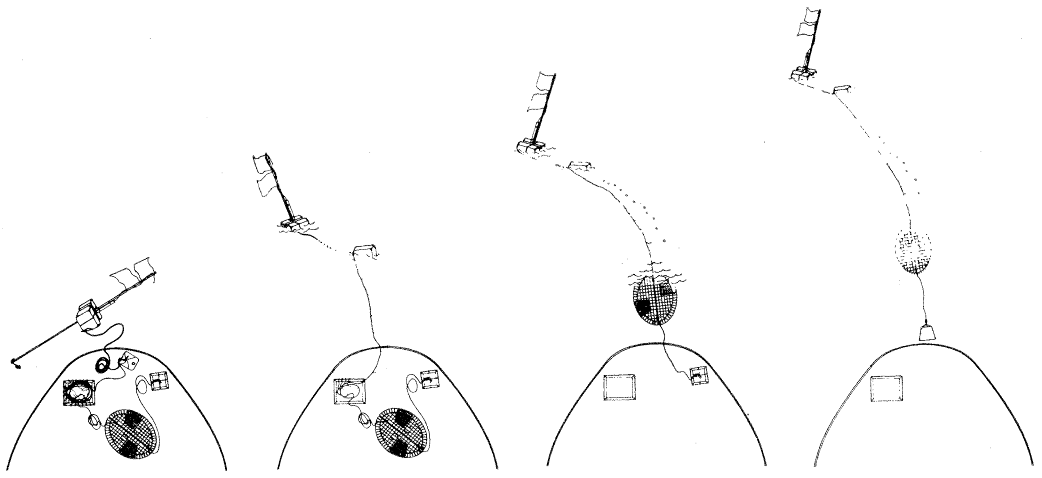

FIG. 6. Deck plan for setting the free vehicle and vertical hookline-trap combination. Process described in text. This diagram is revised from an original by R. R. McConnaughey.

sary to wait until the entire assembly has disappeared. A careful record of the location and the exact time of launching should be made.

Retrieving the free vehicle. Retrieval begins as soon as the free vehicle is located. The mast assembly is approached by the ship at a 90° angle to the current or wind direction on the downcurrent or downwind side. The mast assembly always drifts ahead of the secondary float and hookline. It is difficult for a large ship to come close enough to the mast so it can be gaffed easily. A hand thrown grapnel on a long line usually must be thrown over the handling line (visible on the surface) to snag it and then pull it towards the ship. Schick (1965) describes a grapnel that is fired from a line shooting gun, to increase distance and accuracy. When the mast assembly is next to the ship, it is carefully pulled aboard and placed on deck. Radios and flashing lights (if present) are switched off at this time. The ship's propellors will have been turned off as soon as grapnel contact is made with the gear. The secondary float is next taken aboard, and then the hookline. All lines should be carefully coiled and stored at the time of retrieval.

REFERENCES

Berger, W. H., and A. Soutar. 1967. Planktonic Foraminifera: Field experiment on production rate. Science 156:1495-1497.

Ewing, M., and A. Vine. 1938. Deep-sea measurements without wires or cables. Trans. Amer. Geophys. Union 19:248-251.

Hochachka, P. W., D. E. Schneider, and A. Kuznetsov. 1970. Interacting pressure and temperature effects on enzymes of marine poikilotherms: Catalytic and regulatory properties of FDPase from deep and shallow-water fishes. Marine Biology. 7:285-293.

Hubbs, C. L., and R. R. McConnaughey. 1970. Description of free vehicle vertical setline trap combination developed and used by the marine vertebrates group of Scripps Institution of Oceanography (Unpublished manuscript).

Isaacs, J. D., and G. B. Schick. 1960. Deep-sea free instrument vehicle. Deep-Sea Res. 7:61-67.

Isaacs, J. D., J. L. Reid, Jr., G. B. Schick, and R. A. Schwartzlose. 1966. Near-bottom currents measured in 4 kilometers depth off the Baja California coast. J. Geophys. Res. 71:4297-4303.

Knauss, J. A. 1965. A technique for measuring deep ocean currents close to the bottom with an unattached current meter and some preliminary results. J. Mar. Res. 23:237-245.

Moore, D. G. 1961. The free-corer: Sediment sampling without wire and winch. J. Sediment. Petrology 31:627-630.

Patton, S., and A. J. Thomas. 1971. Composition of lipid foams from swimbladders of two deep ocean fish species. J. Lipid Res. 12:331-335.

Phleger, C. F., A. Soutar, N. Schultz, and E. Duffrin. 1970. Experimental sablefish fishing off San Diego, California. Commer. Fish. Rev. 32:31-40.

Phleger, C. F., and A. A. Benson. 1971. Cholesterol and hyperbaric oxygen in swimbladders of deep sea fishes. Nature 230:122.

Raymond, S. O. 1968. Glass floats and boomerangs. Mar. Sci. Instrum. 4:231-240.

Sachs, P. L., and S. O. Raymond. 1965. A new unattached sediment sampler. J. Mar. Res. 23:44-53.

Schick, G. B. 1965. Shoot a line. Geo-Mar. Technol. 1. No. 10.

Schick, G. B., and J. D. Isaacs. 1961. Underwater remote programming. Undersea Technol. Nov-Dec:29-32.

Schick, G. B., J. D. Isaacs, and M. H. Sessions. 1968. Autonomous instruments in oceanographic research. Mar. Sci. Instrum. 4:203-230.

Schrader, E. W. (ed). 1965*a*. Free probe measures currents on ocean floor. Design News 20:36-37.

Schrader, E. W. (ed). 1965*b*. Magnesium pins corrode in sea water to set release time. Design News 20:92-93.

Schwartzlose, R. A., and J. D. Isaacs. 1969. Transient circulation event near the deep ocean floor. Science 165:889-891.

Sessions, M. H., J. D. Isaacs, and R. A. Schwartzlose. 1968. Underwater photo-optical instrumentation applications. Seminar reprint. Scripps Institution of Oceanography (Unpublished manuscript).

Sholkovitz, E. R. 1970. A free vehicle bottom-water sampler. Limnol. Oceanog. 15:641-644.

Snodgrass, F. E. 1968. Deep-sea instrument capsule. Science 162:78-87.

Van Dorn, W. G. 1953. The marine release-delay timer. Oceanographic Equipment Report No. 2. SIO Ref. 52-23 (Unpublished manuscript).