# 3

# Methods of study of the organisms of the deep-sea floor

To study the organisms of the deep-sea benthic boundary (which of course is well beyond the present range of deep-sea divers), the biologist requires a platform from which to deploy the special sampling gear or experimental apparatus needed to examine, observe or experiment with the biota. This platform can take two forms: a specialized oceanographic research vessel, or a research submersible, usually operated from a research vessel doubling as 'mother' ship.

Usually such vessels are engaged in voyages, or 'cruises', lasting from a few days to several months. Preparations for a deep-sea cruise have to be very thorough as the sites to be sampled are often remote from land. Although the logistics of such an undertaking are complex, involving all aspects of ship management, the scientist in charge of the cruise is responsible for identifying the equipment necessary for sampling as well as the equipment required for onboard laboratory analysis. The different categories of bottom-dwelling deep-ocean fauna (summarized at the beginning of Part II) naturally present differing problems when trying to collect samples, or in deploying other apparatus, for studying them. Furthermore, it will be necessary to accurately estimate bottom depth and positional coordinates of the ship, and for any overside gear in relation to it; while data on the nature of the bottom and the structure and dynamics of the overlying water column will also assist a successful programme. The chief scientist will also be required to programme the activities of the research cruise, and this has to be conducted with the same rigour required for experimental design in the laboratory. Sampling design has become a discipline in its own right, and the reader is referred to Barnett (1974), Elliott (1971) and Green (1979) for simple accounts. However, this has to be tempered by the realities and uncertainties of work at sea, such as bad weather, which puts any gear placed in the sea at severe risk. Hence, gear losses, along with the high cost of operating at sea, have to be accepted as a fact of life.

In this chapter we outline the main features of a deep-sea oceanographic research vessel. We then describe some of the supporting equipment and sampling gear necessary for collecting and observing the organisms of the benthic boundary. Some of the more specialized equipment for monitoring *in situ* the activities associated with these organisms on the seabed are described in relevant later chapters.

## OCEANOGRAPHIC RESEARCH VESSELS

There is a wide variety of research vessels and a review of the different types is beyond the scope of this text; but all share some basic characteristics. Their propulsion is specialized not for speed but to hold position when on station. Although such vessels are often equipped for a variety of non-biological functions, they require specific basic equipment for biological sampling of the deep sea. A seagull's eye view of the working deck area of a typical composite monohull research vessel is shown in Fig. 3.1.

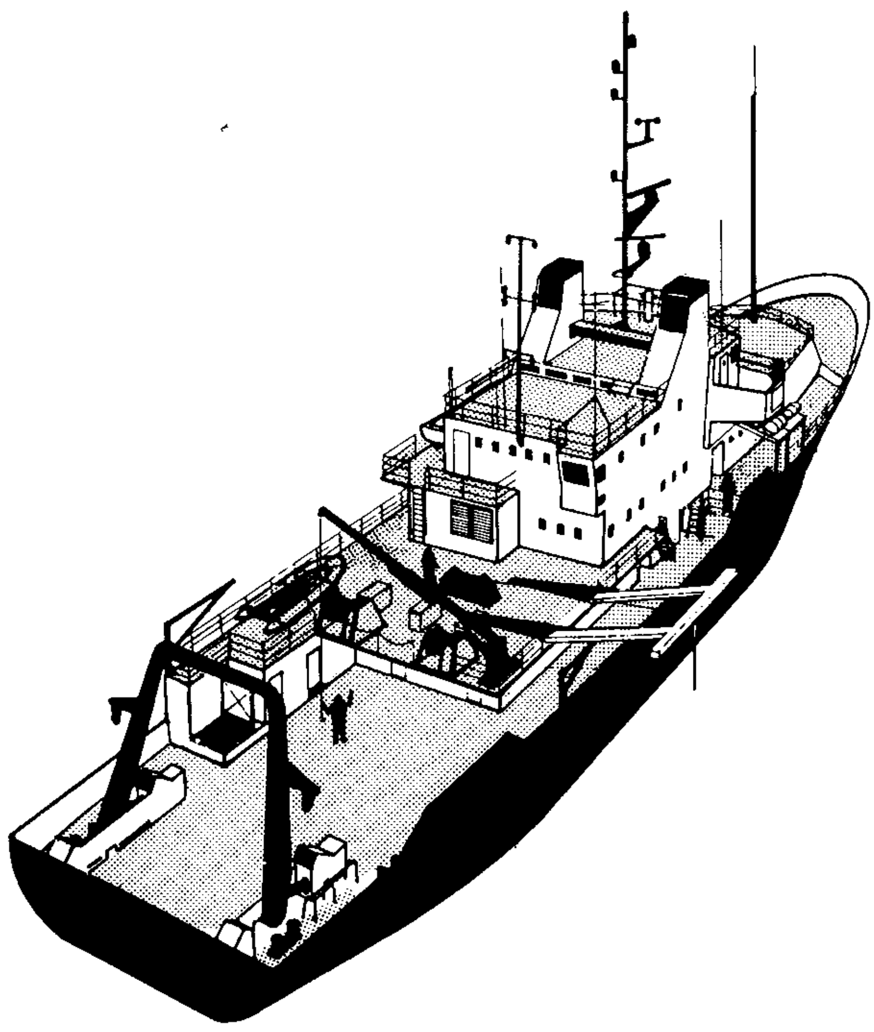

Fig. 3.1. View of stern working decks of the Royal Research Ship 'Challenger', a small multifunction research vessel, 54.3 m overall length, operated by the British Natural Environment Research Council. A controllable pitch propeller and bow thrusters provide manoeuvrability to stay on station. R.R.S. 'Challenger' can carry 14 scientists and is able to stay at sea for about 32 days without refuelling. She carries 13 km of deep trawling wire (tapered from 13 to 19 mm diameter) along with twin drums of 3.4 km of 22 mm heavy trawling wire, on drums mounted below the laboratory space. The wire is lead via sheaves to blocks carried from the stern 'A'-frame, or from the midships 'A'-frame on occasions when it is important to minimize the effect of surge on the wire from the pitching motion of the ship. (Modified from drawing courtesy NERC Research Vessel Base, Barry, S. Wales.)

## FRAMES AND CRANES

To deploy sampling gear over the side, it is necessary to use a frame or crane to allow deck clearance on deployment and retrieval. The most common type is the stern – or midships mounted gantry or 'A-frame' fitted with running blocks. For the vertical deployment of sampling apparatus, cranes are also often used. The A-frame is used especially when equipment is being towed but may also be used for the vertical deployment of sampling gear, or for towing trawls or dredges. If the A-frame is mounted at the stern of the ship, it will experience maximum vertical movement during pitching. As a result, a subsidiary A-frame and cranes for deploying gear vertically, such as box-corers (see p. 48) are often placed near the nodal point of the ship (as on R.R.S. 'Challenger', Fig. 3.1) to minimize sample-damaging surge effects resulting from this vertical movement.

Tension meters, usually consisting of load-cells fitted to a sheave or in the blocks on the A-frame, measure the strain on the wire during pay-out and tell you when the sampling gear is on the bottom. The tension reading is critical in the deployment of box-corers (see below) and will also indicate when a towed trawl or dredge has come fast on the bottom.

## WINCHES AND WIRES

The main wire of a research vessel can be of differing types. The wire's diameter is often 'tapered' by splicing together lengths of decreasing diameter in order to reduce the total load on the wire resulting from its weight and drag in deep deployments. These wires typically consist of 16 strands of galvanized high-tensile steel wire with a rope core and, although very strong, may 'catspaw' or kink if wrongly deployed. To remedy this difficulty, new cables have been developed which consist of three major strands that do not kink when tension is removed from the wire. In addition, wires with an electrically conducting core are available to power on-gear lights or sensors, but the length of these generally limits them to midwater.

To sample the deepest oceans, at least 11 km of wire (cable or warp) would be required to lower sampling apparatus vertically. If sampling equipment is to be towed, the amount of wire necessary to ensure the gear reaches the bottom depends on its weight and drag, the towing speed (drag on cable) and depth. The great weight of the wire payed out to great depths means that the weight and drag of the wire itself becomes evermore important in the equation, resulting in an ever-decreasing ratio of pay-out to depth (Fig. 3.2). A towed length of wire with nothing on its end will be straight, its angle dependent on its drag per unit length, pay-out and towing speed. Because of the time required to pay-out from the winch, it is important to use only sufficient wire to put the gear on the bottom and ensure it stays there. By adding a heavy weight with little drag, the wire begins to curve downwards, the angle between the outboard end and the sea surface increasing; whilst a terminal load with high drag, such as a trawl, will result in an upwards curvature with a decrease in this angle (Fig. 3.3(*a*)). Hence, artificially weighting a trawl by

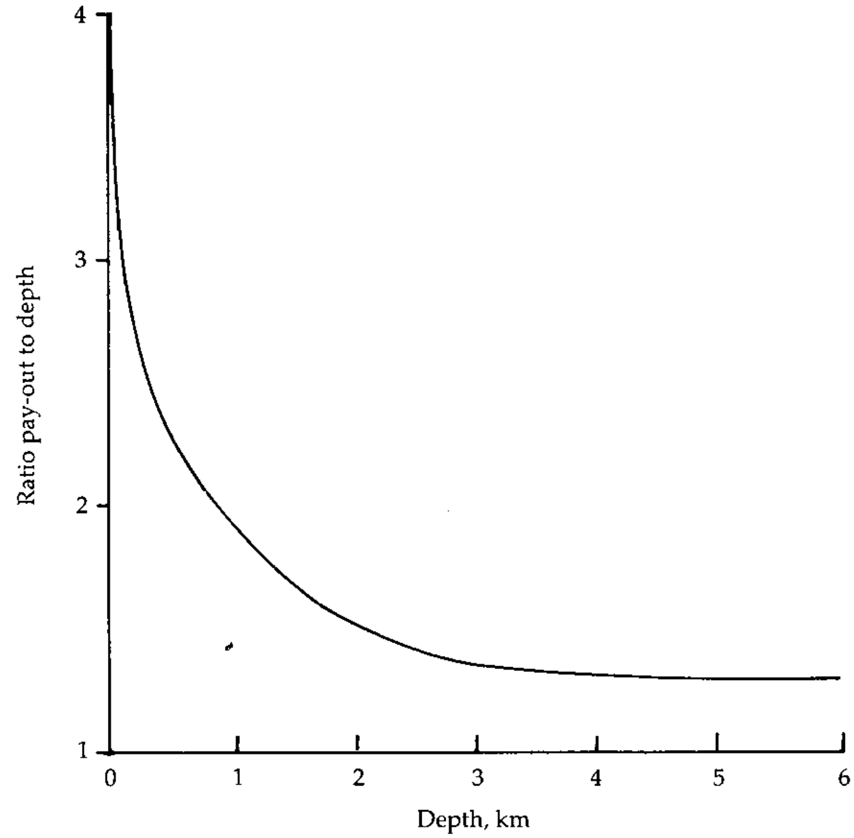


Fig. 3.2. Ratio of wire pay-out to depth (scope ratio) necessary, with the ship steaming at about 1 knot over the ground, to ensure the gear (an anchor dredge) bottoms. Because of the relatively low drag from the gear and the great weight in large pay-outs of wire, the amount of wire need be more than twice the depth only for depths less than 1 km. (Data from Carey & Hancock, 1965.)

attaching weights to the wire can allow a considerable reduction in the pay-out necessary to reach bottom (Rowe & Menzies, 1967; Laubier, Martinais & Reyss, 1972). Where weights are not used, and where the gear is light with little drag, it is reasonable for the purpose of predicting pay-out to assume a straight wire. Here the minimum pay-out at a given speed will then depend on the weight of the wire payed out. The velocity-dependent drag of the gear on the curvature of the wire, and hence the pay-out necessary over a straight wire, becomes important only with larger gear with high drag (Fig. 3.3(*b*),(*c*)), such as fish trawls. The current velocity profile of the water column can also much affect these calculations, but is rarely known. For this reason alone precision is best achieved by use of an acoustic beacon or 'pinger' (see below). A fuller treatment of the mechanics of deep wire deployment is given by Kullenberg (1951) and Laubier *et al.* (1972).

## SWIVELS AND WEAK LINKS

When a piece of equipment is towed at the end of 10 km of wire (as trawls and sleds often are) a tremendous twisting torque develops on the towing wire as it is unwound from the drum. Ball-bearing swivels (see Fig. 3.12(*a*)) are inserted near the towed gear to allow the wire to turn without going into tangles which can easily weaken or even break the wire. The

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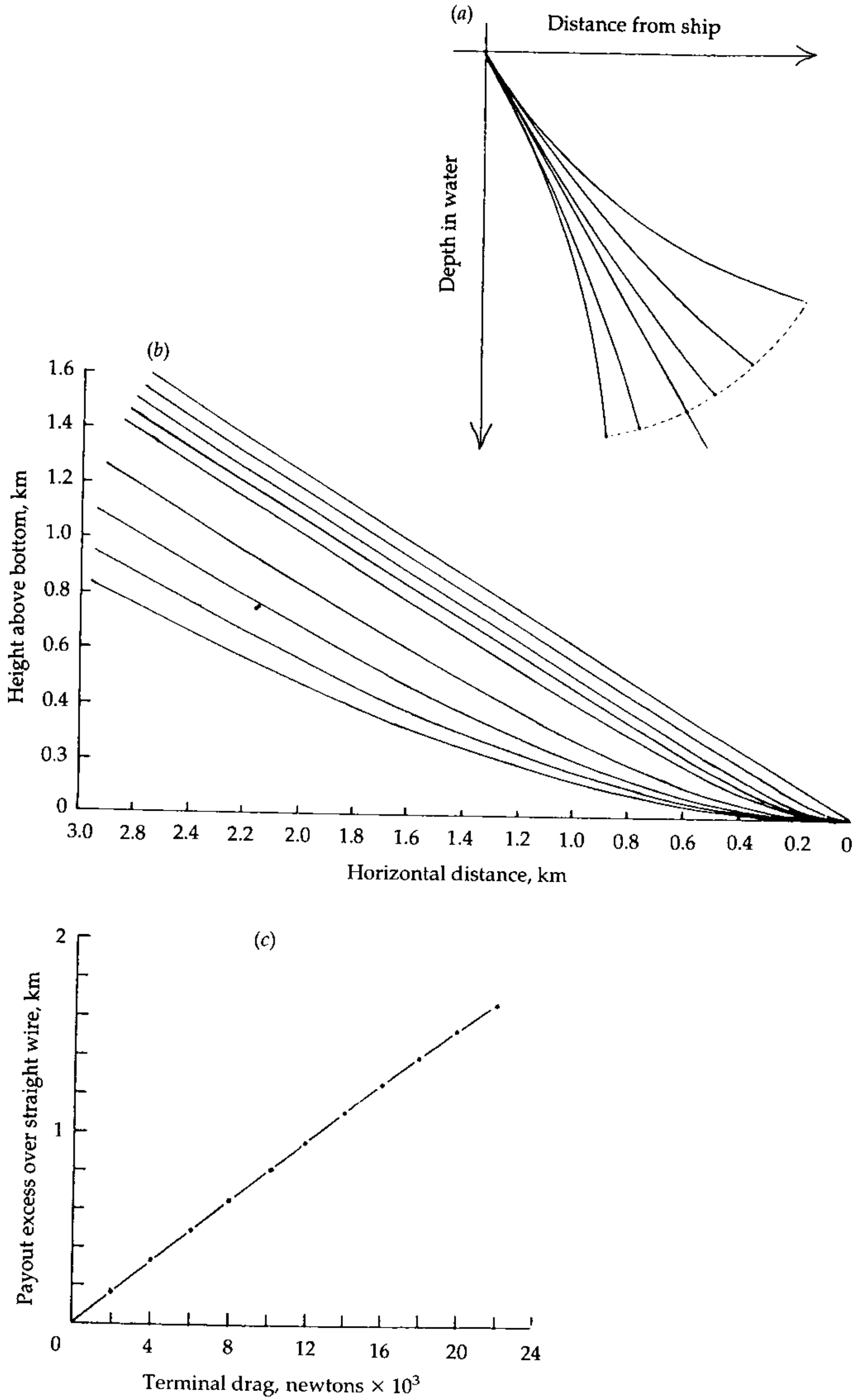



Fig. 3.3. Wire profiles assumed under different conditions at constant speed through water: (*a*) Varying shape of curve expected with increasing drag (left to right) of terminal load relative to its mass: left-hand curves show profile expected when terminal weight is greater than its drag through the water (such as for an epibenthic sled or anchor dredge); right-hand curves when this weight becomes increasingly less than its drag (such as for a fish trawl). Note a straight wire will also be assumed with wire on its own. These curves indicate the advantage gained from weighting a trawl by attaching heavy weights to the wire in order to reduce payout necessary to bottom the gear. (*b*) Family of curves showing profile assumed with increasing drag, such as would be caused by increasing the mouth opening of the sampling gear. (*c*) Calculated excess of wire required as a function of bottom drag on an epibenthic sled. (*b*) and (*c*) calculated using a numerical procedure. (From Booth & Gage, 1980.)

weak link (see Fig. 3.12(*a*)), which consists of either turns of fine gauge wire or a shear pin rated to break at a specified load (which must be less than the 'yield' point of the wire where it becomes permanently stretched prior to breaking), is used in case the towed gear becomes snagged on the seabed. If this occurs, the safety line (Fig. 3.12(*a*)), fitted from the rear of the gear to the ship-side of the weak link, pulls the sampling gear around the obstruction. This prevents the loss of the sample, sampling gear and many metres of wire.

## PRECISION PINGERS

These are acoustic beacons which have a variety of uses in monitoring the depth of deployed equipment when attached to, or clamped to the wire near, the gear. They were originally used as an aid in trawling and grab sampling in order to tell when the gear was on the bottom (Bakus, 1966; Bandy, 1965). The pinger signal is often received using the same transponder as used for the Precision Depth Recorder (PDR) (see below), but for gear towed some distance behind a ship, backwards-looking or directional hydrophones are often necessary. When the direct and bottom-reflected signals converge, the gear is known to have reached bottom. It is also possible by evaluating the time delay of the two sonar

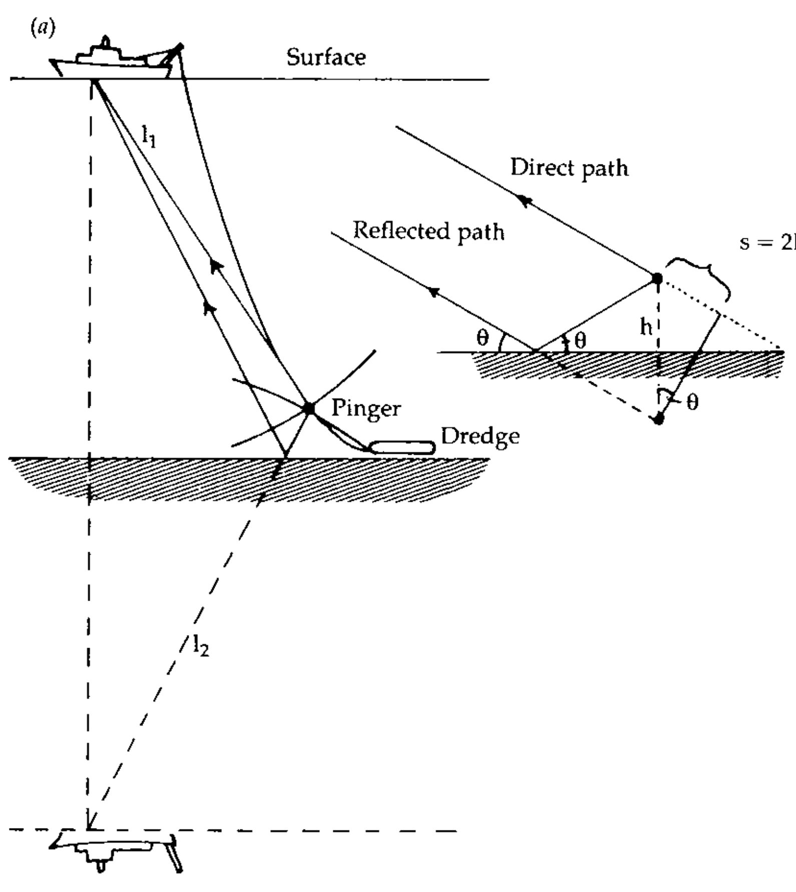
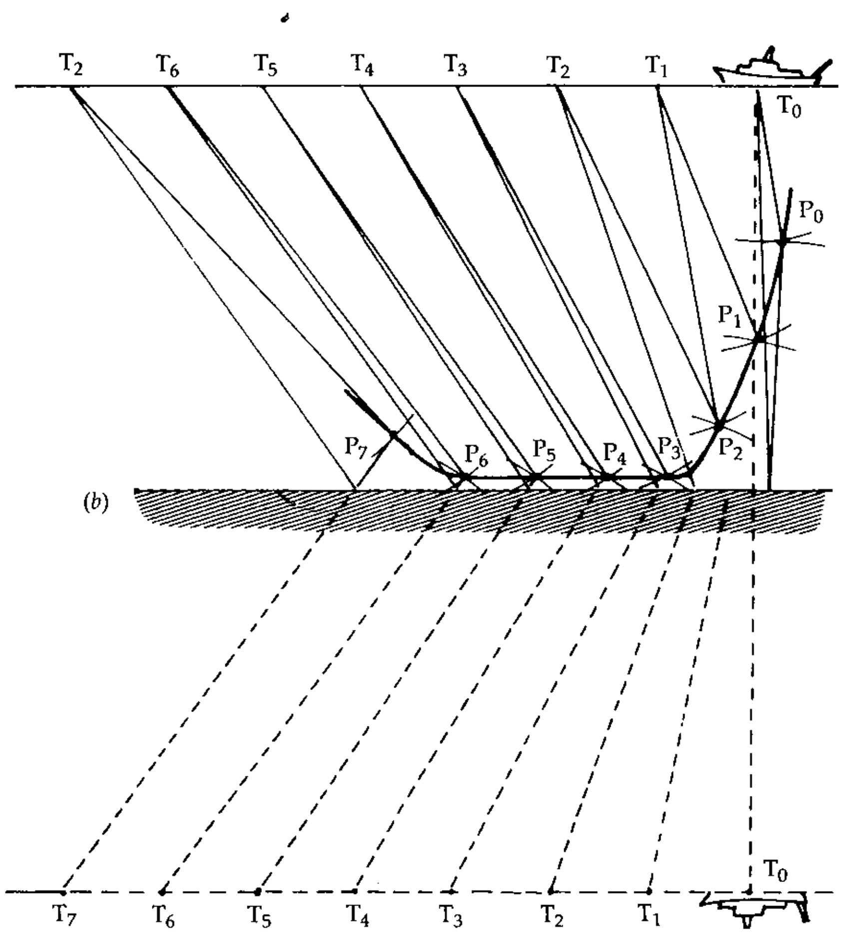



Fig. 3.4. Use of acoustic pinger to evaluate track of sampling gear on bottom. (*a*) The difference, $\delta$, of the sonar paths between the pinger fixed to the wire near the bottom sled shown in (*a*) and the ship, and between the pinger and the ship after reflection of the 'ping' from the bottom, is equal to $2h \sin \theta$, $h$ being the distance of the pinger from the bottom (angle $\theta$ is defined in the inset drawing). Knowledge of the two lengths of these sonar paths permits determination of the exact position of the pinger in relation to the ship in the vertical plane. The pinger is found at the intersection of two circles, one centred on the ship and the other on the 'reflected image' of the ship in relation to the bottom, whose respective radii are $l_1$ (direct path) and $l_2$ (reflected path). These circles intersect at two points, both symmetrical in relation to the vertical plane of the ship.

paths, one received directly from the pinger and the other reflected from the bottom, to determine the exact position of the pinger in relation to the ship in the vertical plane (Fig. 3.4(*a*)). The bottom track of the gear may be calculated by continuously monitoring the operation (Fig. 3.4(*b*)). Hessler & Jumars (1974) describe the use of the pinger in box-coring where it is used in determining the distance of the corer above the seabed. Relatively massive gear such as box-corers can give a pinger reflection which allows direct monitoring of the position of the gear relative to the seabed.

## NAVIGATION

All modern deep-sea research vessels will be equipped with Satellite Navigation systems utilizing Transit satellites and Decca Navigator or Loran C utilizing shore-based medium-frequency radio direction-finding transmitters. The Global Positioning System (GPS) currently coming into service, and to be fully implemented in the mid-1990s, promises to provide ultra-precise, satellite-derived positional fixes from a 'constellation' of up to 24 satellites, so that at least four will be within range of the ship, i.e. more than 5 degrees above the horizon.




(*b*) Shows the successive positions of the ship ($T_0$, $T_1$, ...) and a pinger-monitored beam trawl ($P_0$, $P_1$, ...) plotted by means of this model. (Redrawn from Laubier, Martinais & Reyss, 1972.)

Under the constraints of each system, all can provide continuous readouts of the ship's position during sampling. Using these data, it is possible to plot the position of sampling gear on the bottom which may be 5 km or more behind the ship. A review of position fixing of ship and gear in benthic ecological studies is given by Holme & Willerton (1984). In several recent scientific expeditions to the deep sea involving intensive studies on one station, acoustic transponders (usually three or four) are deployed on the bottom (Fig. 3.5) and the position of sampling equipment is determined relative to these and to absolute position determined by Transit or GPS satellites (Rowe & Sibuet, 1983). Such transponders can be left moored on the bottom for extended periods when they are particularly valuable if the site is to be revisited in the future as part of a long-term experiment.

## PRECISION DEPTH RECORDERS

The precise depth of sampling is obtained by the use of precision echosounding using PDRs, which display depth either on a paper record or digitally. These data are then corrected for the differing speed of sound through water of differing physical properties either manually, or by

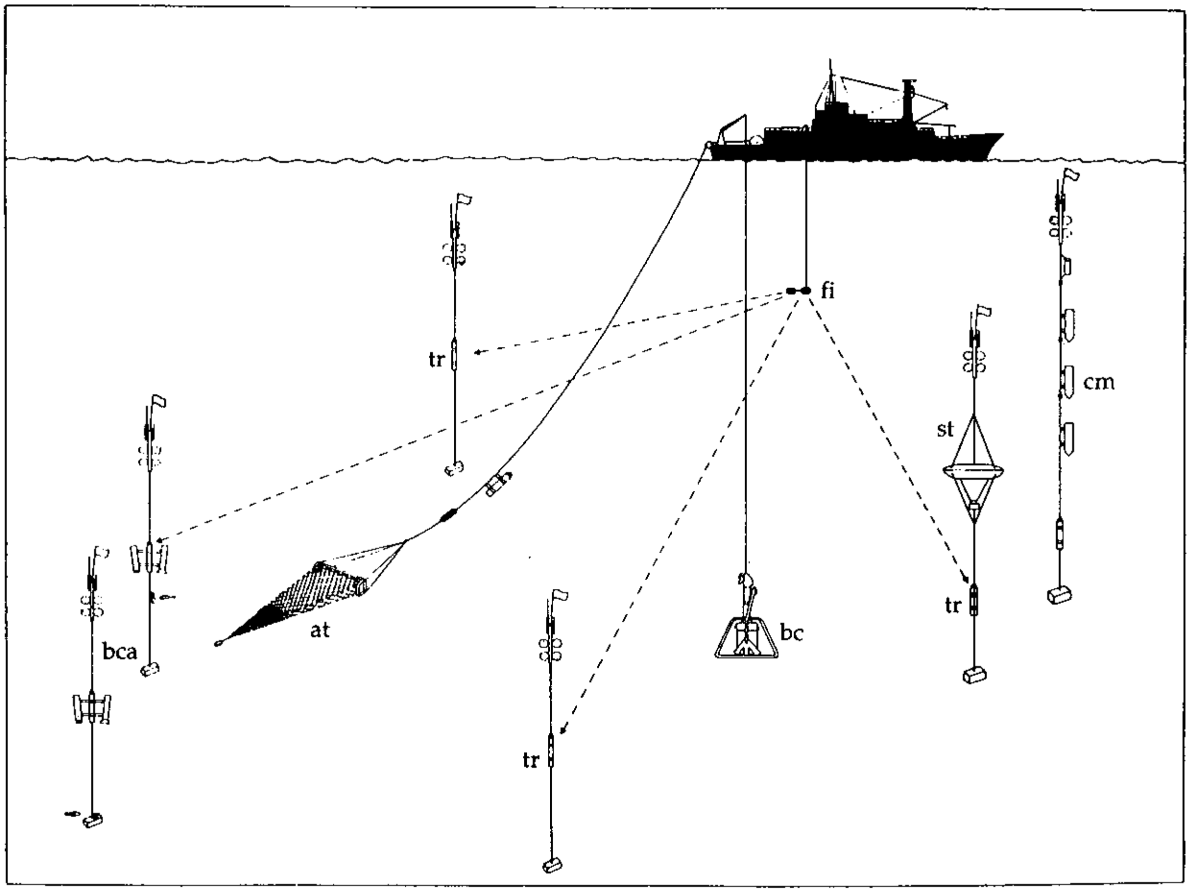



Fig. 3.5. Array of four acoustic transponders as used by the French research vessel 'Jean Charcot' on the Demerby cruise in 1980 for plotting the locations and bottom tracks of the various biological deployments indicated in the diagram; tr, transponder moorings on the bottom; fi, towed 'fish' containing listening transducer; at, Agassiz trawl; bc, box core; bca, baited camera; st, sediment trap. On the right, cm is a multiple current meter mooring. (Modified from Guennegan & Martin, 1985.)

computer program, using empirical tables for geographical areas of the ocean. The PDR may be used for a rough survey of an area before sampling gear is deployed. For a more detailed topographic chart of deep-sea area, swath-mapping sonar, such as 'SEABEAM', consisting of a multibeam echosounder interfaced with a computer and high-speed plotter, will give immediate visualization of seabed topography (Renard & Allenou, 1979; Rowe & Sibuet, 1983).

## RESEARCH SUBMERSIBLES

Although surface ships have been used for deep-sea biological studies for over a century, it is in the last 20 years that rapid advances have been made in the use of manned and unmanned research submersibles for ecological observations and for *in situ* experimentation (Geyer, 1977).

### MANNED SUBMERSIBLES (DEEP-SEA RESEARCH VEHICLES, OR DSRVs)

These may be used for sampling as well as for observational studies, especially in areas inaccessible to sampling gear operated from surface vessels and unmanned submersibles, such as steep rocky slopes and canyons. Heirtzler & Grassle (1976) note that, compared to remote sensing, an observer from a submersible has a much clearer visualization of the interrelationships of environmental components. However, the main benefit of the manned submersible lies in its potential for manipulative experimentation at the deep-sea bed, and for detailed observation within circumscribed areas such as hydrothermal vent fields. More specifically, Grassle (1980) suggests that submersibles are the only way: (a) to sample small-scale features; (b) to sample repeatedly at a specific site over a number of years; (c) to push sampling devices into the seabed without sediment disturbance; (d) to navigate around obstacles in areas of complex topography, and (e) to sample specific layers in the water column. There are very few manned research submersibles with a depth capability greater than 1 km (Heirtzler & Grassle, 1977). Of those capable of 1 km depth, the most sophisticated is the 'Johnson Sealink' which utilizes a plexiglass rather than a steel sphere (Fig. 3.6). Of the deeper diving submersibles which require a steel or titanium sphere with port-holes, the best known are the American 'Alvin' (Fig. 3.7), commissioned in 1964, and the French 'Cyana' and 'Nautile'. Of these, 'Alvin' and 'Cyana' have a depth capability of 4 km and 3 km respectively whilst only the 'Nautile' (see Fig. 15.3), the U.S. Navy's 'Sea Cliff', the Russian 'Mir I' and 'Mir II', and the Japanese 'Shinkai 6500' are capable of descending to 6 km and thus penetrate to all the deep oceans except the trenches. All experimentation must be designed within the manipulative capability of the mechanical arm fitted to the submersible and its maximum lifting capacity. Rowe & Sibuet (1983) summarize the various devices that can be operated by 'Alvin' including devices for sampling the deep-sea bed and for manipulative experimentation. The use of DSRV 'Alvin' in deep-sea experimentation is described in Chapters 6, 8, 11, 12, 14 and 15 of this

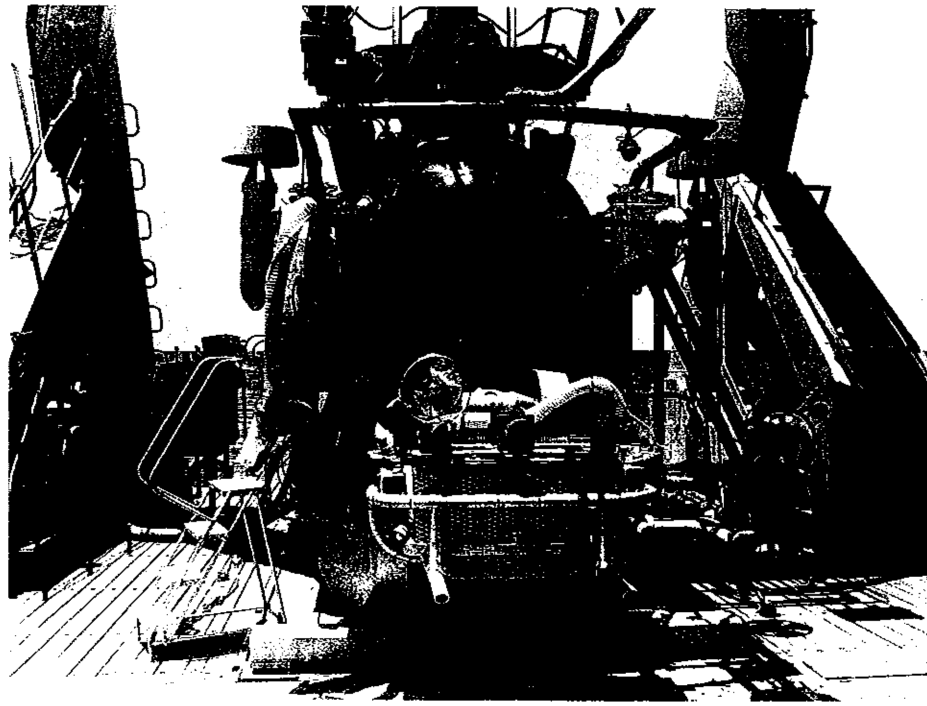


Fig. 3.6. 'Johnson Sea-Link' manned submersible shown on aft deck of mother ship under the A-frame used to lift it into and out of the water. The submersible has a 10-cm thick transparent, acrylic sphere that accommodates the pilot and one observer, and provides panoramic visibility. (Courtesy Harbor Branch Oceanographic Institution Inc.)

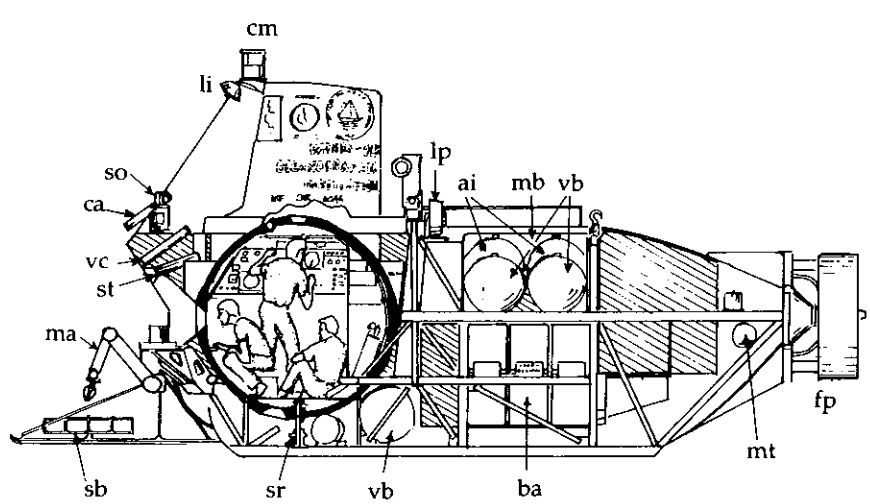



Fig. 3.7. The manned deep-diving submersible DSRV 'Alvin' shown with its pilot and two scientists within the titanium pressure hull (black), and equipped with rotating sample basket (sb) below the manipulator arm (ma) for collecting specimens and transporting experimentation. Other labelling: ca, camera: st, strobe; vc, video camera; so, sonar; li, floodlight; cm, current meter; mb, main ballast; vb, variable ballast; ai, air; mt, mercury trim; ba, batteries; fp, main propeller; lp, rotatable lift propeller; sr, sphere release. Hatched areas, syntactic foam buoyancy. (Modified from Ballard, 1982.)

book. However, the main problem of submersible studies in the deep ocean is their expense, their weather limitation for launch and recovery, and the possible risk to the investigators (Rowe & Sibuet, 1983).

## UNMANNED RESEARCH SUBMERSIBLES (REMOTE OPERATED VEHICLES, OR ROVs)

These include a range of towed, tethered or free-moving vehicles that are usually controlled from the surface. Towed ROVs have been developed from deep-towed instrument packages; they include the American Acoustically Navigated Geologic Underseas Survey (ANGUS), and the newer 'Argo', both of which are towed sleds equipped with a variety of sensors. Although possessing no independent propulsion, 'Argo' is capable of operating to 6 km depth, at altitudes above bottom of 20–40 m, towed by a coaxial cable by which it can be manoeuvred very precisely. This tether also carries power to the vehicle and data from the vehicle's various sensors. These include a wide-area TV imaging system that is integrated with sideways-looking sonar in order to provide a picture of a broad swath of seabed. The small, unmanned 'Jason Jr' vehicle (Fig. 3.8) demonstrates a successful marriage between a ROV and a larger submersible; having been used in umbilical connection to both 'Alvin' and 'Argo'.

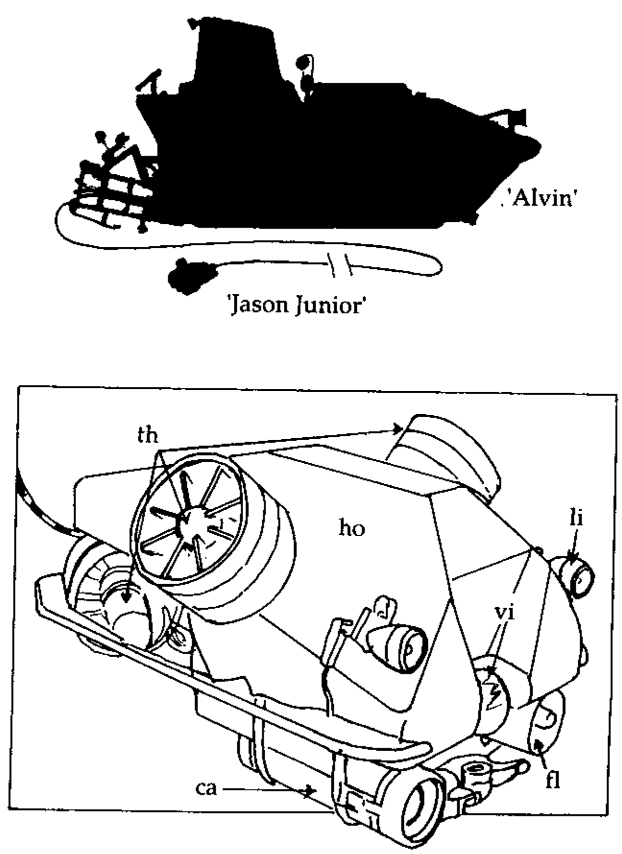



Fig. 3.8. 'Alvin' (above) with the small Remote Operated Vehicle, or ROV, 'Jason Jr' (enlarged in inset below) attached to it by a 61-m long umbilical. ca, camera; fl, flash; th, thrusters; vi, video camera; li, lights; ho, vehicle housing. ((*a*) Modified from Ballard (1975). (*b*) Modified from drawing copyright National Geographic Society.)

The Remote Underwater Manipulator, RUM (Busby, 1977; Jumars, 1978) belongs to a generation of remotely controlled tracked vehicles designed to crawl over the bottom. RUM is controlled and powered from an Oceanographic Research Buoy (ORB), a floating research platform (Jumars, 1978). During expedition 'Quagmire' (Thiel & Hessler, 1974), in addition to its camera and TV capability, RUM was successfully modified to take four square cores 10 × 10 cm each at precisely located stations at a 1.22 km depth site in the San Diego Trough (Jumars, 1978; Jumars & Eckman, 1983). Smith (1974) and Smith & Hessler (1974) have also used RUM for studies of respiration of deep-sea fish and to determine sediment oxygen demand in the San Diego Trough. Untethered ROVs that operate under their own power include the French 'Epaulard', and the Japanese 'Dolphin-3K'. These types of vehicle are under active development in many countries and promise to provide a low-cost, portable vehicle for use in a variety of applications. These will be primarily observational studies using photography and videos, but also manipulations such as coring and the emplacement and retrieval of seabed experiments (Hanson & Earle, 1987). They are also of use in broad surveys of the seabed. Photography as a tool of the deep-sea biologist is discussed below.

The role of submersibles is now firmly established in deep-sea research and offers some of the most exciting prospects for the future.

## SAMPLING EQUIPMENT

The equipment used for sampling in the early voyages (see Chapter 1) consisted of coarse mesh trawls and dredges hauled up on hemp ropes often by muscle power (Mills, 1983; Rice, 1986). These apparatuses are still in use today although they have been updated and supplemented by much more sophisticated sampling devices.

Within the limitations of the research vessel, the type of sampling gear deployed depends on the sort of sample required: is it to be 'quantitative' in the sense of being representative of a known bottom area, or is it sufficient to just catch a representative or selective part of the fauna present in the area? It also depends on the size of the organism or the community of interest (apparatus needed to sample sediment bacteria will be different from that required to catch large swimming animals). The seasonal timing of the sample may also be important. As we shall see later, certain deep-sea processes are driven by seasonally pulsed production so that a seasonal sampling programme may be required. The deployment of the sampling gear also varies – some are towed, some are lowered vertically, and some are deployed untethered as 'free-fall' samplers. Thus we see that the choice of sampler and its deployment depends on a variety of factors. In this section we look at the more common types that have been developed for sampling the organisms of the deep-sea benthic boundary, and outline their purpose.

## QUALITATIVE/SEMI-QUANTITATIVE SAMPLERS: TRAWLS

One of the mainstays of deep-sea biological research since the last century has been the Agassiz trawl (Fig. 3.9(*a*)), also called the Sigsbee or Blake trawl (named, respectively, after the Captain and the ship used by the American pioneering naturalist Alexander Agassiz). This is a double-sided beam trawl adapted from gear once commonly used by coastal fishermen. It has a main net of 20 mm mesh and the cod-end is lined with shrimp netting with a mesh of 10 mm. The Agassiz trawl is used principally for collecting large numbers of benthic megafauna and elements of the benthopelagic fauna (see Chapter 4). The large beam trawl shown in Fig. 5.9(*b*), which similarly has an origin from coastal fisheries, can also be used for catching megafauna.

A variety of trawls have been used to collect benthopelagic fish in the deep sea. Each obtains a different catch, reflecting variations in behaviour and lifestyle of the fish species present, so comparisons between surveys are often difficult unless similar gear is used, fished in a standardized

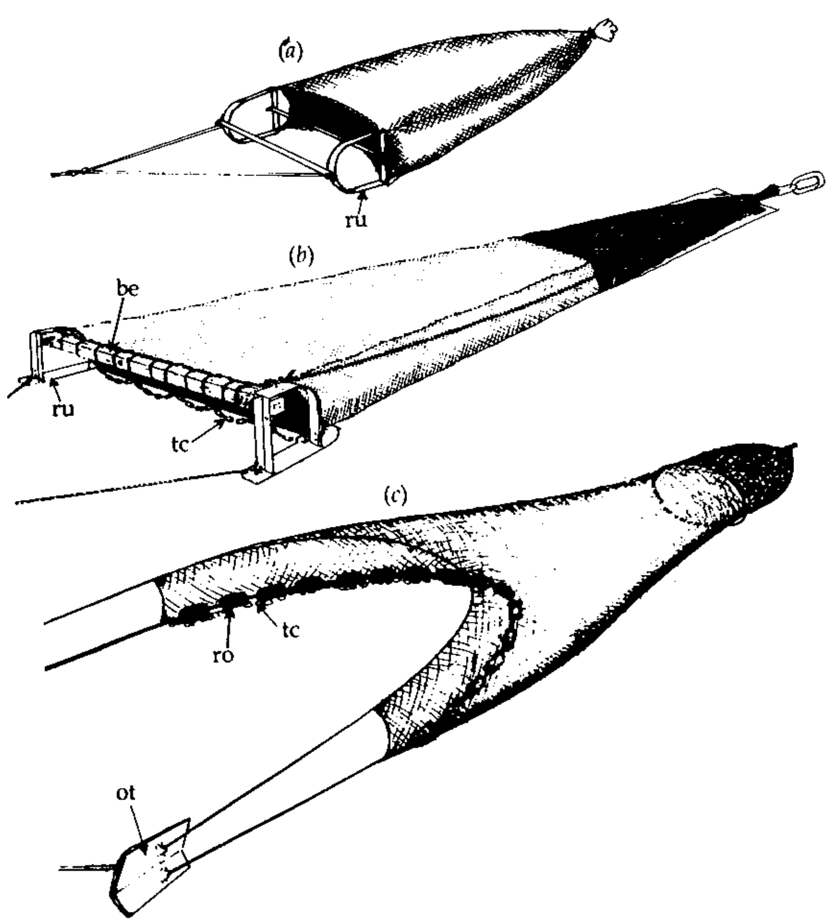



Fig. 3.9. Different bottom trawls drawn roughly to scale. (*a*) 3-m wide Agassiz trawl with: (*b*) large 6-m wide beam trawl operated in recent French studies; (*c*) semiballoon otter trawl (OTSB). ru, metal runner; be, timber beam; tc, tickler chain; ro, rubber rollers on trawl foot rope; ot, steel V-sectioned otter board. ((*a*) and (*b*) modified from drawings in Guennegan & Martin, 1985.)

manner. A large commercial-type twin warp otter trawl has been successful fished down to about 1.25 km (Gordon & Duncan, 1985), but most sampling of benthopelagic fish has been undertaken with the small Marinovitch semiballoon otter trawl (OTSB) (Merrett & Marshall, 1981; Gordon, 1986). The OTSB trawl (Fig. 3.9(*c*)) has a headline of 14.7 m and has been fished down to depths greater than 5 km. The progress of the OTSB during a tow can be monitored by a pinger mounted midway between the door and the wing end of the trawl. The OTSB can be fished either using a single or paired warps. The catches vary with the method used but usually the former method gives a greater catch of both large invertebrates and fish. The OTSB has been widely used throughout the North Atlantic and its catch data have been used to produce a standardized atlas of the distribution of demersal deep-sea fish (Haedrich & Merrett, 1989).

Special cod-end devices have been developed which insulate and protect the catch from thermal shock as the net is being retrieved. Many species in the net are less stressed during capture and more suitable for physiological studies or attempts to culture them. Most deep-sea animals are far less tolerant of increases in temperature than decreases in hydrostatic pressure – the obvious exceptions are those fishes which have swim-bladders.

There is increased sophistication in fishing techniques with the use of electronic instrumentation to determine bottom time of the nets as well as ambient hydrographic information. This is described in more detail for the epibenthic sleds (see below).

### EPIBENTHIC SLEDS

The original epibenthic sled, developed at the Woods Hole Oceanograhic Institution during the 1960s (Hessler & Sanders, 1967), and its subsequent evolution (Aldred *et al.*, 1976; Rice *et al.*, 1982), is designed to catch the smaller animals of the deep-sea floor. The Woods Hole epibenthic sled (Fig. 3.10(*a*)) consists of a flattened mesh bag, resembling a plankton net, mounted in a metal frame attached to wide runners to prevent sinking into the sediment, and is designed to work either way up. The collecting net has a mouth of 81 × 30 cm. The mouth of the frame is formed by a pair of cutting plates whose edges may be raised or lowered. The main net consists of monofilament nylon with a mesh aperture of 1.0 mm. It is protected in the frame by a steel mesh cage. In order to minimize washing of the sample during its recovery to the surface, a conical cod-end extension net about 1.3 m long protrudes from the rear of the sled and is protected from abrasion by the seabed by canvas aprons. Originally the mouth edge was angled so that it would strip off the top-most layer of sediment, but in practice this resulted in the entrance of the sled rapidly clogging with sediment. An apparently minor adjustment to the hinged blade so that its cutting edge is level with, or slightly above, the runners (Fig. 3.10(*b*)), produced startingly better samples of the small-sized fauna associated with the sediment–water interface (Gage, 1975).

In the absence of electronic indicators of whether the sampler is on the

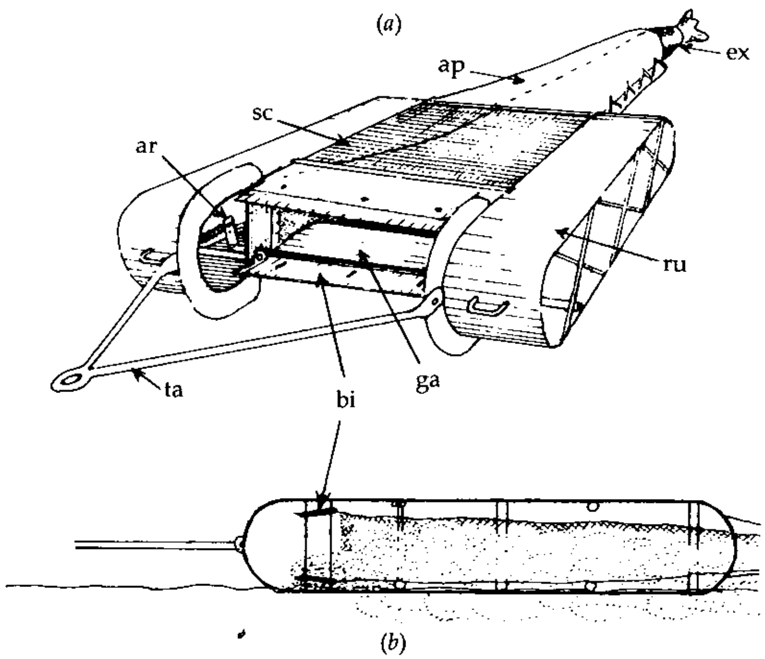



Fig. 3.10. (*a*) Woods Hole pattern epibenthic sled with towing arms (ta) equipped with extension bag (ex) protected by canvas aprons (ap). ru, runners; sc, metal screen protecting the main bag; bi, biting plates shown in typical sampling angle; ga, hinged mouth closing gate shown in open position; closure is effected by release of the spring-loaded arm (ar) by means of timer-controlled release (not visible). (*b*) Probable mode of operation of epibenthic sled when used in the deep sea: the slightly upward inclining surface of the biting edge and metal plate over the front of net disturbs sediment bringing it into suspension, along with contained fauna, so that it is drawn into the mouth opening.

seabed or not, it is often necessary to have a portion of the towing wire on the seabed to be sure the gear stays on the bottom during a tow. The wire disturbs the sediment in front of the net, increasing the catch of small fauna, but scaring away more active species. The nylon mesh bag is designed to filter and retain sediment and fauna $>1$ mm diameter; although, in practice, the catch consists of a muddy mixture of fauna and fine particles which requires careful washing (see p. 52). A timer-released metal gate closes the mouth after sufficient time has elapsed for about an hour's haul on the bottom. This both protects the samples from contamination by planktonic organisms during winching back through the water column (the weight of the gear with relatively small mouth opening prevents fishing during lowering to the bottom), and the winnowing, and consequent loss of small, light fauna, of the muddy catch through the mouth during recovery.

Although this epibenthic sled ushered in a new era of deep-sea biology, it has operational limitations, such as a tendency towards variability between hauls taken at different speeds over the bottom (Gage *et al.*, 1980; Harrison, 1988). The need to determine the distance actually travelled on the seabed, and to record photographically the bottom before being sampled, has been addressed by workers at the Institute of Oceanographic Sciences' Deacon Laboratory in Britain with their Acoustically Monitored Epibenthic Sled. This consists of a steel frame fitted with broad, weighted skids. The mouth measures 2.29 m by 0.61 m and is equipped with an opening/closing mechanism. The main net consists of 4.5 mm terylene mesh with a 1.5 m cod-end of 1.0 mm mesh. Mounted on the top of the sled are pressure housings containing a camera and electronic flash looking obliquely downwards and forwards over the bottom ahead of the mouth. A precision pinger mounted on the frame gives a single pulse every second when the gear is head-up as it is when being lowered to the bottom, while a second pulse is emitted when horizontal on the seabed. A third pulse from a mercury tilt switch attached to one of the opening levers indicates that the mesh covering the mouth has been lowered. If the net leaves the seabed during fishing, or at the end of the haul, the appropriate pulses are lost (Aldred *et al.*, 1976).

A modification to this design replaces the single net with three separate nets (Fig. 3.11), the outer ones having a mesh of 4.5 mm and the central net a 1.0 mm mesh. Above the central net is a suprabenthic net, of 0.33 mm mesh, for the collection of near-bottom plankton. The camera height above the seabed can be varied to give a better photographic resolution of the epibenthic fauna. An odometer wheel, coupled to a potentiometer, measures the distance travelled over the seabed which can be determined during the haul and acoustically transmits the information back to the ship (Rice *et al.*, 1982). Comparison of the bottom area photographed ahead of the mouth with the final catch shows that the gear often misses quite large epifaunal organisms which are clearly visible

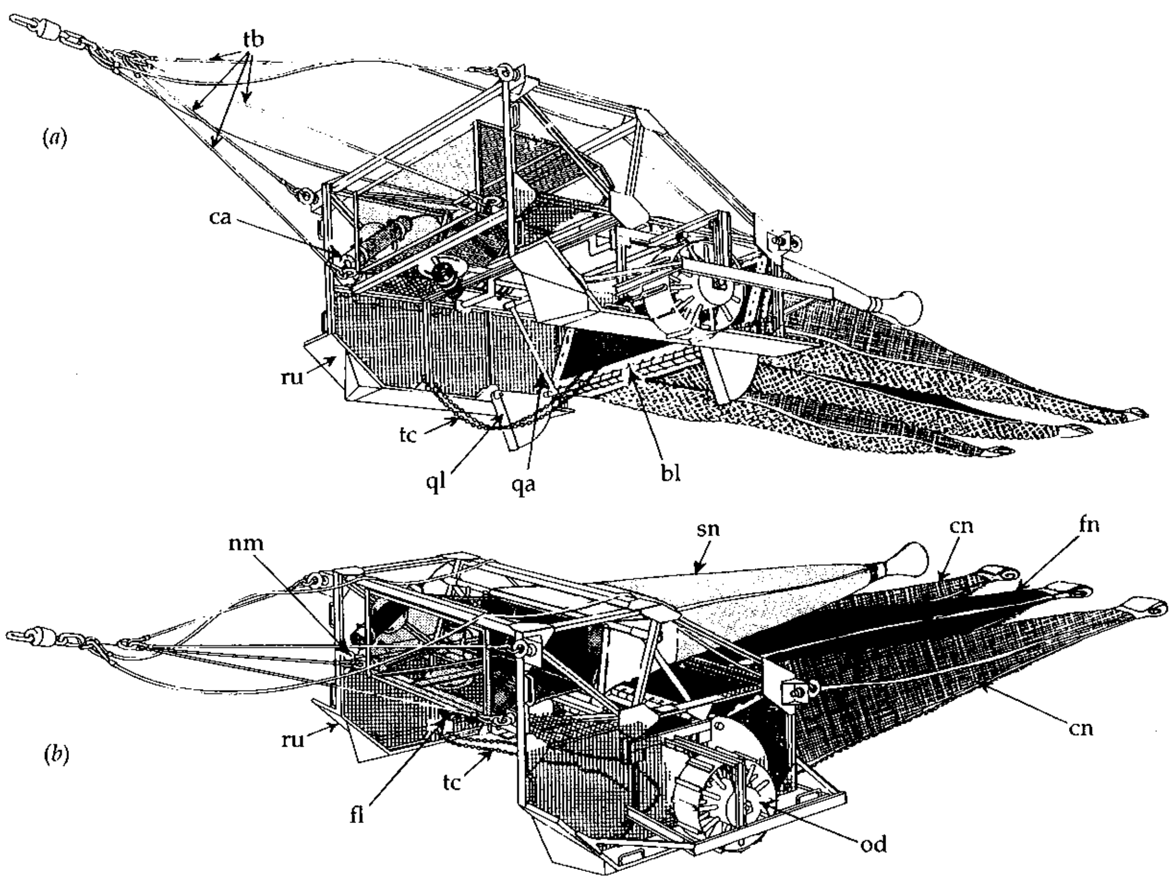



Fig. 3.11. (*a*) Lateral view from below and (*b*) from above of the epibenthic sledge developed by the Deacon Laboratory of the Institute of Oceanographic Sciences in England; tb, towing bridles; ca, camera; ru, metal runner; od, odometer wheel; tc, tickler chain; sn, suprabenthic net; cn, coarse-meshed outer nets; fn, fine-meshed inner net. Closure of the mouth of the nets during descent and ascent from the bottom is effected by a hinged blind (bl) that is forced into the horizontal open position by quadrant levers (ql) linked to a quadrant arm (qa) by contact with the bottom. Other labelling: nm, net monitor, fl, flash. (From Rice *et al.*, 1982.)

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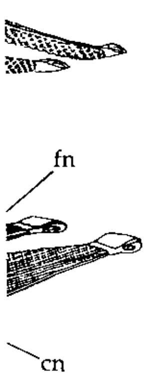


in the photographs, and the performance varies from haul to haul (Rice *et al.*, 1979; Rice, 1987). Hence, even using this level of sophistication, the results remain biased and only provide, at best, semi-quantitative estimates of the benthic community's structure and standing crop.

The sampling gear described above, along with all other towed sampling gear used on the deep-sea bed up to the 1960s, is essentially non-quantitative. This was not a major problem to that date as expeditions were mainly addressing zoogeographic problems. However, in the early 1960s, the emphasis changed from questions of zoogeography to more quantitative studies, particularly as the relative importance (both numerically and in terms of standing crop) of small-sized biota was identified. Owing to the high cost of ship time, it was impractical to use shallow water benthic samplers which sampled only a very small area.

## ANCHOR DREDGES

The Anchor Dredge (Fig. 3.12(*a*)) was devised as a semi-quantitative sampler with a known depth of penetration into the sediment (Fig. 3.12(*b*)). Estimates of area sampled are made by dividing the volume of obtained sediment by the biting depth (Sanders, Hessler & Hampson, 1965). It has a collecting bag made of canvas cloth supported by a 2.5 cm nylon mesh. In the Anchor Box Dredge (Fig. 3.12(*c*)) of Carey & Hancock (1965) the mesh bag was replaced by a steel box, 57 cm wide, with cutting edges equipped with hardened steel teeth. A hinged throat valve, installed at the entrance to the dredge, is designed to prevent contamination by pelagic fauna during deployment and recovery.

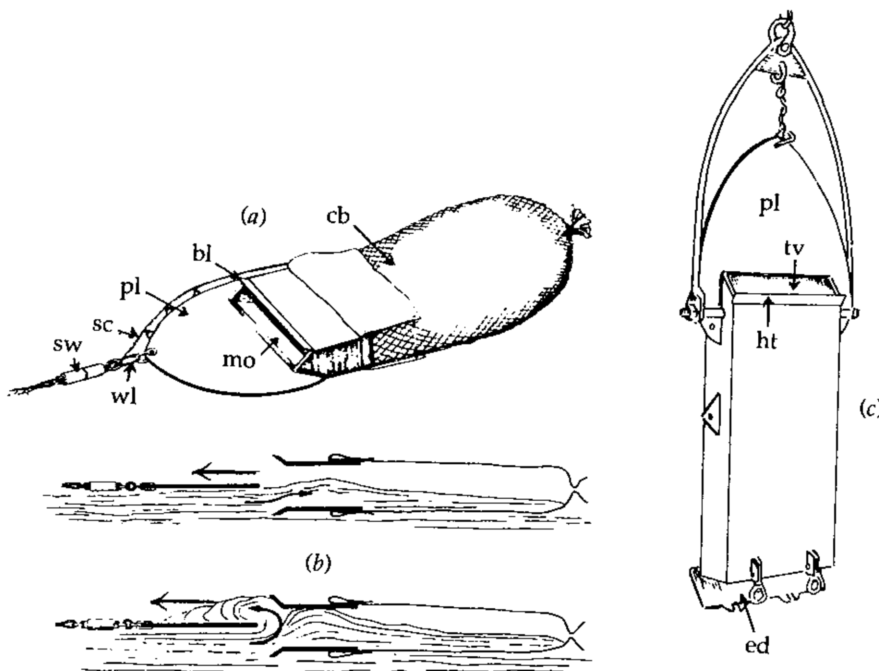


Fig. 3.12. Semi-quantitative dredges: (*a*) Woods Hole deep-sea anchor dredge of Sanders, Hessler & Hampson (1965) showing planing surface (pl), mouth (mo), upper and lower cutting blades (bl), and collecting bag (cb); (*b*) mode of operation, upper shows dredge stripping off *c.* 10 cm thick top layer of sediment until entry of further material (lower) clogs mouth, rejecting further sediment. Large arrow indicates towing direction. (*c*) Anchor box-dredge of Carey & Hancock (1965) which samples similarly. The latter dredge has a similar planing surface (pl); hardened steel teeth (ht) are fitted to the cutting edge, and a V-shaped steel hinged throat valve (tv) swings up during sampling but protects the sample from washing during recovery. The sampled sediment is removed by opening the hinged end door (ed) as shown. Other labelling: sc, safety cable; wl, weak link; sw, swivel. ((*a*) and (*b*) from Sanders, Hessler & Hampson, 1965.)

In both the Anchor Dredge and Anchor Box Dredge, a planing surface in front of the mouth prevents the dredge dipping too deeply into the sediment. This makes it capable of stripping off the top 10 cm of sediment from an area of up to 1.3 $m^2$. Diver observation of the Anchor Box Dredge in shallow water shows that probably only half this area is taken before the friction of sediment entering the box clogs its entrance (Fig. 3.12(*b*)), causing further material to be rejected (Gage, 1975). This study also showed anchor box dredge samples to be deficient in small-bodied animals capable of swimming compared to samples from van Veen grabs and from careful hand coring by divers. The anchor dredge samples contain relatively unbiased samples of the burrowed animals but, because they live at the sediment surface, they are sampled inefficiently (Hessler & Sanders, 1967; Gage, 1975).

## QUANTITATIVE SAMPLERS: GRABS TO BOX-CORERS

Quantitative investigation of deep-sea bottom-dwelling animals began on the 'Galathea' (Spärck, 1951) and with the world-wide Soviet programmes from 1949 (Mills, 1983). Up to the early 1970s the main quantitative samplers were the Okean, Campbell or Petersen grabs (Spärck, 1956*b*; Eleftheriou & Holme, 1984). These grabs, which generally represent enlarged versions of gear in use in shallow water, have their own limitations; either taking too small a sample or, more importantly, having a variable penetration into the sediment depending on the shape of the jaws of the grab. Furthermore, they generate a bow-wave which 'blows' aside the surficial sediment particles along with the important light-bodied animals inhabiting the sediment interface, so once again the samples are unacceptably biased for quantitative studies. Of early samplers, the Reineck box-corer (Reineck, 1963), from which improved designs for geological coring were developed (see Bouma, 1969) was closest to the perfect design but sampled a small surface area only.

Hessler & Jumars (1974) developed the USNEL box-corer at the Scripps Institution of Oceanography in conjunction with the United States Naval Electronic Laboratory (USNEL) at San Diego. This has become the standard gear for deep-sea quantitative sampling of the smaller fauna, and penetrates a precise area of deep-sea sediments to its full depth. It retrieves relatively undisturbed samples covering an area of 0.25 $m^2$ (50 × 50 cm) which is usually a large enough area to provide meaningful number of organisms even at the low population densities existing in the deep sea. The early design has been subsequently improved at Scripps in conjunction with the Sandia Laboratories, New Mexico, and it is the later design that is shown in Fig. 3.13(*a*). The USNEL box-corer consists of a detachable, square, open-ended steel core box, attached to a weighted column. The core box sinks into the sediment guided by its passage through the gimbal mounting on the support frame. The spade, which on deployment was held in the horizontal position by a spring-loaded bolt at the top of the corer, closes the bottom of the core box. The top of the box is closed by flaps which are held open during lowering by levers to allow a through-flow of water during descent and hence minimize the bow-wave as the box-core reaches the seabed. The box-corer is lowered vertically

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from the ship with a pinger attached to the wire about 25 m above. The height above the seabed and subsequent contact is monitored by the pinger whilst the onboard tension meter provides an immediate indication of the gear bottoming.

The box-corer is quickly lowered at *c*. 60 m $min^{-1}$ until it is close to the bottom. Its rate of descent is then reduced to 15–25 m $min^{-1}$. When the gear reaches the seabed, the frame rests on the bottom allowing the heavily ballasted core box to sink into the sediment (shown in inset to Fig. 3.13). This allows a spring-loaded bolt to withdraw, releasing the length of cable needed for the closure of the spade. This occurs as hauling starts, the spade arm cutting down into the sediment until it closes the bottom of the box. A lead or rubber sheet on its upper surface seals the base of the core as the gear is pulled out. As the core is pulled out, there is a marked increase in tension in the warp which suddenly decreases as the core breaks free of the seabed. The gear is retrieved at 50 m $min^{-1}$. A success-

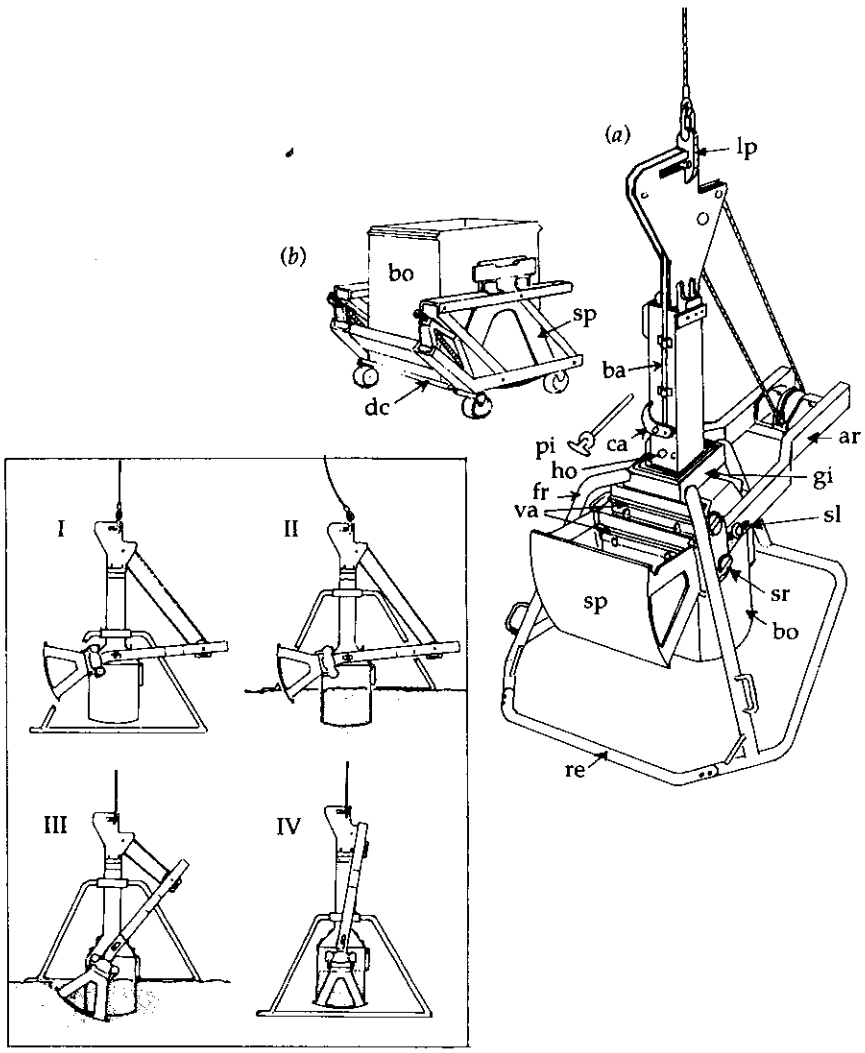
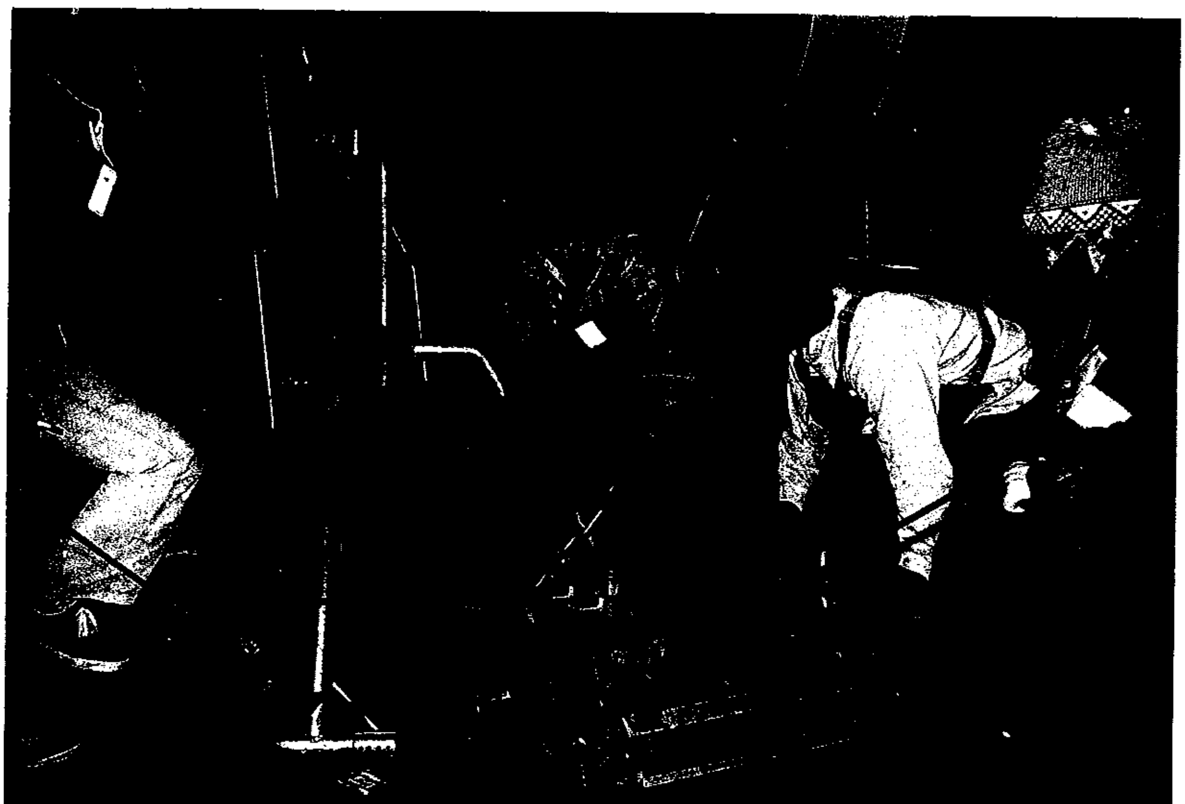



Fig. 3.13. Hessler/Sandia USNEL box-corer showing (*a*) view of gear cocked ready for deployment hanging from ships' wire (inset shows the sequence, I–IV, of operation of the gear before, on, and after leaving the seabed). On deck the pins (pi) are inserted in the holes (ho) at the bottom of the lead-ballasted column to prevent it from descending through the gimbals (gi) of the supporting frame (fr). A spring-loaded bolt, which is locked by means of a sliding bar, locates in a locking plate (lp), that prevents the wire being pulled through the pulley system to draw the arm (ar) of the spade (sp) to the closed position below the removable core box (bo). On bottoming (II) the heavy corer slides through the gimbals into the sediment, turning the cam (ca) that pulls the sliding bar down to release the locking bolt from the locking plate (lp) previously preventing the wire from being drawn through. A fine wire link preventing spring-loaded closure of the paired vent valves (va) over each side of the box is broken sealing the top of the box from washing during its ascent to the surface. Winching in the slack wire above the bottomed corer (III) first swings the arm down so that the spade cuts into the sediment and the spade is pulled up tight against the lower edge of the box by means of slots (sl) cut in its hinged attachment to the column. This seals the box, and the whole gear is then broken out of the seabed with its sample (IV). (*b*) The box with contained sample is removed along with the spade, which is released from the arm by undoing its attachment (sr), onto the dolley cart (dc) that is placed in position underneath. The sample is then wheeled away from the gear for processing after removing part of the lower frame (re).

ful box-core sample will retain the clear overlying water (characterized by its low temperature) with an undisturbed sediment surface. Once on deck, the box-core can be removed from the corer (Fig. 3.14) for sieving or subsampling. The 'vegematic' modification is fitted with a liner made up of a grid of 25 10 × 10 cm square subcore tubes (Jumars, 1975*a*). This has proved valuable in understanding small scale spatial variability in the deep sea (see Chapter 6).

Carefully obtained box-core samples can provide excellent quantitative samples of the smaller animals of the sediment-dwelling community that are markedly superior to those obtained by grabs (Smith & Howard, 1972). However, they are not completely without bias. Jumars (1975*b*) showed that the outermost 'vegematic' subcores have significantly lower numbers of fauna than the inner nine subcores, indicating that there is still some 'bow-wave' on the superficial sediment where most fauna live (see Chapter 6). As a consequence, many investigations utilize only the nine inner cores for quantitative analysis. Small-diameter core tubes, pushed into the centre of the box, may be used to study the smallest animals and for microbial studies. The USNEL box-corer has become the standard quantitative sampler in deep-sea investigations, and has been used world-wide.

Fig. 3.14. Photograph of USNEL box corer on stern deck of 'Thomas Washington' showing dolley cart for supporting and positioning the sample box being wheeled into position (foreground). (Courtesy Prof. R. R. Hessler, Scripps Institution of Oceanography.)



## SMBA MULTIPLE CORER

This device (Fig. 315), developed at the Scottish Association for Marine Sciences (SAMS), provides an alternative method of obtaining small-diameter cores virtually free of bow-wave-derived bias (Barnett *et al.*, 1984). The multiple corer is based on the Craib Corer (Craib, 1965) and consists of an outer framework supporting a weighted assembly of plastic core tubes of 56.5 mm internal diameter (25.1 $cm^2$ area) hanging from a water-filled dashpot. When lowered, the frame rests on the seabed (see inset in Fig. 3.15), the wire slackens, and the dashpot dampens the descent of the coring assembly so that the core tubes enter the seabed as slowly as possible. A ball-valve mechanism seals the top and bottom of the tube to prevent loss or disturbance of the core during recovery. The efficiency of this gear in sampling even the smallest and lightest of particles without bow-wave disturbance is testified by its success in sampling the easily resuspended phytodetrital floc lying on the seabed (Gooday, 1988). In addition to faunal and microbial sampling, this apparatus has been successfully modified for determination of *in situ* microbial metabolism (Patching *et al.*, 1986).

## OTHER SAMPLERS

All these samplers are designed for use on a wire from the ship. However, Rowe & Clifford (1973) describe modifications to the Birge–Ekman box-corer (a small quantitative sampler developed in the early years of this century) for use by 'Alvin', or by scuba divers in shallow water. This

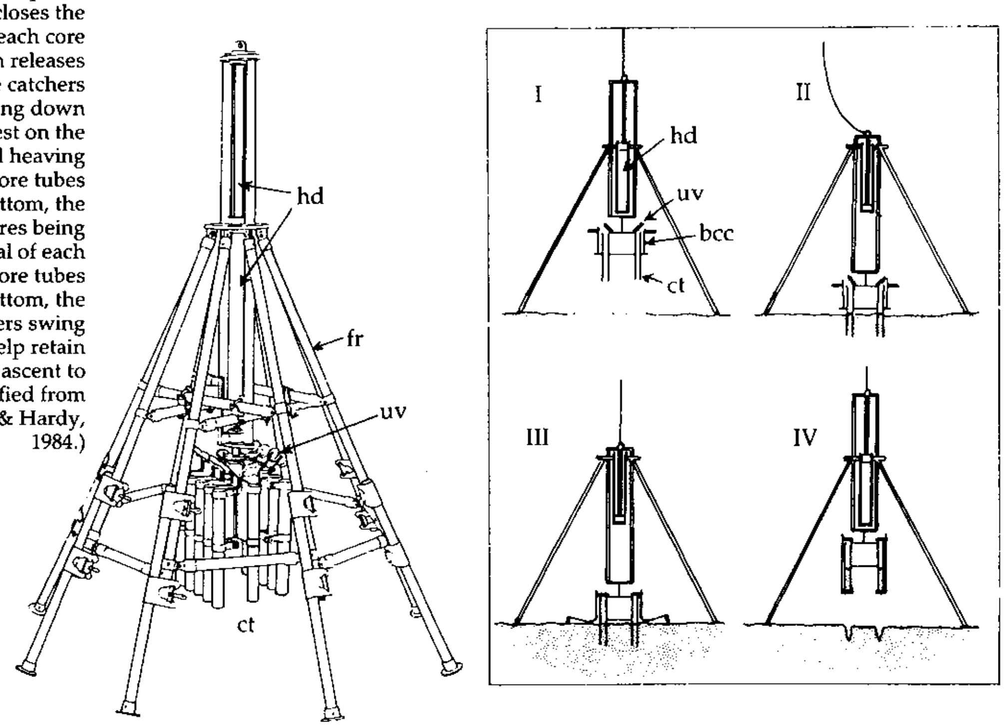



Fig. 3.15. SMBA multiple corer. A sliding framework supported by a hydraulic damper (hd) carries an assembly of core tubes (ct) within a supporting outer framework (fr). The inset shows the sequence of operation on the seabed: after contact with the bottom (I), the wire slackens as the weight of the corer is taken by the outer framework and allowing the assembly of core tubes (only two are shown in the inset drawings) to slowly descend into the sediment, damped by the hydraulic damper, with the upper core valves (uv) open. When the wire is winched in to lift the gear a special mechanism first closes the valve on top of each core tube (III) and then releases the bottom core catchers (bcc) which swing down until they rest on the seabed. Continued heaving then pulls the core tubes out of the bottom, the sediment cores being retained by the seal of each top valve. As the core tubes break out of the bottom, the bottom core catchers swing into place and help retain the cores on their ascent to the surface. (Modified from Barnett, Watson & Hardy, 1984.)

small, lightweight corer consists of an open-ended box measuring 15 × 15 cm. It is pushed into the bottom using the submersible's manipulator arm and is closed by means of spring-powered, hinged, biting jaws at the bottom.

A large multiple box-corer that can obtain nine separate box-cores, each measuring 12 × 20 cm in area, and incorporating a video camera monitor has also been built for shelf work in the Antarctic (Gerdes, 1990) and, with modification, should work well in the deep sea.

## SAMPLE WASHING

Samples of the larger deep-sea animals collected in coarse-meshed trawls usually come up well washed, and the specimens can be sorted on deck into the major taxa. However, most fine-meshed trawl samples, along with box-core samples, bring up large quantities of fine sediment from which the delicate-bodied small fauna must be gently separated. Those methods used when sampling shallow water benthos tend to be too vigorous and cause unacceptable damage to the more delicate deep-sea specimens. One of the best methods of gently separating the smaller animals from the sediment has proved to be the elutriation technique of Sanders *et al.* (1965). Aliquots of the muddy sample are placed in a dustbin modified with a spout (Fig. 3.16). A suspension is created using a large-volume flow of filtered seawater. The mixture overflows through the spout on to a fine-meshed sieve that retains the fauna but allows through all the sediment particles less than the sieve aperture (with a mesh size depending on the category of fauna to be retained – see Chapter 7 for discussion of mesh sizes and the size categories of smaller fauna). The residue can then be fixed generally using 5% formalin in seawater, prior to long-term preservation in 80% ethanol. The preservative can have a small quantity of propylene glycol (1% by volume) added to prevent fauna from completely drying out during the long process of sorting the sample into the different taxa using a binocular low-power microscope.

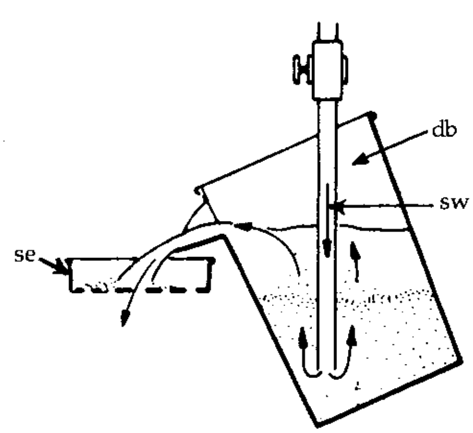



Fig. 3.16. Elutriation apparatus for washing deep-sea benthic samples. db, dustbin; sw, incoming flow of filtered seawater; se, fine-meshed sieve to screen off fauna from overflowing water. (From Sanders *et al.*, 1965.)

## PHOTOGRAPHY AND TELEVISION

Much has been written about the use of photography in the deep sea (Hersey, 1967; Heezen & Hollister, 1971; Menzies *et al.*, 1973; Rowe & Sibuet, 1983). Photographs give us a permanent visual representation of the deep-sea bed better than can be obtained by any other technique at present, although direct observation from submersibles recorded on video is better for some purposes. In modern studies, the camera is often used mounted on a sled (sometimes in conjunction with epibenthic sleds – see above), or on submersibles, or above baited traps (see below). Analysis of oblique photographs of the bed can resolve surface structures and small organisms more clearly than those taken straight downwards. This can be aided by superimposition of a perspective grid that permits accurate quantitative measurements (Barham *et al.*, 1967; Grassle *et al.*, 1975; Wakefield & Genin, 1987). The main types of camera used in deep-sea studies include:

- (i) The downwards-looking stereo camera lowered on a vertical wire which can be used to take plan pictures of the seabed (Fig. 3.17(*a*)). The device is repeatedly 'pogo-sticked' along the bottom with an electronic flash being fired when a weight makes contact with the bottom and the film wound on. (In many deep-sea cameras a shutter is superfluous owing to the lack of light in the deep ocean.)
- (ii) The obliquely mounted camera on a sled that is towed behind the ship and photographs are taken at preset time intervals (Fig. 3.17(*b*)).
- (iii) Cameras are incorporated into multi-instrumented towed arrays such as 'Deep Tow' (Busby, 1977), or 'Raie' (Fig. 3.17(*c*)) which is similar to the 'Argo' vehicle described previously under ROVs. Such packages typically include sub-bottom profiling, sidescan sonar and a proton magnetometer. They are lowered to 15 to 200 m above the seabed and towed at about 1.5 kt. The large-scale photographic coverage has limitations in resolution of deep-sea organisms for identification, but is useful for broad-scale surveys of the nature of the deep-sea bed.
- (iv) Free-vehicle camera system, e.g. 'Bathysnap' (Lampitt & Burnham, 1983) (Fig. 3.17(*d*)). This can be deployed at the seabed for long time periods independent of a ship and recovered later. Once deployed, the camera will take photographs at set time intervals over a long period, together with current speed and direction recordings on the moored current meter. At the end of the deployment, the camera is released from its mooring by an acoustic or timed release and floats to the surface to be retrieved by a surface vessel. 'Bathysnap' has been successfully deployed in determining seasonal changes at the seabed over a period of 6 months (Fig. 11.3).

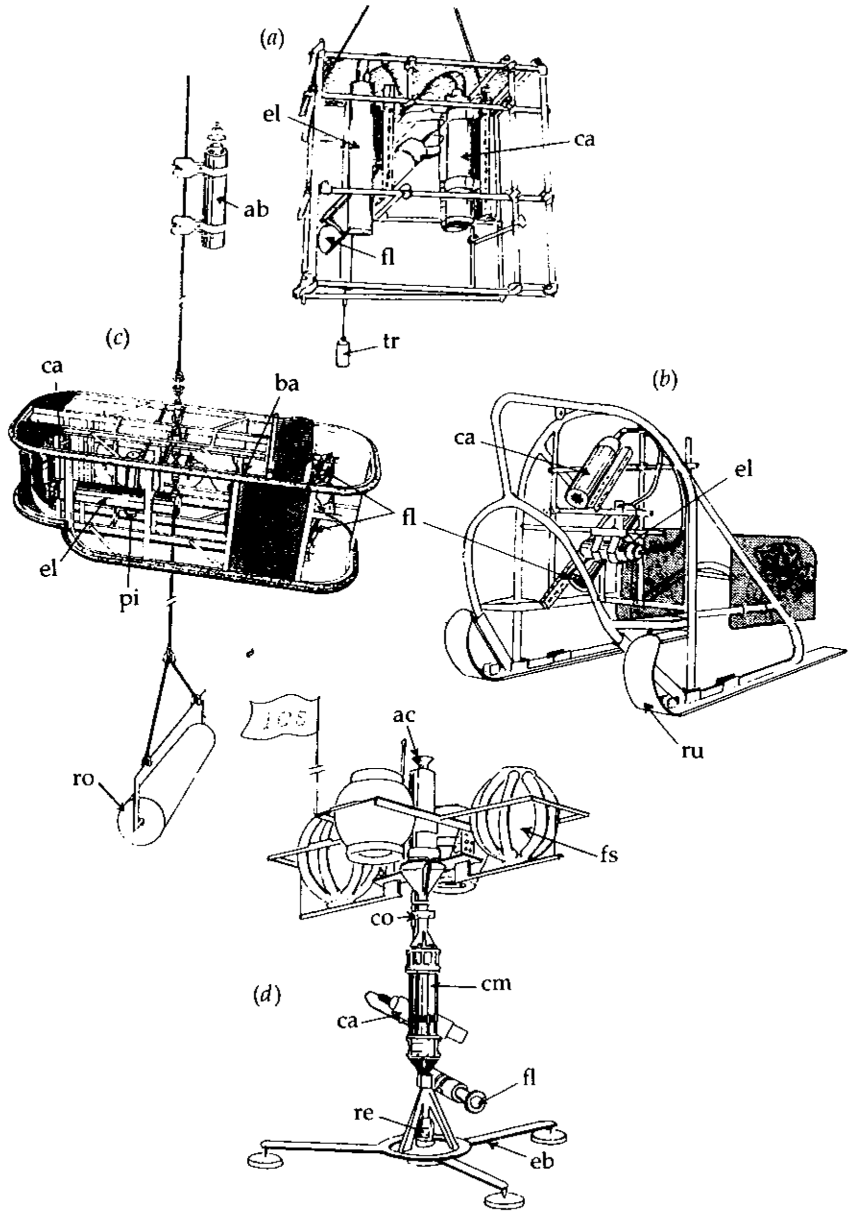



Fig. 3.17. Gear for photography of the deep-sea bed. Common labelling: ca, camera(s); fl, flash; el, electronics. (*a*) Stereo camera system for seabed photography developed by A. J. Southward at the Marine Biological Association (MBA) at Plymouth, UK; the twin downward-looking cameras (ca) and flash (fl) within the framework are triggered by bottom contact of the small suspended trigger weight (tr). The electronics are in another pressure housing. (*b*) Camera sled used by A. J. Southward at MBA, Plymouth; the automatically firing camera and flash are protected by a metal framework mounted on runners (ru) allowing it to be towed over the seabed. (*c*) Deeply towed camera fish, 'Raie' (a similar gear is called 'Angus' in the United States). (A similar, though more sophisticated system, 'Deep Tow,' was used to take the photographs in Figs 2.12 and 2.13.) The 3-m long framework is weighted with a heavy roller (ro) that just makes contact with the bottom: at an altitude of 3 m the field of view of the camera inclined at 10° from the vertical is 7 m$^2$. There are dual flashes, batteries (ba), and the whole system is monitored with an acoustic pinger (pi) and an acoustic beacon (ab) mounted on the wire. (*d*) 'Bathysnap,' a free vehicle time-lapse camera system developed by the U.K. Institute of Oceanographic Sciences; the oblique field of view of the camera provides good resolution of relief and material such as phytodetrital 'fluff' (see Fig. 11.5) that may be difficult to see in 'straight down' photographs. The gear is also equipped with a recording current meter (cm) and compass (co).
*continued*

(v) Underwater television has yet to have wide application in the deep sea as there is a heavy power drain on the conducting cables from the camera to the surface vessels. However, this is being improved by the use of signal transmission using fibre optics. High-resolution video cameras and recorders attached to either submersibles or free vehicles have proved to be an excellent means of recording behaviour of deep-sea organisms (e.g. Laver *et al.*, 1985). High-resolution cameras can now yield single frames almost as good as those from still photography.

Although sent to the bottom with overall negative buoyancy the flotation spheres (fs) provide sufficient positive buoyancy to bring the free vehicle to the surface on the acoustic command system (ac) receiving a sonic signal from the ship that activates release (re) of the expendable base (eb). ((*a*) and (*b*) from photographs and drawings in Southward *et al.*, 1976; (*c*) from Guennegan & Martin, 1985; (*d*) from Lampitt & Burnham, 1983.)

Rowe & Sibuet (1983) suggest that the future of underwater television lies in the control of remote manipulators and vehicles. Future development involving electronic cameras will further help to resolve the problems associated with transmitting the information long distances through water.

(vi) Acoustic tracking. This new approach employs an array of high-resolution, narrow-beam sonar in an autonomous package that is moored on the deep-sea bed as a free vehicle. The instrument is capable of detecting and tracking individual pelagic animals by measuring their target strength, and promises to provide data on the movements of the larger swimming animals in relation to the flux of organic matter to and from the BBL (Smith, Alexandrou & Edelman, 1989).

## BAITED TRAPS

These were first used at the turn of the century during the cruises of Prince Albert I of Monaco in the 'Hirondelle'. Various recent designs of baited traps mostly utilizing slow-dissolving releases to drop ballast after a period of time, in order to bring them back under positive buoyancy of glass flotation spheres, are shown in Fig. 3.18(*a*)–(*d*). It was only in the mid-1970s that Isaacs & Schwartzlose (1975) first described a baited trap and camera combination for deep-sea studies. (A similar French gear is shown in Fig. 5.18(*c*).) The apparatus is allowed to free fall to the seabed. The time-lapse camera takes photographs of the bait at predetermined intervals. At the end of the period of deployment, the camera is released on command from the surface by means of an acoustic release and it floats to the surface. Baited traps have proved particularly successful in catching, and observing, animals that are motile and well dispersed on the seabed, such as giant amphipods and large fish, that may be able to avoid trawled sampling gear (Dayton & Hessler, 1973; Dahl *et al.*, 1976; Hessler *et al.*, 1978; Thurston, 1979; Ingram & Hessler, 1987). The fate of large food falls into the deep sea may also be examined by this method (Rowe & Staresnic, 1979; Rowe & Sibuet, 1983).

## *IN SITU* MEASUREMENTS OF BIOLOGICAL PROCESSES ON THE SEABED

All the methods discussed so far are for the collection or observation of deep-sea invertebrates or fish. Some biological processes, such as growth and reproduction, can be measured from a time series of these samples. However, there are some ecological processes than can be measured *in situ* at both the individual and population levels. Sediment recolonization has been measured in long deployments of trays of defaunated, natural sediment which are eventually recovered to the surface (Grassle, 1977; Maciolek *et al.*, 1987*a*,*b*; Grassle & Morse-Porteous, 1987; Desbruyères, Bevas & Khripounoff, 1980), while similar experiments have studied the special faunas which colonize wood by setting out 'wood islands' on the deep-ocean floor (Turner, 1973; Maddocks & Steineck, 1987). *In situ*

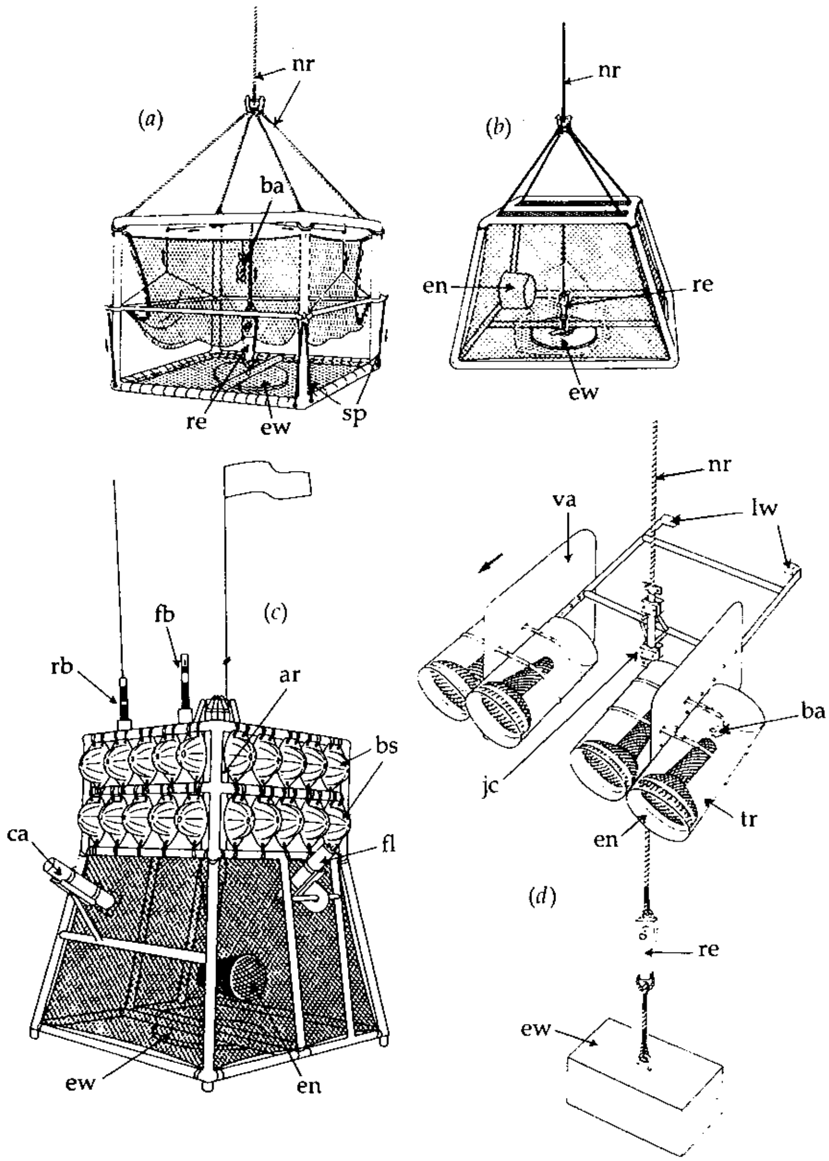



Fig. 3.18. Various types of deep-sea bottom traps. Common labelling: nr, nylon rope; re, magnesium release mechanism; ew, expendable ballast weight; bs, buoyancy spheres; ba, bait; en, entrance. (*a*) and (*b*) are relatively small traps of roughly 0.8 $m^2$ volume with a plastic pipe frame and equipped with a release mechanism that drops the circular expendable ballast allowing the trap to ascend with its catch by means of glass buoyancy spheres (not shown) attached further up the nylon rope. Trap (*a*) allows large predators, attracted by the suspended bait, to enter. Curtain-like sides are pulled down by springs (sp) to trap the animals when the ballast is released. Trap (*b*) is smaller and has a simple conical entrance. (*c*) is a larger trap used by IFREMER, Brest, that also operates as a free vehicle with the buoyancy (40 spheres) attached directly to the top of the cuboid cage of 8 $m^2$ volume. This trap is equipped with a time-lapse camera (ca) and flash (fl), and has an acoustic release (ar) that operates on command from the ship. The flashing light beacon (fb), flag and radio beacon (rb) aid in location and recovery of the trap at the surface. (*d*) Free-orientating trap array designed at the Scripps Institution of Oceanography for collecting scavenging amphipods. The traps are free orientating by means of a vanes (va), counterweight (lw) and jointed clamp (jc) on to the nylon rope. A release system with expendable ballast weight, similar to (*a*) and (*b*) allows recovery of the traps after a set time. The conical mesh entrance of each small, acrylic trap chamber (tr) always lies downstream to the current (arrow), the animals being attracted by the odour plume from the bait inside. (From Guennegan & Martin, 1985.)

methods for measurement of metabolic processes have been developed because deep-sea organisms can not normally be retrieved alive without employing special collectors which maintain bottom temperature and pressure.

The two parameters that have been measured to determine metabolic rates in the deep sea are: rate of oxygen consumption and nutrient exchange in sealed enclosures (Smith & Hinga, 1983). These authors have described *in situ* apparatus for determining these parameters in large invertebrates, fish and in the whole sediment community. Further details of both sorts of *in situ* apparatus are provided in Chapters 8 and 11, respectively.