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History and research approaches

To most people corals are synonymous with the bright, well-lit waters of tropical coral reefs. Yet in fact the majority of corals inhabit deep, cold waters across a diverse range of marine environments from inland fjords to the continental shelf, slope, offshore banks, seamounts and even the abyssal plain. While we have known about these cold-water corals for hundreds, or even thousands, of years it is only in the last ten years that research into the biology of the corals themselves, the ecology of the habitats they provide and the geology of the structures they form has gathered pace. Cold-water coral habitats are biodiversity rich. Recent work has revealed them as unique palaeoceanographic archives. Sadly all too many surveys have shown they have been damaged by human activity. In this book we have tried to summarise the many, varied and exciting developments in our understanding of cold-water corals. Research effort on cold-water corals is now increasing exponentially around the world and it has been challenging to compress this body of work into the pages of one book. Before we consider cold-water corals and some of these recent findings in more detail we begin with a brief historical summary and an outline of the research approaches used to study cold-water corals.

1.1 History

1.1.1 Early history and taxonomy

The history of modern research on cold-water corals goes back to the late eighteenth century. Among the first written records discussing cold-water corals are notes by the Right Reverend Erich Pontoppidan, Bishop of Bergen, in his 1755 book *The Natural History of Norway*. In Chapter 6, Sea-vegetables of Norway, Pontoppidan discusses one particularly fine coral specimen that was 'entirely white, the flowers much larger than the former [specimen], some of them even exceeding a shilling; and likewise expanded like a flower in full bloom, for which singular beauty I caused a draught of it to be taken'. The accompanying drawing illustrates the species described three years later by Carl von Linné (Linnaeus) as *Madrepora pertusa* (= *Lophelia pertusa*) in *Systema Naturae*, the book that laid the foundation of modern taxonomy. Pontoppidan goes on to describe how 'The fishermen often sell coral bushes to the apothecaries at Bergen' but, although he believed it might have medical effects when taken internally, he sounded a little sceptical of its wider medicinal properties: 'that the little beads, made of coral . . . are endued with any such singular virtue that applied externally, or hung about the neck, . . . preservative against the apoplexy, the plague, and other contagions, I cannot admit, having no evidence of it, but must leave it to rest upon its own credit'. With an eye on the precious coral fishery in the Mediterranean, Pontoppidan concludes by wondering 'Possibly could white coral be brought into fashion, a diligent search might procure as great a quantity in our seas'. On the last point he was certainly correct, we now know that Norwegian waters support spectacular white coral (*L. pertusa*) deep-water reefs.

Studies of these Norwegian coral reefs began to appear just over a decade later when another theologian, Johan Ernst Gunnerus, Bishop of Trondheim (Colour plate 1) published his 1768 work *Om Nogle Norske Coraller* (*On Some Norwegian Corals*). One of his illustrations is reproduced in Fig. 1.1. Gunnerus was a pioneer of the natural sciences. He founded the Royal Norwegian Society of Sciences and Letters, was in frequent correspondence with Linnaeus and is famous for his descriptions of many animals from the basking shark *Squalus maximus* (= *Cetorhinus maximus*) to the roundnose grenadier *Coryphaenoides rupestris* and the gorgonian octocoral *Gorgonia resedaeformis* (= *Primnoa resedaeformis*).

The early days of cold-water coral research were dominated by efforts in Europe and North America to describe the variety of species dredged from the deep sea. The British naturalist Philip Henry Gosse was among the first to focus on the biology of living corals and sea anemones. His mid-nineteenth century descriptions encouraged fashionable Victorians to dabble in seawater aquaria and he summarised his work in his 1860 book *A History of the British Sea-Anemones and Corals* (Colour plate 2). Cairns (2001a) outlined the history of taxonomic research on the azooxanthellate scleractinians. The rate of coral description relates clearly to the research effort and comes in four major pulses: (1) the worldwide revision of the Scleractinia by Henri Milne Edwards and Jules Haime (1848–50); (2) the new species described chiefly by Louis François de Pourtalès, P. Martin Duncan and Henry N. Moseley from pioneering late nineteenth century deep-sea dredging expeditions (1867–81); (3) the new species described chiefly by Alfred W. Alcock, Emil von Marenzeller and Thomas W. Vaughan from

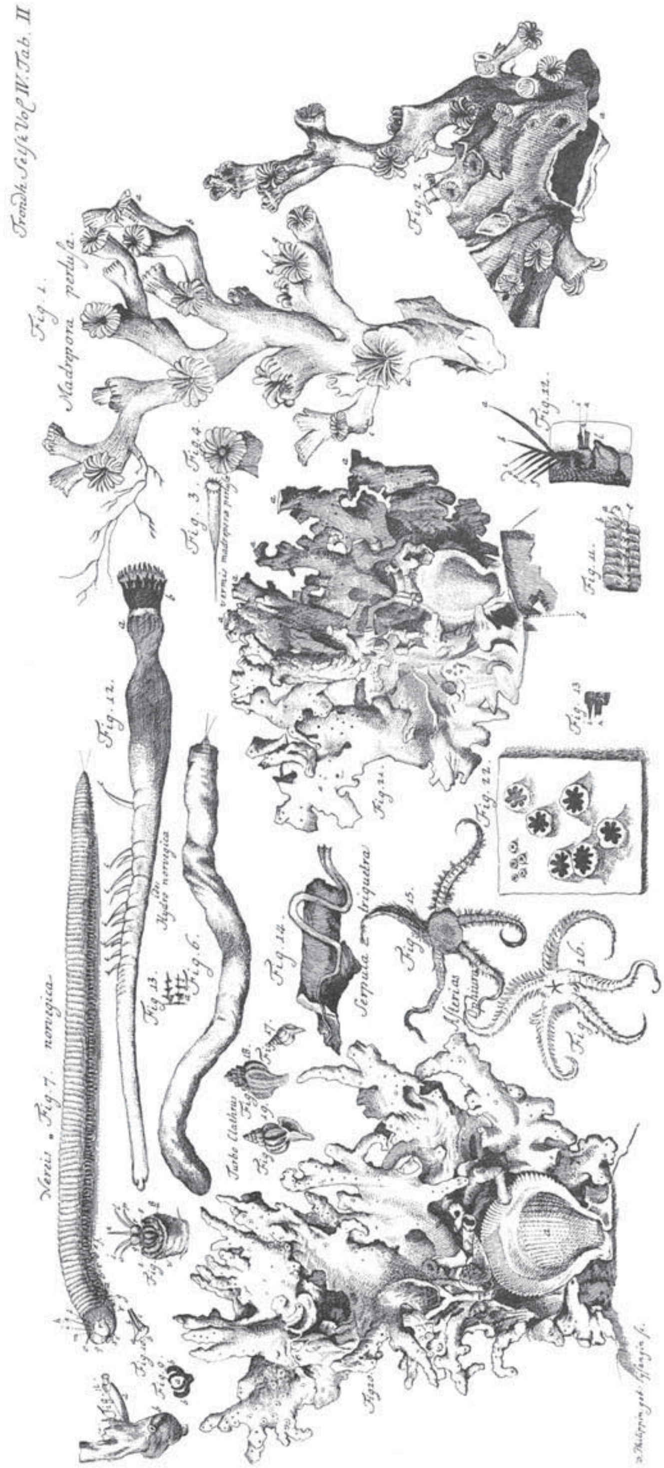

Fig. 1.1 Plate II from Gunnerus (1768) illustrates fragments of cold-water corals including *Madrepora pertusa* (= *Lophelia pertusa*) along with common associated fauna including the polychaete worm *Nereis norvegica* (= *Eunice norvegica*), gastropod molluscs and ophiuroid echinoderms.

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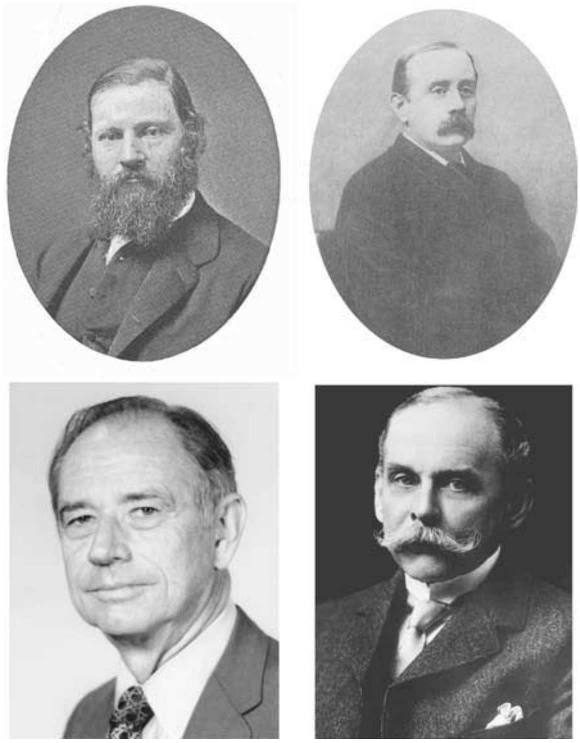

Fig. 1.2 Notable coral taxonomists, clockwise from top left: Louis François de Pourtalès (1824–80), Henry N. Moseley (1844–91), Alfred W. Alcock (1859–1933) and Frederick M. Bayer (1921–2007).

regional deep-sea dredging expeditions in the Indo-Pacific (1898–1907); and (4) the most recent pulse of descriptions based upon larger collections by vessels from France, New Zealand, the Netherlands and the USA alongside full-time research efforts by taxonomists such as Stephen Cairns and Helmut Zibrowius between 1977 and 2004. Figure 1.2 shows some notable coral taxononists.

Bayer (2001) reviewed octocoral research beginning with the first published drawings of octocoral sclerites from *Corallium rubrum* by John Ellis (1755) through to the first global monograph on 'zoophytes' by Peter Pallas (1766) and the critical recognition by Valenciennes (1855) that sclerites differed between species and so could be used as a taxonomic characteristic. Many of the sclerites described by Valenciennes were subsequently illustrated by Kölliker (1865). The early oceanographic expeditions of the late nineteenth century, such as that of *HMS Challenger*, greatly boosted the number of known octocoral species (Wright & Studer, 1889) and the early twentieth century saw a period of taxonomic revision by Kükenthal in his unfinished series *Versuch einer Revision der Alcyonaceen* (*An Attempted Revision of the Alcyonaceans*). In terms of deep-sea pennatulacean records, Kükenthal and Broch's (1911) description of specimens taken during the 1898–9 German *Valdivia* expedition from the eastern Atlantic to Antarctica, including the western Pacific is particularly notable, as was Kükenthal's (1919) account of the *Valdivia* Gorgonacea, which laid the foundation for his later revision of all Octocorallia in 1924. In the early twentieth century, Kükenthal recognised 141 certain and 134 doubtful species of Pennatulacea (Kükenthal, 1915) and 805 certain and 255 doubtful species of Gorgonacea (Kükenthal, 1924). Regional monographs and further species descriptions in the latter half of the twentieth century continued to add to this total. Of the approximately 3200 octocorals recognised today, around 75% are from deep waters (>50 m, see Section 2.2.4, p. 37).

Both octocoral and scleractinian taxonomy has been pursued by only a handful of scientists, often in their spare time. For example, alongside their taxonomic exploits many of the azooxanthellate scleractinian workers were primarily palaeontologists while others had a bewildering variety of jobs including school inspector, catholic priest and medical entomologist (Cairns, 2001a). Sadly this trend has if anything worsened and globally there are only a handful of coral taxonomists capable of identifying and describing cold-water corals. Many still pursue coral taxonomy in their spare time.

1.1.2 Pioneering deep-sea expeditions

The science of oceanography became established following the global expedition of *HMS Challenger* (1872–6) led by Charles Wyville Thomson and the epic collection of 50 scientific report volumes it subsequently generated under the auspices of John Murray. The impetus for the expedition had been to investigate Edward Forbes's azoic theory (based on dredging results from the Aegean Sea) that no animal life could persist below 300 fathoms (600 m). Having been to Norway and seen dredge hauls by Michael Sars rich in animal life from these and greater depths, Charles Wyville Thomson lost little time in joining forces with William B. Carpenter to set about persuading the British government to fund deep-sea dredging expeditions. These began in 1868 with the cruise of *HMS Lightning* to the waters between Scotland and the Faroe Islands. Both the *Lightning* and subsequent *HMS Porcupine* expeditions recovered cold-water corals in their dredges. These coral species were discussed in a series of papers to the Zoological Society of London and the Royal Society in the 1870s by P. Martin Duncan (Duncan, 1870, 1873, 1878).

Although less well known, the northwest Atlantic dredging expeditions co-ordinated through the Museum of Comparative Zoology at Harvard (USA) actually preceded the cruise of *HMS Lightning* by a year. Between 1867 and 1880 these expeditions covered over 600 deep-water stations recovering many cold-water coral specimens. Whereas the vessels *Lightning*, *Porcupine* and *Challenger* were converted British Royal Navy ships, the US expeditions used a series of US Coast Guard Steamers, the *Corwin*, *Bibb*, *Hassler* and *Blake*. Louis François de Pourtalès laid the foundations of North American cold-water coral taxonomy in his descriptions of the corals recovered during these expeditions (Fig. 1.3). Indeed of his 59 scleractinian coral descriptions, 47 remain valid today (Cairns, 2001a).

But it was the *HMS Challenger* expedition that revolutionised our understanding of the oceans. The dredge hauls taken during the expedition's circumnavigation of the globe put Forbes's azoic theory to rest once and for all – animal life was recovered from depths of 5500 m, an astonishing achievement at the time, and over 4000 new marine species were described. The *HMS Challenger* was built in 1858 as a Royal Navy corvette, a small, lightly armed and manoeuvrable warship. The *Challenger* sailed between survey stations and used her 1200 horse-power steam engine for dredging. Of her seventeen guns, all but two were removed to make space for laboratories and scientific sampling apparatus. Under Captain George Nares were a total ship's party of about 240 including 20 officers. There were just six scientists led by Charles Wyville Thomson (see Linklater, 1972 for a detailed history of the *Challenger* expedition). Henry Moseley, who joined as the expedition's naturalist, described the cold-water corals collected by *Challenger*. He subsequently outlined the voyage and his natural history observations in his 1879 book *Notes by a Naturalist on* HMS Challenger. Of the 48 scleractinian corals he described, 39 remain valid (Cairns, 2001a) and his skilful illustrations are among the finest available to this day (see Fig. 3.4, p. 72).

As mentioned, the dredging work of Michael Sars in Norway was part of the impetus for the *Challenger* expedition. Sars (1865) used dredging to describe coral banks formed by *Oculina prolifera* (= *Lophelia pertusa*) in Oslofjord. After the pioneering nineteenth-century expeditions established the science of deep-sea dredging on the high seas others were quick to take up the techniques of dredging and trawling and apply them through the remaining years of the nineteenth and first half of the twentieth centuries. There are many historical examples, summarised in Teichert (1958), including Dons (1944) from Norway and Joubin (1922) from the Irish and French margins.

1.1.3 The modern era begins

The next quantum leap in our understanding of cold-water corals came with the development of survey sonars after the Second World War, see Section 1.2.1, p. 13, and the use of manned research submersibles from the late 1960s and through the 1970s. After two hundred years of relying on sample material

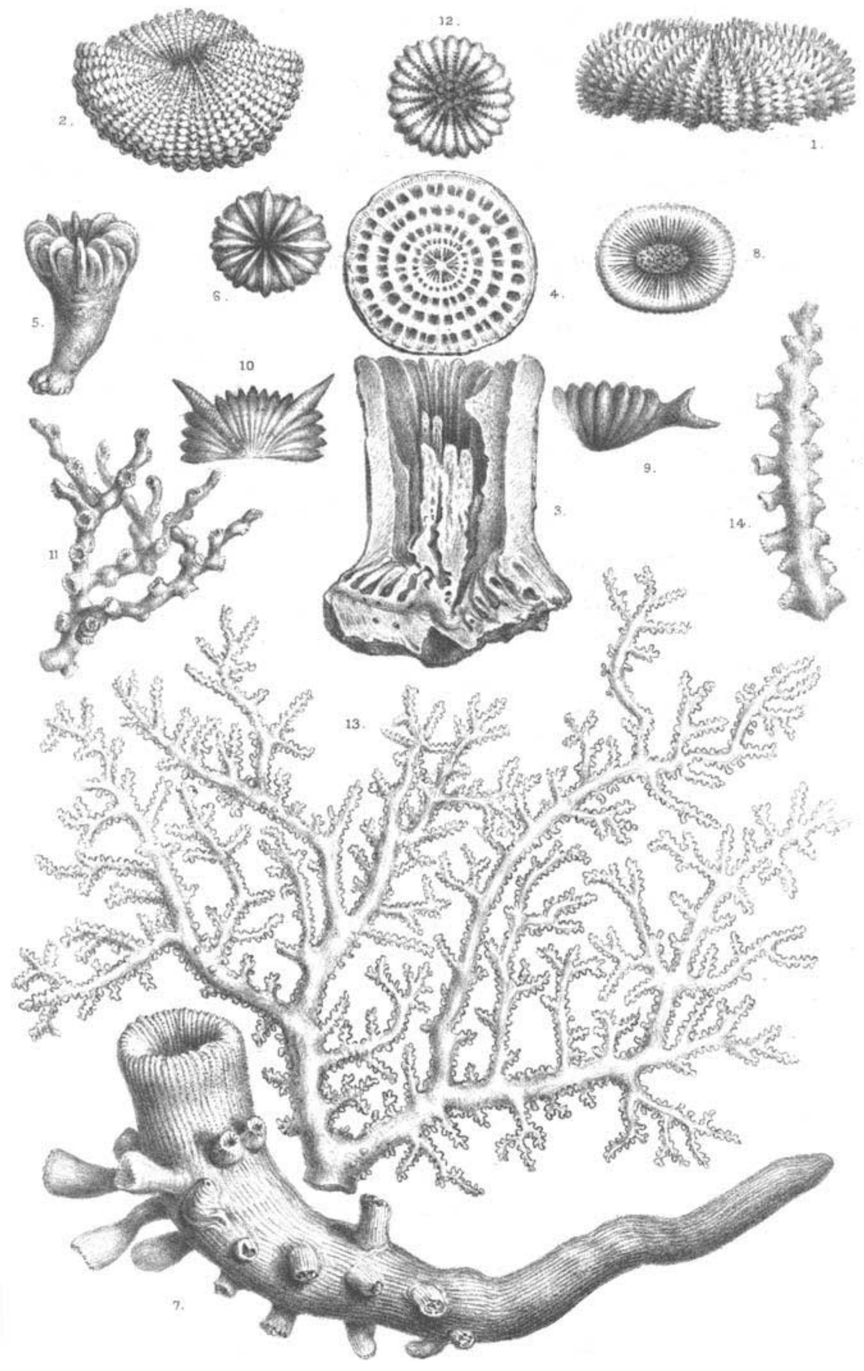

Fig. 1.3 Plate V from Pourtalès (1871) *Deep-sea Corals*, published as an Illustrated Catalogue of the Museum of Comparative Zoology at Harvard College. (1) *Diaseris crispa* (= *Fungiacyathus crispus*); (2) the same viewed

dragged from the depths and dumped onto the deck of a ship, research submersibles gave scientists the first chance to see deep-water animals in their habitats on the seafloor. The 'deep submergence vehicle' *Alvin*, named for Allyn Vine of the Woods Hole Oceanographic Institution, was brought into service in 1964. *Alvin*'s first use in cold-water coral research was to investigate mounds found on the Blake Plateau, off South Carolina (USA), following up earlier echosounder observations by Stetson *et al*. (1962). In July 1967, Milliman *et al*. (1967) dived an area of seabed mounds and found cold-water corals including *Lophelia* and *Dendrophyllia profunda* (= *Enallopsammia profunda*) along with a characteristic community of other suspension feeders. In 1971, A. Conrad Neumann dived in *Alvin* at the base of the Little Bahama Bank and northeastern Straits of Florida to depths of up to 700 m. During these dives he noted extensive areas of rocky mounds, hundreds of metres long and up to 50 m in height. These lithified mounds were richly colonised by cold-water corals and other suspension-feeding animals – subsequently Neumann *et al*. (1977) coined the term 'lithoherm' to describe them.

On the other side of the Atlantic the manned submersible *Pisces III* was used to examine cold-water corals in the northeast Atlantic (Colour plate 3). In June 1973, John Wilson surveyed *Lophelia pertusa* colonies growing on Rockall Bank and noted that they tended to form distinctive patches on the seabed, helping to explain characteristic patterns he had seen on side-scan sonagraphs. He reasoned that the colonies grew from their initial larval settlement point and gradually spread out covering a wider area, a process probably accelerated by sponge bioerosion. Using *Pisces III*, Wilson was able to document coral patches in various stages of development up to 50 m across. He subsequently summarised his observations in his classic description of cold-water coral patch development (Wilson, 1979).

The *Pisces III* submersible became infamous just two months after John Wilson's 1973 Rockall Bank dives. In August of that year the submersible was being used to help lay trans-Atlantic telephone cables approximately 100 miles west of Ireland. While being lifted back on board its mother ship, the *DE Vickers Voyager*, the submersible and its two-man crew were dropped and sank to a depth of 500 m. With life support systems for just three days an international rescue

Caption for Fig. 1.3 (cont.)
from above; (3) *Thecocyathus lævigatus* in vertical section (= *Tethocyathus laevigatus*); (4) the same in horizontal section; (5) *Desmophyllum solidum* (= *Thalamophyllia riisei*); (6) the same from above; (7) *Dendrophyllia cornucopia* (= *Eguchipsammia cornucopia*); (8) the same from above; (9) magnified portion of *Deltocyathus agassizii* (= *D. calcar*) from the side; (10) the same from below; (11) *Oculina tenella*; (12) the same from above; (13) *Stylaster filogranus*; (14) magnified branch from the same.

effort was quickly launched. Three other submersibles were flown to Ireland, *Pisces II* from England, *Pisces V* from Canada and an early remotely operated vehicle *CURV III* from the USA. After over three harrowing days several lines were attached to the stricken submersible and it was brought back to the surface. Both pilot and observer survived.

These pioneers of human exploration of the deep ocean set the stage for the work we describe in this book. Studies of cold-water corals, particularly the increased activity from the 1990s onwards, have relied on technological innovations in surveying and sampling. Many of these have been made since the 1970s, often driven by the requirements of offshore hydrocarbon development. Next we review briefly some of the methods available to cold-water coral researchers, focusing primarily on the two themes of this book, the geological and biological sciences.

1.2 Research approaches

Advances in our understanding of cold-water corals in recent decades have, in no small measure, been due to advances in submarine surveying, sampling and monitoring technologies. What was once a hostile, remote and mysterious realm is now becoming an increasingly practical area in which to observe and experiment thanks to improved deep-sea technology. Advances in genetics are also providing new insights into cold-water coral dispersal and reproduction alongside glimpses of this habitat's microbial diversity. Likewise, advances in analytical geochemistry have allowed us to use cold-water corals as environmental archives, and helped us understand biogeochemical and diagenetic processes. Many of these advances are explored in later chapters. Here we focus on how technology has enabled us to map, sample and monitor cold-water coral habitats with a concluding comment on how future advances may allow new insights and perspectives.

As recently as the 1990s, and sometimes to this day, attempts to locate cold-water coral reefs and mounds involved sampling the seabed using low-resolution echosounder data and scattered notes of coral occurrence, often from fishing records. Even knowing exactly where the research vessel was, let alone where the sampler on the seabed was relative to the vessel, was a challenge before satellite navigation through global positioning systems (GPS). Now we can not only fix the position of the ship to within a few metres but can also locate the sample with similar accuracy using through-water acoustic ultra-short baseline (USBL) navigation transponders. Improved design means research vessels can now hold position precisely over a site using dynamic positioning (employing directional thrusters). Before this vessels were often at the mercy of wind and water currents making accurate sampling a function of informed guesswork, timing and piloting skill. With a target several hundred metres beneath the ship there was a limit to what research objectives could be achieved. Once on deck, retrieved samples were usually out of context. Scientists could identify the species and sediments present but were largely left to guess at how the animals functioned and interacted with one another. Since dredges and trawls are dragged across the seafloor they give a greater chance of hitting a patchy target but such samples contain species and sediments from a number of habitats and/or facies mixed together, and are often damaged and biased towards certain organisms or grain sizes.

Advanced technologies now enable us to produce very accurate and detailed digital maps at a range of scales, and precisely sample and observe features either in person or remotely. However, before we outline these it is worth stressing that cold-water coral habitats still challenge us; for example, the fast-flowing currents that characterise these areas impose limitations on equipment and survey design. Deep waters require strong pressure housings for instrumentation, great lengths of cable on powerful winches and large deep-sea vessels capable of getting to and remaining at remote sites for weeks on end. This all makes research cruises to cold-water coral habitats costly undertakings. Observation periods may be limited to slack waters between tides, and local currents may dictate the direction in which instruments can be towed and can make manoeuvring submersibles or remotely operated vehicles (ROVs) difficult during peak tidal flows. This imposes limitations on the work that can be carried out and can cause valuable time spent offshore to be lost.

Corals grow on hard substrata and their accumulated remains may prove difficult to sample. Coral carbonate mounds can be precipitous and lithified, limiting sampling and sometimes damaging equipment (Fig. 1.4). Cold-water coral reefs

Fig. 1.4 A ‘banana core’ bent during sampling coral carbonate mound sediment.